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Lifting velocity as a predictor of intensity and level of effort during the prone bench pull exercise

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Lifting velocity as a predictor of intensity and level of effort during the prone bench pull exercise

Velocidad de ejecución como un indicador de intensidad y grado de esfuerzo en el ejercicio de remo tumbado

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Para mis padres, que con su amor
y apoyo incondicional han sido la luz
que guía cada uno de mis pasos

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Abbreviations

1RM, one-repetition maximum.

ANOVA, analysis of variance.

BP, bench-press exercise.

BS, back-squat exercise.

CI, confidence intervals.

CV, coefficient of variation.

ES, effect size.

FW, free-weight.

ICC, intraclass correlation coefficient.

MPV, average velocity from the beginning of the concentric phase until the barbell's acceleration falls below gravity [−9.81 $m \cdot s^2$].

MV, average velocity from the beginning of the concentric phase to the point where the bar reaches its highest elevation.

$MV_{fastest}$, fastest MV within a set.

MV_{last}, last MV within a set.

MVTs, minimum velocity thresholds.

P, *p*-value.

PBP, prone bench-pull exercise.

PV, peak velocity attained at any point during the concentric phase.

$PV_{fastest}$, fastest PV within a set.

PV_{last}, last PV within a set.

r, Pearson's product-moment correlation coefficient

R^2, coefficient of determination from the Bland-Altman plots.

r^2, Pearson's multivariate coefficient of determination.

RT, resistance training.

RTF, repetitions to momentary failure.

SD, standard deviation.

SEE, standard error of the estimate.

SM, Smith machine.

SSC, stretch-shortening cycle.

VBT, velocity-based training.

VLTs, velocity loss thresholds.

XRM, load that allows a given number of repetitions to be completed before reaching muscular failure.

Abstract / Resumen

Resistance training (RT) has long been recognized as a cornerstone not only for athletic performance but also for overall health and well-being. Beyond enhancing muscle size, strength, and power, RT plays a vital role in preventing and managing a wide range of health conditions. However, the success of RT in inducing these positive outcomes relies heavily on the careful manipulation of training variables (*e.g.,* exercise selection, load intensity, volume, rest intervals, and lifting velocity).

A common issue faced by coaches and athletes is determining the appropriate weight to lift in a specific exercise, as the intensity of the resistance directly influences the degree of adaptation. Two of the most frequently used methods for prescribing training intensity involve assigning a load relative to the individual's maximum strength capacity (*i.e.,* %1RM) or determining the load that allows a specific number of repetitions before reaching muscular failure (*i.e.,* 7RM represents the maximum weight with which an individual can complete seven repetitions before failure; XRM). However, traditional approaches to assessing 1RM and XRM are often criticized for being time-intensive, physically exhausting, and mentally demanding.

Velocity-based training (VBT) has emerged as a modern, objective, and auto-regulatory approach to resistance training. Due to its methodological robustness and feasibility within an athlete's daily routine, one promising method for predicting XRM is through monitoring lifting velocity at maximal concentric effort during submaximal loads. This novel VBT's application establishes an individualized linear relationship between the maximum repetitions to momentary failure (RTF) and maximum velocity of the set $V_{fastest}$ (*i.e.,* individualized RTF-$V_{fastest}$ relationships). Then, it uses this data to predict different RTFs in subsequent sessions based on the specific training objectives.

From a biomechanical and training perspective, the present thesis aims (1) to determine the basic properties of the RTF-$V_{fastest}$ relationship, such as goodness-of-fit, reliability, and accuracy (*i.e.,* error in RTF prediction), and (2) to offer guidance on implementing various methodological factors that can impact the accuracy of RTF prediction, including the magnitude of loads lifted, the number of loads, and the specific lifting velocity variable considered. Of note, conducting methodological studies provide a solid foundation for improving and optimizing the techniques and tools used in future research, ensuring consistent advancements in knowledge and technology.

The thesis' results suggest that the individualized RTF-$V_{fastest}$ relationships demonstrate: (I) a higher goodness-of-fit compared to generalized models which remains stable over time, (II) a range from acceptable to high between-session reliability for $V_{fastest}$ values associated with specific RTFs, (III) a high stability over time for $V_{fastest}$ values associated with specific RTFs and, (IV) an acceptable RTF prediction accuracy under free-fatigue conditions. Complementary, the basic properties from individualized RTF-$V_{fastest}$ relationships are extrapolated to different equipment (*e.g.,* Smith machine or free-weight), lifting velocity variables (*e.g.,* fastest mean or peak velocity within a set), magnitude of the loads analyzed (from 60% to 90%1RM), number of sets (from 2 to 4 sets), and resting time (from 5 to 10 minutes) used for the equation's construction.

From a practical standpoint, RTF-$V_{fastest}$ relationships can be constructed using a simple linear regression model by executing sets to failure with varying loads (from 2 to 4 sets). This approach requires the monitoring of two variables for the modelling: (i) RTF for each set and, (ii) $V_{fastest}$ within each set. Once established, coaches simply need to measure the $V_{fastest}$ against a given load (typically occurring in the first 1-3 repetitions). Then, this velocity can be inserted the individualized equation for obtaining the RTF prediction in real-time. Finally, readers should know that nowadays, monitoring lifting velocity can be easily done with affordable and accessible devices, making it feasible for use in any sports context.

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El entrenamiento de fuerza (EF) ha sido reconocido desde hace tiempo como un pilar fundamental, no solo para el rendimiento atlético, sino también para la salud y el bienestar general. Más allá de mejorar el tamaño muscular, la fuerza y la potencia, el EF desempeña un papel vital en la prevención y gestión de una amplia gama de condiciones de salud. No obstante, el éxito del EF para inducir estos resultados positivos depende en gran medida de la manipulación cuidadosa de las variables del entrenamiento (*e.g.,* la selección de ejercicios, la carga, el volumen, los intervalos de descanso y la velocidad de levantamiento).

Un problema común al que se enfrentan los entrenadores y los atletas es determinar el peso adecuado para levantar en un ejercicio específico, ya que la intensidad de la resistencia influye directamente en el grado de adaptación. Dos de los métodos más utilizados para prescribir la intensidad del entrenamiento consisten en asignar una carga relativa a la capacidad máxima de fuerza del individuo (*i.e.,* %1RM) o determinar la carga que permite realizar un número específico de repeticiones antes de alcanzar el fallo muscular (*i.e.,* 7RM representa el peso máximo con el cual una persona puede completar siete repeticiones antes de llegar al fallo; XRM). Sin embargo, los enfoques tradicionales para evaluar el 1RM y el XRM suelen ser criticados por ser física y mentalmente demandantes.

El entrenamiento basado en la velocidad (VBT) ha surgido como un enfoque moderno, objetivo y autorregulador del entrenamiento de fuerza. Debido a su solidez metodológica y viabilidad dentro de la rutina diaria de un atleta, un método prometedor para predecir el XRM es a través del monitoreo de la velocidad máxima de levantamiento durante cargas submáximas. Esta novedosa aplicación del VBT establece una relación lineal individual entre las repeticiones máximas hasta el fallo momentáneo (RFM) y la velocidad máxima de la serie (*i.e.,* es decir, relaciones individualizadas RFM-velocidad). Luego, utiliza estos datos para predecir diferentes RFM en sesiones posteriores, en función de los objetivos de entrenamiento específicos.

Desde una perspectiva biomecánica y de entrenamiento, esta tesis tiene como objetivo (1) determinar las propiedades básicas de la relación RFM-velocidad, como el ajuste del modelo, la fiabilidad y la precisión (*i.e.,* el error en la predicción de las RFM), y (2) ofrecer orientación sobre la implementación de varios factores metodológicos que pueden afectar la precisión de la predicción de la RFM, incluyendo la magnitud de las cargas levantadas, el número de cargas, y la variable específica de la velocidad de levantamiento considerada. Cabe destacar que la realización de estudios metodológicos proporciona una base sólida para mejorar y optimizar las técnicas y herramientas utilizadas en futuras investigaciones, garantizando avances consistentes en el conocimiento y la tecnología.

Los resultados de la tesis sugieren que las relaciones individualizadas RFM-velocidad demuestran: (I) un mayor ajuste del modelo en comparación con los modelos generalizados y, que se mantiene estable a lo largo del tiempo; (II) una fiabilidad entre sesiones que varía de aceptable a alta para los valores de velocidad asociados con RFM específicas; (III) una alta estabilidad a lo largo del tiempo para los valores de velocidad asociados con RFM específicas; y (IV) una precisión aceptable en la predicción de la RFM bajo condiciones sin fatiga. Complementariamente, las propiedades básicas de las relaciones individualizadas RFM-velocidad se extrapolan a diferentes equipamientos (*e.g.,* máquina Smith o pesos libres), variables de velocidad de levantamiento (*e.g.,* velocidad media o velocidad pico dentro de una serie), magnitud de las cargas analizadas (del 60% al 90%1RM), número de series (de 2 a 4 series) y tiempo de descanso (de 5 a 10 minutos) utilizadas para la construcción de la ecuación.

Desde un punto de vista práctico, las relaciones RFM-velocidad pueden construirse utilizando un modelo de regresión lineal simple, ejecutando series hasta el fallo con cargas variables (de 2 a 4 series). Este enfoque requiere el monitoreo de dos variables para el modelado: (i) las RFM de cada serie y (ii) la velocidad más rápida dentro de cada serie. Una vez establecidas, los entrenadores solo necesitan medir la velocidad más rápida contra una carga determinada (que típicamente ocurre en las primeras 1-3 repeticiones). Luego, esta velocidad puede insertarse en la ecuación individualizada para obtener la predicción de la RFM en tiempo real. Finalmente, los lectores deben saber que hoy en día, el monitoreo de la velocidad de ejecución se puede realizar fácilmente con dispositivos económicos y accesibles, lo que lo hace viable su uso en cualquier contexto deportivo.

Objectives / Objetivos

This doctoral thesis has been organized into seven studies based on the following objectives:

Study I: *Can Lifting Velocity Predict Repetitions to Failure? A Systematic Review.*

Objective 1: to determine the basic properties of the RTF-velocity relationship, such as goodness-of-fit, reliability, and accuracy (*i.e.,* error in RTF prediction).

Objective 2: to offer guidance on implementing various methodological factors that can impact the accuracy of RTF prediction, including the magnitude of loads lifted, the number of loads, and the specific lifting velocity variable considered.

Study II: *Lifting Velocity as a Predictor of the Maximum Number of Repetitions That Can Be Performed to Failure During the Prone Bench Pull Exercise.*

Objective 3: to compare the goodness-of-fit of generalized and individualized RTF-velocity relationships modelled considering $MV_{fastest}$ and $PV_{fastest}$ from training sets.

Objective 4: to determine the between-sessions reliability of $MV_{fastest}$ and $PV_{fastest}$ values associated with different RTFs (from 1RTF to 15RTF).

Objective 5: to elucidate whether the errors in the prediction of the RTF under fatigued and non-fatigued conditions differ between generalized and individualized RTF-velocity relationships.

Study III: *Lifting Velocity Predicts the Maximum Number of Repetitions to Failure With Comparable Accuracy During the Smith Machine and Free-Weight Prone Bench Pull Exercises.*

Objective 6: to compare the goodness-of-fit between the generalized and individualized RTF-$MV_{fastest}$ relationships obtained during the SM and FW variants of the PBP exercise.

Objective 7: to compare and associate the $MV_{fastest}$ values associated with each RTF (from 1 to 15 RTFs) between both individual estimation methods (multiple-point *vs.* two-point) and PBP exercises (SM *vs.* FW).

Objective 8: to explore whether the accuracy in the prediction of RTFs is affected by fatigue (set 1 *vs.* set 2), the type of RTF-$MV_{fastest}$ relationships (generalized *vs.* multiple-point *vs.* two-point), and PBP exercise (SM *vs.* FW).

Study IV: *Exploring the Relationship Between Maximum Number of Repetitions and Fastest Lifting Velocity During the Prone Bench Pull: Are They Affected by the Stretch-shortening Cycle?*

Objective 9: to compare the goodness-of-fit of individualized RTF-$MV_{fastest}$ and RTF-$PV_{fastest}$ relationships between the concentric-only and eccentric-concentric PBP exercises.

Objective 10: to compare the $MV_{fastest}$ and $PV_{fastest}$ values associated with different RTFs (from 1 to 15) between both PBP exercises and modelling procedures (*i.e.,* multiple-point *vs.* two-point).

Study V: *The Effect of Lifting Straps on the Prediction of the Maximal Neuromuscular Capabilities and 1 Repetition Maximum During the Prone Bench Pull Exercise.*

Objective 11: to compare the L-V relationship variables between two modelling procedures (multiple-point *vs.* two-point) performed with and without lifting straps.

Objective 12: to compare the 1RM prediction accuracy between two modelling procedures (multiple-point *vs.* two-point) and three types of MVT (general *vs.* individual *vs.* average optimal) performed with and without lifting straps.

Study VI: *Impact of Lifting Straps on the Relationship Between Maximum Repetitions to Failure and Lifting Velocity During the Prone Bench Pull Exercise.*

Objective 13: to compare the goodness-of-fit between the generalized and individualized RTF-$MV_{fastest}$ and RTF-$PV_{fastest}$ relationships obtained during the SM PBP exercise performed with and without lifting straps.

Objective 14: to compare the $MV_{fastest}$ and $PV_{fastest}$ associated with different RTFs (from 1 to 15) between both execution equipment (*i.e.,* with *vs.* without lifting straps) and prediction methods (*i.e.,* multiple-point *vs.* two-point).

Study VII: *Stability of the Relationship Between Maximum Repetitions to Failure and Lifting Velocity Over a 6-weeks Strength Training Program.*

Objective 15: to compare the time effect (1^{st} *vs.* 2^{nd} *vs.* 3^{rd} *vs.* 4^{th} testing session) on the goodness-of-fit (r^2 and SEE) of the RTF-$MV_{fastest}$ and RTF-$PV_{fastest}$ relationships.

Objective 16: to compare the time effect (1^{st} *vs.* 2^{nd} *vs.* 3^{rd} *vs.* 4^{th} testing session) on the consistency of the predicted $MV_{fastest}$ and $PV_{fastest}$ values associated with 3, 9 and 15RTFs.

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Tesis doctoral organizada en siete estudios en base a los siguientes objetivos:

Estudio I: *¿Puede la velocidad de ejecución predecir las repeticiones hasta el fallo (RFM)? Una revisión sistemática.*

Objetivo 1: Determinar las propiedades básicas de la relación RFM-velocidad, tales como el ajuste, la fiabilidad y la precisión (*i.e.,* el error en la predicción de RFM).

Objetivo 2: Ofrecer pautas sobre cómo implementar diversos factores metodológicos que puedan influir en la precisión de la predicción de RFM, incluyendo la magnitud de las cargas levantadas, el número de cargas y la variable específica de velocidad de levantamiento considerada.

Estudio II: *Velocidad de ejecución como predictor del número máximo de repeticiones que se pueden realizar hasta el fallo durante el ejercicio de remo tumbado.*

Objetivo 3: Comparar el ajuste de las relaciones RFM-velocidad generalizadas e individualizadas modeladas considerando las velocidad media y velocidad pico de ejecución.

Objetivo 4: Determinar la fiabilidad entre sesiones de la velocidad media y velocidad pico asociadas a diferentes RFM (de 1RFM a 15RFM).

Objetivo 5: Determinar si los errores en la predicción del RFM en condiciones de fatiga y no fatiga difieren entre las relaciones RFM-velocidad generalizadas e individualizadas.

Estudio III: *La velocidad de ejecución predice el número máximo de repeticiones hasta el fallo con una precisión comparable durante el ejercicio de remo tumbado en máquina Smith (MS) y con peso libre (PL).*

Objetivo 6: Comparar el ajuste entre las relaciones generalizadas e individualizadas RFM-velocidad obtenidas durante las variantes MS y PL en el remo tumbado.

Objetivo 7: Comparar y asociar los valores de velocidad asociadas a cada RFM (de 1 a 15RFM) entre ambos métodos de estimación individual (múltiples puntos *vs.* dos puntos) y tipo de ejercicio (MS *vs.* PL).

Objetivo 8: Explorar si la precisión en la predicción de RFM se ve afectada por la fatiga (serie 1 *vs.* serie 2), el tipo de relación RFM-velocidad (generalizada *vs.* múltiples puntos *vs.* dos puntos) y el ejercicio remo tumbado (MS *vs.* PL).

Estudio IV: *Exploración de la relación entre el número máximo de repeticiones y la velocidad de ejecución durante el ejercicio de remo tumbado: ¿Están afectadas por el ciclo de estiramiento-acortamiento?*

Objetivo 9: Comparar el ajuste de las relaciones individualizadas RFM-velocidad entre los ejercicios de remo realizados sólo de forma concéntrica y de forma excéntrica-concéntrica.

Objetivo 10: Comparar los valores de velocidad asociados con diferentes RFM (de 1 a 15RFM) entre ambos ejercicios de remo tumbado y procedimientos de modelado (*e.g.,* múltiples puntos *vs.* dos puntos).

Estudio V: El efecto de las correas de levantamiento sobre la predicción de las capacidades neuromusculares máximas y la una repetición máxima durante el ejercicio de remo tumbado.

Objetivo 11: Comparar las variables de la relación carga-velocidad entre dos procedimientos de modelado (múltiples puntos *vs.* dos puntos) realizado con y sin corras de levantamiento.

Objetivo 12: Comparar la precisión de la predicción de 1RM entre dos procedimientos de modelado (múltiples puntos *vs.* dos puntos) y tres tipos de mínimo umbral de velocidad (general *vs.* individual *vs.* óptimo promedio) realizado con y sin corras de levantamiento.

Estudio VI: Impacto de las correas de levantamiento en la relación entre repeticiones máximas hasta el fallo y la velocidad de ejecución durante el ejercicio de remo tumbado.

Objetivo 13: Comparar el ajuste entre las relaciones generalizadas e individualizadas RFM-velocidad obtenidas durante el ejercicio de remo tumbado en MS, realizados con y sin correas de levantamiento.

Objetivo 14: Comparar los valores de velocidad asociados a diferentes RFM (de 1 a 15RFM) entre ambos tipos de equipamiento (con *vs.* sin correas de levantamiento) y métodos de predicción (múltiples puntos *vs.* dos puntos).

Estudio VII: Estabilidad de la relación entre el número máximo de repeticiones hasta el fallo y la velocidad de levantamiento a lo largo de un programa de entrenamiento de fuerza de 6 semanas.

Objetivo 15: Comparar el efecto del tiempo (1^{ra} *vs.* 2^{da} *vs.* 3^{ra} *vs.* 4^{ta} sesión de evaluación) sobre el ajuste de las relaciones RFM-velocidad.

Objetivo 16: Comparar el efecto del tiempo (1^{ra} *vs.* 2^{da} *vs.* 3^{ra} *vs.* 4^{ta} sesión de evaluación) sobre la consistencia de los valores de velocidad asociados con 3, 9 y 15RFM.

1. A Deductive Introduction: Can Lifting Velocity Predict Repetitions to Failure? A Systematic Review

Miras-Moreno, S., Pérez-Castilla, A., Weakley, J., Rojas-Ruiz, FJ & García-Ramos, A.

Brief overview

The RT is well-recognized as an effective method to develop athletic performance because it has the potential to induce favorable adaptations in muscle hypertrophy, strength, and power[45]. However, the neuromuscular adaptations induced by RT strongly depend on the manipulation of RT program variables such as the exercise type and sequence, loading magnitude, volume, inter- and intra-set rest periods, and lifting velocity[3,45]. A common concern for coaches is deciding how much weight their athletes should lift in a particular exercise since RT-induced adaptations are highly dependent on the intensity used[49,80]. The two RT prescription methods most used consist of assigning a load relative to the individual's maximal dynamic strength capacity (*i.e.,* %1RM]) or the load that allows a given number of repetitions to be completed before reaching muscular failure (*e.g.,* 7RM represents the load with which subjects can complete seven repetitions, no more, before reaching failure)[84]. However, the traditional procedures for determining both the 1RM and XRMs have the drawbacks that they are time consuming, and physically and psychologically demanding[63,76]. Therefore, it is not surprising that some studies have been conducted to elucidate whether the 1RM and XRMs can be estimated with acceptable precision without the need of performing a maximal lift or a set of repetitions to failure[16,21,74].

A potential method for predicting both the 1RM and XRMs consists of recording the velocity at which submaximal loads are lifted[17,21]. Researchers have reported the general relationship between lifting velocity and the %1RM in different exercises such as the BP[24], PBP[16], BS[5], leg-press[5] or shoulder press[30]. Other studies have attempted to estimate the 1RM through the modelling of the individualized load-velocity relationship in exercises such as the BP[17], PBP[16], lat pull-down[74], seated cable row[74], BS[85], or deadlift[40]. Nowadays, it seems to be consensus that the individualized load-velocity relationship allows estimating the 1RM with a greater precision than generalized load-velocity relationships mainly because the %1RM-velocity relationship is subject-specific[17,75]. However, some coaches prefer to prescribe the loads to match a specific XRM rather than using the %1RM prescription method due to the high inter-subject's variability in the RTF against a given %1RM[25,72], although the inter-subject variability seems to be reduced when the loads are prescribed based on the individual load-velocity relationship[29,79]. Unfortunately, unlike the 1RM prediction method, little information exists regarding the possibility of predicting the XRMs from the recording of lifting velocity[21]. This is important due to the need of objective methods for monitoring proximity to failure in order to increase maximal strength and hypertrophy[67].

To our knowledge, only García-Ramos et al.[21] have examined the possibility of predicting different XRMs from the recording of lifting velocity. When pooling the data of all subjects, these authors revealed in the BP exercise a positive association between the highest lifting velocity of the set and the RTF (r^2 = 0.774), but the SEE was too high (3.6 repetitions). Similar to the evidence reported for the 1RM prediction[16,17], more accurate predictions of the XRM were obtained when the individualized RTF–velocity relationships were modelled (median r^2 = 0.984). However, it is important to elucidate whether these findings can be extrapolated to other exercises, especially considering the disparate success of using lifting velocity to predict the 1RM in different exercises (*i.e.,* more accurate for upper-body compared to lower-body exercises)[54]. In addition, a limitation of the study of García-Ramos et al.[21] is that the accuracy of individualized RTF–velocity relationships was not examined under fatigue. Therefore, it remains unknown whether the accuracy of individualized RTF–velocity relationships could be compromised in practice where athletes frequently perform multiple sets of the same exercise.

The present thesis pretends to demonstrate that the $MV_{fastest}$ and $PV_{fastest}$ within a set may be able to predict different RTFs during the PBP exercise[21,43,58–60]. When modelling data involving multiple loads, regardless of considering the data from a single subject (individualized RTF-velocity relationship) or across different subjects (general RTF-velocity relationship), a positive association has been found between RTF and the fastest set velocity for upper- and lower-body exercises[21,43,58–60]. These relationships can be easily constructed by applying a linear regression model to RTF and $MV_{fastest}$ or $PV_{fastest}$ recorded under at least two distinct loads[21,43,58–60]. Once this relationship is constructed, coaches can prescribe in subsequent training sessions the $MV_{fastest}$ or $PV_{fastest}$ corresponding to the desired RTF. Although this approach allows athletes and coaches to objectively predict the RTF using a non-invasive method (*i.e.,* recording lifting velocity), no previous systematic review has analyzed the different methodological factors that could influence its accuracy under field conditions. Therefore, the specific objectives of the present systematic review are two-fold: (1) to determine the basic properties of the RTF-velocity relationship, such as goodness-of-fit, reliability, and accuracy (*i.e.,* error in RTF prediction), and (2) to offer guidance on implementing various methodological factors that can impact the accuracy of RTF prediction, including the magnitude of loads lifted, the number of loads, and the specific lifting velocity variable considered.

!

Readers should be aware that the following chapters from the present doctoral thesis, **do not follow a chronological order.** On the contrary, it follows a deductive method that starts with the current general methodological knowledge of RTF-velocity relationships and gradually delves into the methodological peculiarities of each specific case.

Methods

Search Strategy

The systematic research was performed by two authors (SMM and AGR) based on the Preferred Reporting Items for Systematic Reviews and Meta–Analyses (PRISMA) guidelines[65]. The research was searched on the following academic databases: Pubmed, SPORTDiscus and Scopus, gathering any data to the last updating of March 27, 2024. The following terms were included into the search: (‘resistance train*’ OR ‘resistance exercise*’ OR ‘strength train*’ OR ‘strength exercise*’ OR ‘weight train*’ OR ‘weight lift*’) AND (‘monitor* velocity’ OR ‘lift* velocity’ OR ‘record* velocity’ OR ‘barbell velocity’) AND (‘repetition* to failure’ OR ‘maxim* repetition*’ OR ‘musc* failure’). The studies were identified by searching ‘titles, abstracts, and key words’ and then, the results were imported into a reference manager (www.rayyan.ai)[64]. The systematic review title, objectives, search strategy, eligibility criteria, and risk of bias assessment was registered on January 30, 2024, on the Open Science Framework (osf.io/trkb4) (**Figure 1**).

Eligibility and Data

Only original articles were included when the following criteria were met: (a) full-text published in English, (b) published in the selected academic databases, (c) human data, (d) at least two sets at different loads were performed to failure within the same testing session, (e) the maximum number of repetitions and the repetitions with the fastest velocity of the set were monitored and reported, (f) the procedures were performed without a current experimental condition (except for under controlled fatigue states) that may enhance or compromise the performance (*e.g.,* nutritional supplements or blood flow restriction) and (g) only multi-joint weight-lifting exercises (*e.g.,* traditional fixed-load RT exercises). Cross-sectional and exercise training studies were eligible but, only pre-intervention tests were used for training studies. Additionally, a backward screening (*i.e.,* reference lists from eligible full-texts) and forward screening (*i.e.,* citations from eligible full-texts) were performed manually. In the case of the identification of relevant papers, the same abovementioned inclusion criteria were performed. Disagreements were solve stablishing a consensus between the reviewers or when necessary, through an additional reviewer (APC).

The following descriptive data were extracted from eligible studies: title, participants characteristics (*i.e.,* sex, 1RM strength and relative to body mass), RT exercise, number of sets, loads, resting time between sets, lifting velocity variables (*i.e.,* $MV_{fastest}$ and $PV_{fastest}$), type of relationships (*i.e.,* generalized and individualized), modelling procedure used (*i.e.,* multiple- or two-point methods) and, type of muscle failure reached (*i.e.,* volitional or momentary) (**Table 1**). Regarding the basic properties of the RTF–velocity relationships, the following data were extracted: goodness-of-fit, reliability values of the velocity values associated to each RTF, absolute number of repetition error, and sensitivity to fatigue protocol (*i.e.,* number of sets, loads and resting time) (**Table 2**). In the case of unreported data, one author (SMM) emailed the manuscript’s corresponding author to request the raw or mean values (RTF and fastest velocity within a set). Extracted data were assessed for accuracy by a third reviewer (APC).

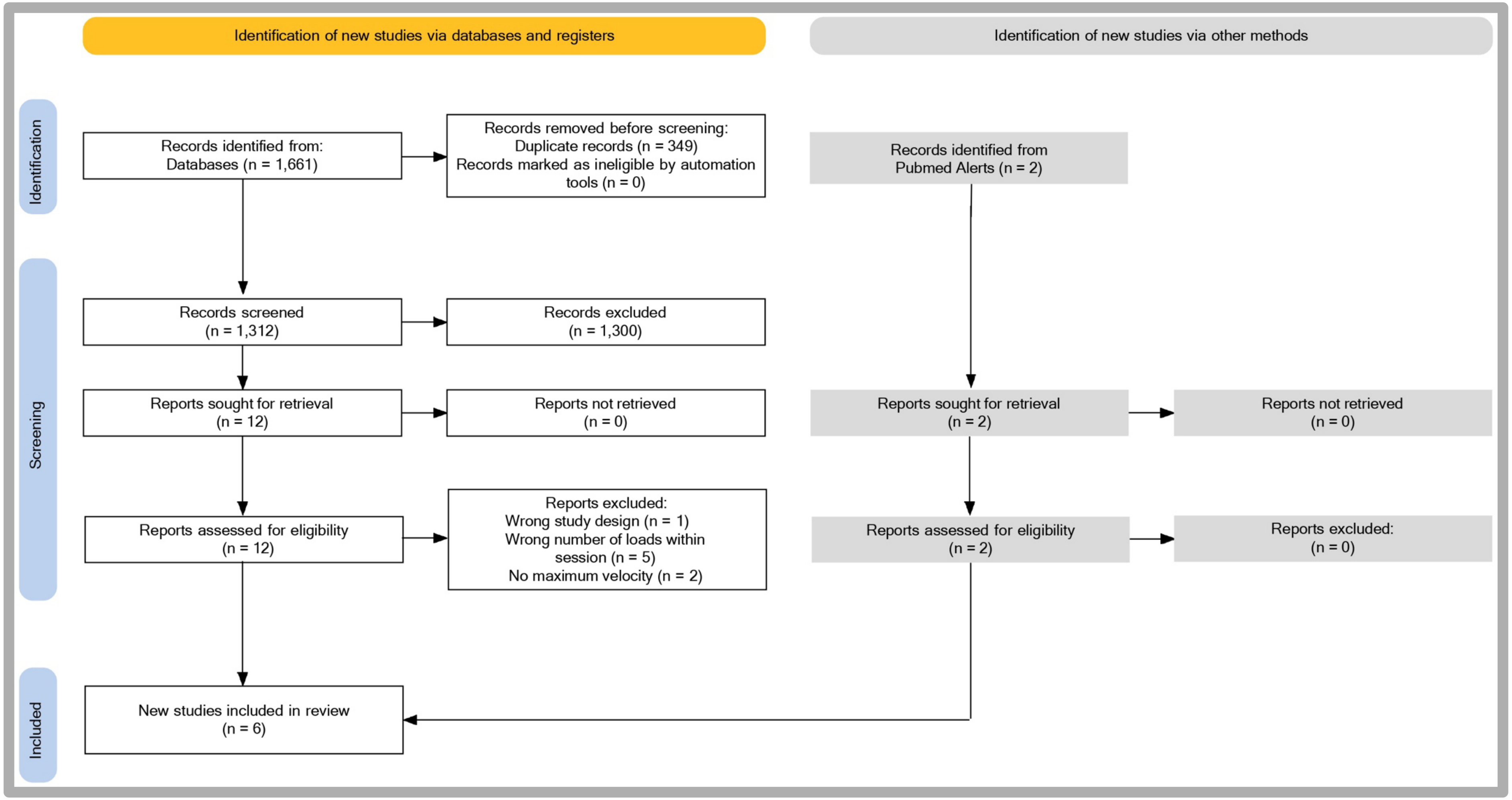


Figure 1. *PRISMA flow diagram detailing the inclusion and exclusion of the records screened.*

Table 1. *Summary of descriptive values derived from the studies included exploring the RTF-velocity in this systematic review.*

Study	Participants	Exercise(s), load(s) and resting time	Lifting velocity variables	Type of relationships	Modelling procedures	Type of muscular failure
García-Ramos et al., 2018 [21]	21 males [1RM: 84.0 ± 17.7 kg (1.15 ± 0.21 kg/kg BM)]	SM Bench press 60-70-80-90%1RM (random) 10 minutes between sets	Mean velocity	Generalized and individualized	Multiple-point	Momentary Failure
Miras-Moreno et al., 2022 [59]	20 males [1RM: 78.8 ± 12.0 kg (1.02 ± 0.15 kg/kg BM)] 3 females [1RM: 44.4 ± 4.0 kg (0.71 ± 0.06 kg/kg BM)]	SM Prone bench pull 60-70-80-90%1RM (random) 10 minutes between sets	Mean velocity Peak velocity	Generalized and individualized	Multiple-point	Momentary Failure
Jukic et al., 2023 [43]	31 males [1RM: 149.3 ± 23.6 kg (BM: 85.05 ± 13.71 kg)] 15 females [1RM: 83.2 ± 19.9 kg (BM: 67.45 ± 8.25 kg)]	FW Back squat 90-80-70%1RM (fixed) 10 minutes between sets	Mean velocity	Generalized and individualized	Multiple-point	Momentary Failure
Miras-Moreno et al., 2023 [60]	23 males [1RM: 84.8 ± 12.9 kg (1.06 ± 0.17 kg/kg BM)]	FW Prone bench pull 60-90-70-80%1RM (fixed) 5 minutes between sets	Mean velocity	Generalized and individualized	Multiple-point Two-point	Momentary Failure
Miras-Moreno et al., 2024 [58]	20 males [1RM: 88.9 ± 11.0 kg (1.10 ± 0.17 kg/kg BM)]	SM Prone bench pull with straps 60-80-70%1RM (fixed) 5 minutes between sets	Mean velocity Peak velocity	Generalized and individualized	Multiple-point Two-point	Momentary Failure
Janićijević et al., 2024 [36]	30 males high level wrestlers [1RM: 164.8 ± 25.5 kg (BM: 79.90 ± 7.90 kg)]	FW Back squat 90-80-70%1RM (fixed) 5 minutes between sets	Mean velocity	Generalized and individualized	Multiple-point	Momentary Failure

RTF, repetitions to failure; 1RM, one-repetition maximum; BM, body mass; SM, Smith machine; FW, free-weight.

Table 2. *Summary of the basic properties of the RTF–velocity relationships from studies included in this systematic review.*

Study	Goodness-of-fit	Between-session reliability	Accuracy (Absolute repetitions errors)	Sensitivity to fatigue protocol
García-Ramos et al., 2018 [21]	*Generalized* (MV) r^2 = 0.77; SEE = 3.5 repetitions *Individualized* (MV) r^2 = 0.98 [0.86–0.99]	Within-subject CV (MV) = 6.2% [4.7–7.1] ICC (MV) = 0.88 [0.87–0.93]		
Miras-Moreno et al., 2022 [59]	*Generalized* (MV) r^2 = 0.70; SEE = 3.6 repetitions *Individualized* (MV) r^2 = 0.96 [0.83–1.00] SEE = 1.7 [0.3–4.7] repetitions *Generalized* (PV) r^2 = 0.67; SEE = 3.7 repetitions *Individualized* (PV) r^2 = 0.97 [0.84–1.00] SEE = 1.4 [0.2–4.7] repetitions	Within-subject CV (MV) = 3.8% [3.5–5.4] ICC (MV) = 0.82 [0.78–0.83] Within-subject CV (PV) = 3.5% [3.0–6.7] ICC (PV) = 0.88 [0.87–0.93]	*Generalized vs. Multiple-point* Set 1 (MV): 3.4 ± 2.4 *vs.* 2.3 ± 1.5 Set 2 (MV): 4.3 ± 2.3 *vs.* 2.9 ± 1.8 Set 3 (MV): 4.0 ± 2.2 *vs.* 2.6 ± 1.5 Set 4 (MV): 4.1 ± 2.4 *vs.* 2.7 ± 1.5 Set 1 (PV): 2.8 ± 2.4 *vs.* 2.1 ± 1.0 Set 2 (PV): 3.8 ± 1.7 *vs.* 2.5 ± 1.5 Set 3 (PV): 3.6 ± 1.6 *vs.* 2.2 ± 1.4 Set 4 (PV): 3.4 ± 1.7 *vs.* 2.4 ± 1.3	4 sets 75%1RM 2 minutes inter-set rest
Jukic et al., 2023 [43]	*Generalized* (MV) r^2 = 0.49; SEE = 3.6 repetitions *Individualized* (MV) r^2 = 0.98 [0.50–1.00] SEE = 1.1 [0.1–4.2] repetitions	Within-subject CV (MV) = 7.2% [6.1–10.4]* ICC (MV) = 0.75 [0.46–0.78]*	*Generalized vs. Multiple-point* *Set 90%1RM (MV): 2.1 ± 1.6 *vs.* 1.7 ± 1.9 *Set 2 80%1RM (MV): 2.5 ± 2.1 *vs.* 1.8 ± 1.5 *Set 3 70%1RM (MV): 3.8 ± 2.9 *vs.* 2.3 ± 1.7	3 sets 90-80-70%1RM 10 minutes inter-set rest
Miras-Moreno et al., 2023 [60]	*Generalized* (MV) r^2 = 0.67; SEE = 6.6 repetitions *Individualized* (MV) r^2 = 0.94 [0.79–1.00] SEE = 3.0 [0.5–9.5] repetitions		*Generalized vs. Multiple-point vs. Two-point* Set 1 65%1RM (MV): 5.1 ± 4.0 *vs.* 5.7 ± 5.7 *vs.* 6.4 ± 6.1 Set 2 65%1RM (MV): 4.6 ± 3.4 *vs.* 5.0 ± 4.1 *vs.* 6.7 ± 4.9 Set 1 85%1RM (MV): 2.8 ± 2.3 *vs.* 2.4 ± 2.1 *vs.* 3.0 ± 2.5 Set 4 85%1RM (MV): 3.3 ± 2.2 *vs.* 3.0 ± 1.8 *vs.* 3.7 ± 2.6	4 sets random sequence 65-85%1RM 2 minutes inter-set rest

Miras-Moreno et al., 2024 [58]	*Generalized* (MV) r^2 = 0.57; SEE = 7.5 repetitions *Individualized* (MV) r^2 = 0.95 [0.87–0.99] SEE = 2.7 [0.1–9.6] repetitions *Generalized* (PV) r^2 = 0.66; SEE = 6.7 repetitions *Individualized* (PV) r^2 = 0.97 [0.88–1.00] SEE = 2.3 [0.1–10.3] repetitions			
Janićijević et al., 2024 [36]	*Generalized* (MV) r^2 = 0.84; SEE = 1.9 repetitions* *Individualized* (MV) r^2 = 0.97 [0.88–1.00] SEE = 1.3 [0.1–2.8] repetitions*	Within-subject CV (MV) = 4.6% [4.0–8.0] ICC (MV) = 0.48 [0.46–0.53]	*Generalized vs. Multiple-point* Set 1 (MV): 1.4 ± 1.0 *vs.* 1.3 ± 1.0 Set 2 (MV): 1.1 ± 0.8 *vs.* 1.3 ± 1.0 Set 3 (MV): 1.6 ± 1.0 *vs.* 1.7 ± 1.7 Set 4 (MV): 1.3 ± 1.3 *vs.* 1.8 ± 1.7	4 sets 75%1RM 2 minutes inter-set rest

r^2, Pearson's multivariate coefficient of determination; SEE, Standard error of the estimate; CV, coefficient of variation; ICC, intraclass correlation coefficient model 3.1; MV, average velocity from the first positive velocity until the velocity was 0 $m \cdot s^{-1}$; PV, maximum velocity value recorded during the concentric lifting phase; 1RM, one-repetition maximum; SM, Smith machine; FW, free-weight; Generalized, pooling together the data from all subjects; Multiple-point, more than two experimental points included into the modelling procedure; Two-point, only two distant experimental points are included into the modelling procedure. **A-posteriori* analyses performed not related to the original study's aims.

Assessment of Reporting Quality

Two authors (SMM and AGR) graded the quality studies based on the modified version of the Downs and Black checklist[11]. Nonetheless, not all the assessment criteria were applicable to the studies from this review (only 17 of the 27 binary items ['0': unable to determine and '1': yes] were used). Differences were solved by reaching a consensus between the authors or when required, through the involvement of an additional author (APC). Of note, this modified checklist has been previously used in systematic reviews from sports science[89].

Results

Identification of Studies

The systematic search yielded 1661 studies, with no manuscripts identified by reviewing reference lists. From the manuscripts identified, 349 were removed as duplicates. During the time that involved the study analyses, two additional eligible studies that emerged via Pubmed alerts were included. The first screening involved the analyses of the titles and abstract of the remaining 1312 studies with only 12 studies sought for full-text screening. During the full text review, 8 studies were deemed to meet the inclusion criteria but, only 6 studies specifically analyzed the RTF-velocity relationships[21,36,43,58–60]. The remaining studies focused on alternative methods to prescribe the proximity-to-failure through estimating the RTF and repetitions in reserve using the velocity loss[72,73] (**Figure 1**).

Quality of Research Reporting

The research quality of the reported studies investigating the RTF-velocity relationships was found to be nearly perfect (mean ± SD) 15.0 ± 0 based on the Downs and Black checklist. However, all the studies consistently did not include the item 17 related to the calculation of statistical power and, item 18 related to the statistical analyses used, since the assumption of independence was violated during the construction of generalized RTF-velocity relationships (*i.e.,* multiple data points from same participants are included in the equations and r^2 can be inflated).

Study Characteristics

From all the participants involved in the included 6 studies (n = 145), females only represented the 12.4% (n = 18)[21,36,43,58–60]. The most investigated RT exercise was the PBP[58–60] followed by BS[36,43] and BP[21]. The RTF-velocity relationships were constructed in the SM[21,58–60] and FW exercises[36,43,60].

All the studies used the $MV_{fastest}$ to construct the generalized (*i.e.,* pooling together the data from all the participants) and individualized (*i.e.,* data obtained for each participant) RTF-velocity relationships and only two studies used the $PV_{fastest}$[58,59]. The multiple-point modelling procedure (*i.e.,* from 3 to 4 sets to failure ranging from 60-90%1RM)[21,36,43,58–60] was used in all these studies, whereas the two-point method (*i.e.,* performing sets to failure against only 2 loads) was applied in two studies[58,60] (**Table 1**).

Statistical Analyses Included from Studies

The goodness-of-fit from RTF-velocity relationships were assessed through the median value and range from r^2 and SEE[21,36,43,58–60]. The between-session reliability of the fastest velocity within a set associated to each RTF (from 1RTF to 15RTF) was assessed using the within-subjects CV (standard error of measurement/subjects' mean score × 100) and the ICC model 3.1[21,36,59]. A high and acceptable reliability was considered when the CV was lower than 5% and 10%, respectively[21,36,59]. The prediction accuracy was computed as the absolute and raw errors obtained when estimating the RTF and was calculated as follows: RTF estimation error = RTF performed – RTF predicted.

Basic Properties: Goodness-of-fit

All the included studies investigated the goodness-of-fit of RTF-velocity relationships through the construction of generalized (*i.e.,* pooling together the data from all subjects) and individualized (*i.e.,* separately for each subject) equations (**Figure 2**).

Generalized RTF-velocity relationships always revealed a lower goodness-of-fit (r^2 = 0.49–0.84) compared to individualized RTF-velocity relationships (r^2 = 0.94–0.98) for the included RT exercises (**Table 2**). Moreover, the goodness-of-fit was comparable for $PV_{fastest}$ and $MV_{fastest}$ during the construction of the individualized RTF-velocity relationships for SM FW PBP exercises[59,60]. The use of different inter-set rest time (from 5 to 10 minutes) did not show differences in the goodness-of-fit of RTF-velocity relationships for PBP nor BS exercises[36,43,58–60]. The goodness-of-fit of the generalized RTF-velocity relationships in the BS exercise was superior for high-level male wrestlers (r^2 = 0.84)[36] compared to recreationally trained males and females[43].

Basic Properties: Between-session reliability

The velocity associated with each RTF showed an acceptable absolute and relative between-session reliability from 1 to 15 RTF during FW BP and BS, whereas for the PBP exercise was found to be high (**Table 2**)[21,36,43,59]. The $MV_{fastest}$ and $PV_{fastest}$ values revealed comparable absolute and relative between-session reliability during the PBP exercise[59]. The resting time between sets (ranging from 5 to 10 minutes) did not impact the between-session reliability of the velocity values associated for a given RTF (*e.g.,* CV = 4.6% *vs.* 7.2% during the BS exercise, respectively)[36,43].

Basic Properties: Accuracy in the RTF prediction

The prediction accuracy was higher for individualized compared to generalized RTF-velocity relationships for all the RT exercises analyzed[43,59,60] with the only exception of the study from Janićijević et al.[36] who found a comparable prediction accuracy for both equations in high level wrestlers (**Table 2**).

The increment of the load was accompanied by a higher prediction accuracy during PBP exercise (absolute errors: set 1 at 65%1RM = 5.7 ± 5.7 repetitions; set 1 at 85%1RM = 3.0 ± 1.8 repetitions) and BS exercise (absolute errors: 70%1RM = 2.3 ± 1.7 repetitions; 80%1RM = 1.8 ± 1.5 repetitions; 90%1RM = 1.7 ± 1.9 repetitions)[43,60].

The increment of fatigue (*i.e.,* from 10 to 2 minutes of inter-set rest) was accompanied by a lower prediction accuracy for PBP exercise (absolute errors: set 1 at 75%1RM = 2.3 ± 1.5 repetitions; set 4 at 75%1RM = 2.7 ± 1.5 repetitions) and for BS exercise (absolute errors: set 1 at 75%1RM = 1.3 ± 1.0 repetitions; set 4 at 75%1RM = 1.8 ± 1.7 repetitions)[36,59]. Additionally, the number of loads used for modelling the RTF-velocity relationships during the PBP exercise could affect the prediction accuracy with the multiple-point method (absolute errors: set 1 at 85%1RM = 2.4 ± 2.1 repetitions; set 2 at 85%1RM = 1.8 ± 3.7

repetitions) revealing a greater accuracy than the two-point method (absolute errors: set 1 at 85%1RM = 3.0 ± 2.5 repetitions; set 2 at 85%1RM = 3.7 ± 2.6 repetitions)[43,59].

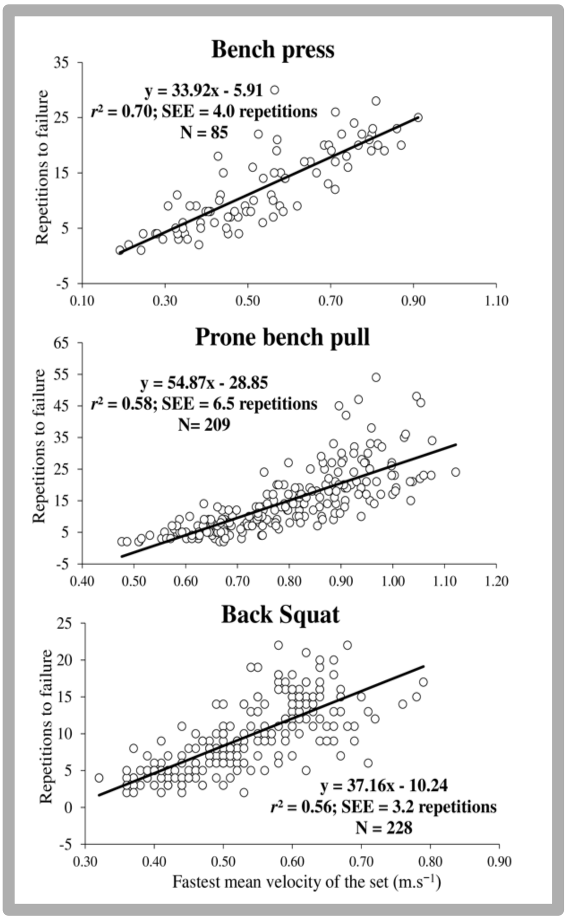


Figure 2. *Relationship between the maximum repetitions to failure (RTF) and the fastest mean velocity within a set ($MV_{fastest}$) values during the bench press (BP), prone bench pull (PBP) and back squat (BS) from all the data of the included studies.*

Discussion

The main findings of this systematic review are that regardless of the equipment used (*i.e.,* SM *vs.* FW exercises), lifting velocity variables (*i.e.,* $MV_{fastest}$ vs. $PV_{fastest}$), magnitude of the loads (*i.e,* from 60%1RM to 90%1RM), number of the sets (*i.e.,* from 3 to 4 sets) and rest time provided (*i.e.,* from 5 to 10 minutes), the construction of the individualized RTF-velocity relationships present: (i) an excellent goodness-of-fit, (ii) acceptable to high between-session reliability for the velocity values were associated for a given RTF (from 1–15 RTF), (iii) an acceptable prediction accuracy (~ 2 repetitions errors) during fatigue-free sets (*i.e,* 10 minutes of resting time) but, (iv) unacceptable estimation errors under fatigue conditions for inexperienced subjects.

These results suggest that individualized RTF-velocity relationships are a valuable tool for practitioners using RM zones for training prescription and that the RTF-velocity relationship should be constructed under fatigue conditions (*i.e.,* inter-set rest) similar to those that will be experienced by the subject during actual RT sessions. Finally, further studies should explore how different levels of fatigue affect the prediction accuracy of RTF when: (i) different modelling procedures are used (*i.e.,* multiple- vs. two-point), (ii) different loads (*e.g.,* 60-90%1RM) are intended to predict (*i.e.,* the increment of load allows for lower RTF and consequently, it cannot be used the same absolute errors criterion accuracy for different loads) and, (iii) athletes with different RT experience are involved.

During the construction of the load-velocity relationships, it is advisable to use linear relationships rather than second-order polynomial regression models due to its greater simplicity and reliability[15,75]. Furthermore, research indicates that there is less within-subject than between-subjects variability for the velocity corresponding to specific submaximal %1RMs[15,75]. This finding advocates for the construction of individual rather than general load-velocity relationships[15,75]. In agreement with previous VBT literature, our systematic review confirms that individualized RTF-velocity relationships are linear (from 1 to 30 RTFs) and also stronger (*i.e.,* high r^2 and low SEE) when compared to generalized regression models during the BP, PBP, and BS exercises[21,36,43,58–60]. Essentially, this indicates that there is a lower within-subject variability for the velocity corresponding to different RTFs compared to the between-subjects variability. Moreover, considering that RTF-velocity relationships vary with different variants of the same RT exercise (*e.g.,* differences between FW and SM PBP exercise were found), it is imperative for coaches to construct the RTF-velocity relationships tailored to each specific RT exercise[58–60].

In all the included studies, the individualized RTF-velocity relationships were constructed when multiple loads were lifted to failure (*e.g.,* 60%1RM, 70%1RM, 80%1RM, and 90%1RM referred to as 'multiple-point method')[21,36,43,58–60]. Nevertheless, the multiple-point method can be quite time-intensive and may lead to substantial fatigue, potentially affecting training adaptations or impairing performance in subsequent sessions. Based on the high linearity of individualized RTF-velocity relationships, Miras-Moreno et al.[60] recently proposed to simplify the RTF-velocity construction by lifting only two distant loads (*e.g.,* 60%1RM and 90%1RM, referred to as the 'two-point method'). However, the multiple-point method revealed a lower RTF for a given lifting velocity compared to the two-point method (*e.g.,* multiple-point: 1RTF = 0.57 ± 0.06, while two-point: 3RTF = 0.57 ± 0.05, respectively) during the PBP exercise[58,60]. These differences may be attributed to the less intensive procedure of the two-point method allowing more RTF for a given velocity (*i.e.,* since fatigue affects more the number of RTF than velocity, a lower slope was found for the multiple-point method)[58,60]. However, these results should be taken with caution, since the two-point method has been only explored during the PBP exercise and the optimal experimental points for its construction are still unknown[14,18].

A critical methodological consideration for modelling the load-velocity relationship is choosing the best lifting velocity variable[15,19]. In fact, the selection of the most common lifting velocity variables (*i.e.,* MV, MPV and PV) directly impact the linearity and goodness-of-fit of the load-velocity relationships[15,19]. From these variables, the MV is generally preferred due to greater linearity of the load-velocity relationships and between-session reliability for the velocities associated for a given %1RM[15,19]. In contrast, two studies reported a comparable goodness-of-fit and between-session reliability of the RTF-velocity relationships using both $MV_{fastest}$ and $PV_{fastest}$ during the PBP exercise[58,59]. Nonetheless, unlike the load-velocity relationships, this issue has been less explored with RTF-velocity relationships and further studies should consider incorporating other lifting variables, such as MPV, during other RT exercises as this will help establish the best velocity output to monitor.

Obtaining metrics for monitoring an athlete's training status with a high degree of reliability is crucial[1]. Between-session reliability provides information on the consistency of individual scores (*i.e.,* absolute reliability, typically measured as within-subject CV) and the stability of an individual's position within a group (*i.e.,* relative reliability, typically measured as ICC)[1,92]. The between-session reliability for the velocity values associated with each RTF was acceptable for BP and BS exercises but, high for the PBP exercise when the multiple-point method was used[21,36,43,59]. However, unlike the load-velocity relationships, no previous study has explored whether the two-point method could be a more reliable modelling procedure than the multiple-point method[14,18,57]. Additionally, the long-term variability of the RTF-velocity relationships remains uncertain, which could potentially influence coaching decisions (*e.g.,* when an athlete's RTF-velocity equation needs to be reassessed). Even more importantly, it is still unknown how different RT programs (*e.g.,* high volume [repetitions] or high power [maximal concentric velocity] training) may influence the RTF-velocity relationship. For example, previous research has demonstrated that a 4-weeks power training program led to a greater MV increase across the full load-velocity spectrum compared to maximal strength-oriented RT[68].

The most significant factors that impact the accuracy of 1RM predictions derived from load-velocity relationships which may also affect the RTF-velocity relationships, include[15]: (i) RT exercise selection, (ii) which velocity variable is selected, (iii) the regression model applied and, (iv) number of experimental points used. However, since the RTF are dependent of the load lifted, it is difficult to suggest when the prediction accuracy would be acceptable (*e.g.,* 2 repetitions errors are less problematic for 60%1RM than 80%1RM). Nonetheless, it is reasonable to suggest that as the load-velocity relationships, a lower degree of freedom of movement would allow a higher RTF prediction accuracy[15]. However, this systematic review found comparable absolute errors for PBP and BS exercises (2.3 ± 1.5 *vs.* 2.3 ± 1.7, respectively) against approximately the same relative load (~70%1RM) and fatigue experienced (accuracy obtained from the first set)[43,59]. In fact, it seems that a subject's RT experience plays a more crucial role than the degrees of freedom of the movement, not only during low-fatigue conditions but also during high levels of fatigue (*e.g.,* similar absolute repetitions errors comparing the 1 set: 1.3 ± 1.0 and 4 set: 1.8 ± 1.7 [mean ± SD] when only 2-minutes of inter-set rest was implemented during BS exercise for high-level wrestlers)[36].

Regarding the use of different lifting velocity variables, both $MV_{fastest}$ and $PV_{fastest}$ would allow similar accuracy predictions during the PBP but, it is plausible to suggest that in another RT exercise, where different velocity-time pattern occur (*e.g.,* the $PV_{fastest}$ is obtained earlier during the PBP compared to BP exercise[78]), results may differ. As expected, incorporating a differing number of experimental points into the modeling procedure (*i.e.,* multiple-point *vs.* two-point methods) would affect the RTF prediction accuracy. This issue can be attributed to the fact that increasing the number of sets into the modelling procedure affects the RTF-velocity relationships explained by the fact that fatigue impacts the number of RTF more than $MV_{fastest}$[59,60]. The unique study that directly compared both methods found that the two-point method exhibited higher prediction errors compared to the multiple-point method[60]. However, these results should be taken with caution and further studies should specifically explore the accuracy of different methods together with different levels of fatigue.

Although this is the first systematic review to outline the fundamental aspects of the RTF-velocity relationships, it is important to recognize several limitations and suggest directions for future research. First, due to the small number of studies that have investigated the RTF-velocity relationships these results can be only extrapolated to BP, PBP and BS exercise.

Second, the short-term reliability has been assessed within the same week whereas the long-term reliability and, how different RT programs can manipulate the RTF-velocity relationship, is unknown. Third, it remains uncertain under which fatigue conditions the use of either the multiple- or two-point method is advisable, as previous studies have not investigated this matter. Fourth, it is not clear which lifting variable provides the highest goodness-of-fit, reliability, and prediction accuracy during different RT exercises. Fifth, other factors such inter-set rest time (*e.g.,* which is the most optimal inter-set resting time for the construction of the relationship[35]) and feedback (*e.g.,* usually a high frequency of feedback is recommended to increase the performance on each repetition[89]) may influence the RTF-velocity relationships.

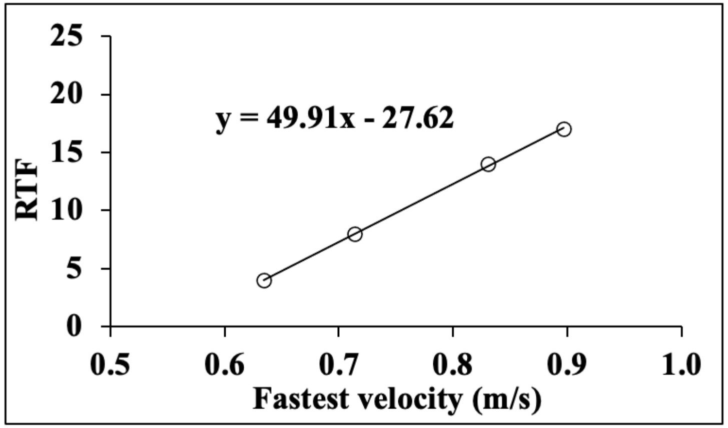
Conclusions

The findings of this systematic review indicate that individualized RTF-velocity relationships demonstrate a higher goodness-of-fit and more accurate RTF predictions compared to generalized models. These individualized relationships also show a range from acceptable to high between-session reliability for velocity values associated with specific RTFs (from 1–15 RTF). Although the accuracy of RTF-velocity relationships under fatigue-free conditions (*e.g.,* first set prediction or apply >10 minutes of inter-set rest) is generally acceptable, it is significantly compromised by varying levels of fatigue during the training sessions aimed to predict (fatigue affects more to RTF than velocity). However, it is important to note that prediction errors due to fatigue may be minimized when assessing athletes with extensive RT experience. Additionally, the basic properties of the RTF-velocity relationships seem to be unaffected using different equipment (SM *vs.* FW), lifting velocity variables ($MV_{fastest}$ *vs.* $PV_{fastest}$), magnitude of the loads analyzed (from 60% to 90%1RM), number of sets (from 3 to 4 sets), and resting time (from 5 to 10 minutes) used for the equation's construction. Finally, given that fatigue can impact the accuracy of RTF-velocity predictions, it is recommended to select a modelling procedure that best aligns with the specific fatigue conditions intended to be predicted.

Practical Applications

The construction of the individualized RTF-velocity relationships can be efficiently determined using a simple linear regression model by executing sets to failure with varying loads (from 2 to 3 sets). This approach requires the monitoring of two variables for the modelling: (i) RTF for each set and, (ii) $MV_{fastest}$ or $PV_{fastest}$ within each set. Once established, coaches simply need to measure the $MV_{fastest}$ or $PV_{fastest}$ against a given load (typically occurring in the first 1-3 repetitions). Then, this velocity can be inserted into the individualized equation for obtaining the RTF prediction in real-time (**Figure 3 and 4**).

	Set 1	Set 2	Set 3	Set 4
Fastest velocity (m/s)	0.90	0.83	0.71	0.63
RTF	17	14	8	4



Slope	49.91	
y-intercept	-27.62	
Velocity for predicting (m/s)	0.80	
Predicted RTF (repetitions)	12	
Goodness-of-fit	*r2* = 1.00	
	SEE = 0.15	repetitions

Cells to modify

RTF	Velocity (m/s)
1RTF	0.57
2RTF	0.59
3RTF	0.61
4RTF	0.63
5RTF	0.65
6RTF	0.67
7RTF	0.69
8RTF	0.71
9RTF	0.73
10RTF	0.75
11RTF	0.77
12RTF	0.79
13RTF	0.81
14RTF	0.83
15RTF	0.85
16RTF	0.87
17RTF	0.89
18RTF	0.91
19RTF	0.93
20RTF	0.95

Slope	0.020
x-intercept	0.553

Figure 3. *Illustration of an Excel spreadsheet that can be used for estimating the maximum repetitions to failure (RTF) and velocities associated with different RTF through two simple steps: (i) monitoring the RTF and maximum velocity within a set against at least two different external loads, and (ii) once the individual RTF-velocity is constructed, we have to indicate the velocity obtained to predict different RTF for a given absolute. Click here to download the excel.*

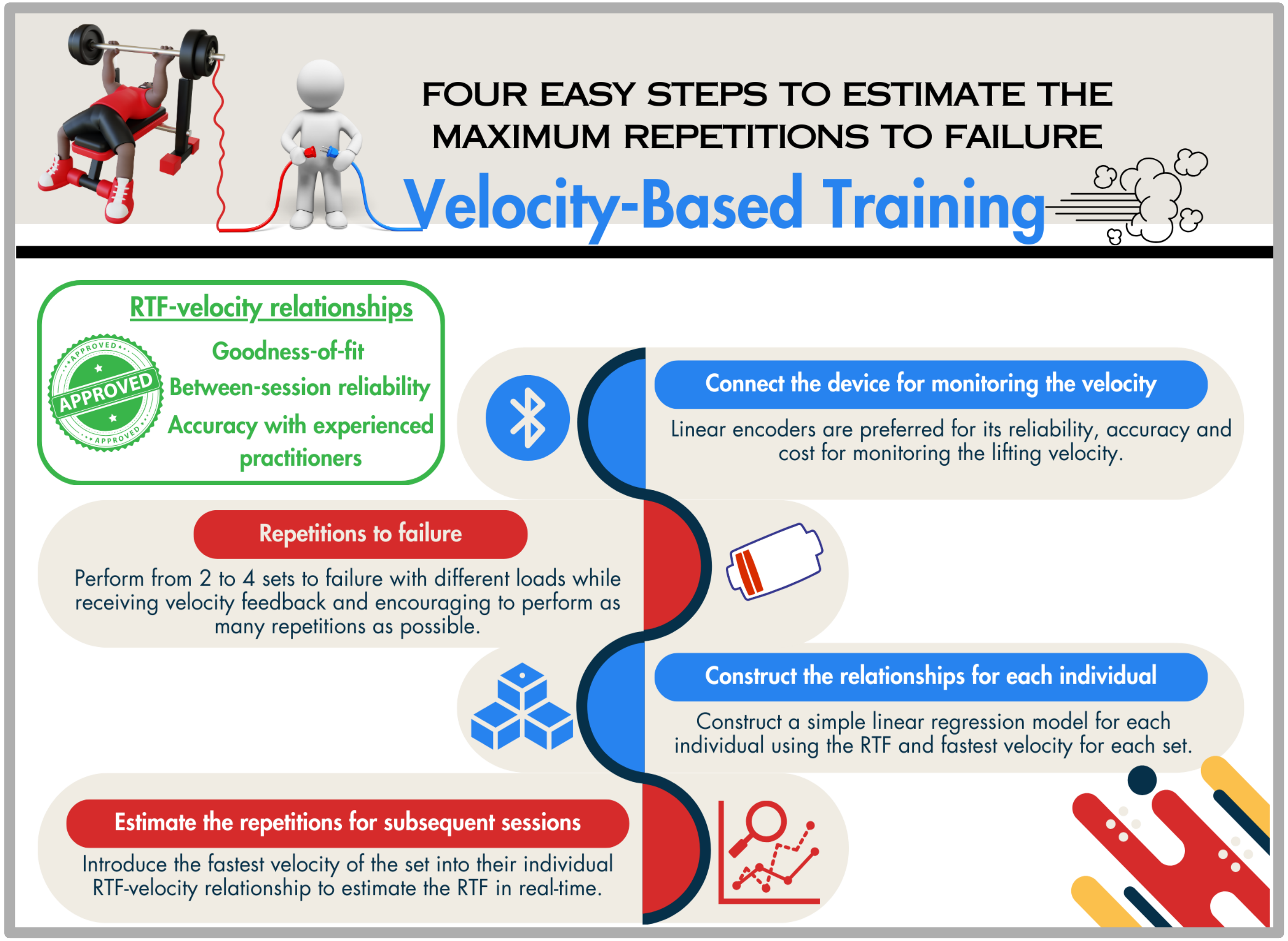


Figure 4. *Basic properties of the RTF-velocity relationships and four steps for predicting different RTF.*

2. Lifting Velocity As a Predictor of the Maximum Number of Repetitions That Can Be Performed to Failure During the Prone Bench Pull Exercise

Miras-Moreno, S., Pérez-Castilla, A. & García-Ramos, A.

Brief overview

The PBP exercise is a multi-joint upper-body exercise frequently used to improve muscular strength, hypertrophy, and power in sports disciplines such as rowing[12,47] or kayaking[12,87]. These training adaptations depend not only on exercise selection, but also on the proper management of acute training variables such exercise intensity[3,45]. Exercise intensity has commonly been prescribed based on the percentage of the one-repetition maximum (%1RM)[16,18,90]. However, due to the large between-subject variability reported for the RTF against a given %1RM, this percentage-based prescription method has been discouraged for prescribing a fixed number of repetitions across individuals[21,59,72]. For this reason, practitioners have alternatively used the XRM prescription method[27,45,84]. However, the accuracy of the XRM prescription method is inevitably affected by daily fluctuations in individuals' strength levels[84]. In this context, it is not practical to assess the XRM in every training session. Moreover, it could hinder training goals, like reducing volume due to fatigue from testing daily the XRM[84]. To overcome these limitations, researchers have examined the possibility of predicting the RTFs through recorded lifting velocity[21,43,59].

Despite the extensive research on the VBT topic, the PBP has received less attention than other RT exercises, even though it is a crucial exercise for enhancing strength and power of upper-body muscles. To gain insight related to the potential use of lifting velocity for predicting the RTF, we investigated whether lifting velocity could be an accurate predictor of the RTF during the PBP exercises under fatigued and non-fatigued conditions. To answer this research question, the following specific objectives were considered: (i) to compare the goodness-of-fit of generalized and individualized RTF-velocity relationships modelled considering $MV_{fastest}$ and $PV_{fastest}$ from training sets, (ii) to determine the between-sessions reliability of $MV_{fastest}$ and $PV_{fastest}$ values associated with different RTFs (from 1RTF to 15RTF), and (iii) to elucidate whether the errors in the prediction of the RTF under fatigued and non-fatigued conditions differ between generalized and individualized RTF-velocity relationships. We hypothesized that (i) individualized RTF-velocity relationships would present a higher goodness-of-fit (*i.e.,* higher r^2 and lower SEE) than generalized RTF-velocity relationships[21], (ii) the $MV_{fastest}$ and $PV_{fastest}$ associated with different RTFs would report an acceptable reliability (CV < 10%)[21], and (iii) the individualized RTF-velocity relationships would report lower errors in the prediction of the RTF than the generalized RTF-velocity relationships under both fatigued and non-fatigued conditions, while the lack of previous studies did not allow us to hypothesize whether the errors in the RTF prediction would be affected by the number of sets performed.

Methods

Design

A repeated-measures design was used to explore the possibility of predicting the RTF from the recording of lifting velocity during the PBP exercise. Subjects came to the laboratory on 4 occasions, twice a week, during 2 consecutive weeks, with at least 48 hours of rest between consecutive sessions (**Figure 5**). The first session was used for anthropometric measures and to determine the PBP 1RM. The second and third sessions were identical and consisted of single sets of repetitions to momentary failure separated by 10 minutes against 4 loads (60%1RM, 70%1RM, 80%1RM, and 90%1RM)[21]. The fourth session consisted of 4 sets of RTF separated by 2 minutes against the 75%1RM load. Subjects were instructed to lift the barbell as fast as possible from the first to the last repetition of all sets. All sessions were performed at the same time of the day for each subject (± 3 hours) and under similar environmental conditions (~22ºC and ~60% humidity) (**Figure 5**).

The between-sessions reliability of the individualized RTF-velocity relationships was assessed considering the data of the second and third testing sessions. For the remaining analyses, only the RTF-velocity relationships obtained in the third session were considered. The RTF-velocity relationships were constructed considering the number of repetitions performed before reaching muscular failure and the $MV_{fastest}$ or $PV_{fastest}$ of the set.

Subjects

Twenty-three collegiate sports science students, 20 men (age = 25.6 ± 5.3 years [range: 20-45 years]; body mass = 77.6 ± 8.7 kg; stature = 1.79 ± 0.06 m; PBP 1RM = 78.8 ± 12.0 kg [1.02 ± 0.15 normalized per kg of body mass]) and three women (age = 28.6 ± 8.5 years [range: 20-37 years]; body mass = 61.7 ± 1.5 kg; stature = 1.71 ± 0.05 m; PBP 1RM = 44.4 ± 4.0 kg [0.71 ± 0.06 normalized per kg of body mass]), participated in this study (data presented as means ± SD). All subjects were physically active and had 5.0 ± 3.1 years of RT experience (men: 5.2 ± 3.0 years; women: 4.7 ± 4.6 years). All subjects had previous experience with the PBP exercise before the study onset. They were informed of the study procedures and signed a written informed consent form before the study onset. The study protocol adhered to the tenets of the Declaration of Helsinki and was approved by the institutional review board (IRB approval: 2046/CEIH/2021).

Testing procedures

1RM assessment (Session 1)

The warm-up consisted of jogging, dynamic stretching, upper-body joint mobilization exercises, and 2 sets of 5 repetitions of the PBP exercise against 17 and 30 kg. After warming-up, subjects completed an incremental loading test to determine their PBP 1RM[16]. The initial external load was set at 20 kg for all subjects, and it was progressively increased in 10 kg increments until the attained MV was lower than 0.80 $m \cdot s^{-1}$. From that moment, the load was progressively increased in steps of 5 to 1 kg until the 1RM was achieved. Two repetitions were performed with light-moderate loads (MV ≥ 0.80 $m \cdot s^{-1}$) and 1 repetition with heavier loads (MV < 0.80 $m \cdot s^{-1}$). Recovery time was set to 3 minutes for light-moderate loads and 5 minutes for heavier loads.

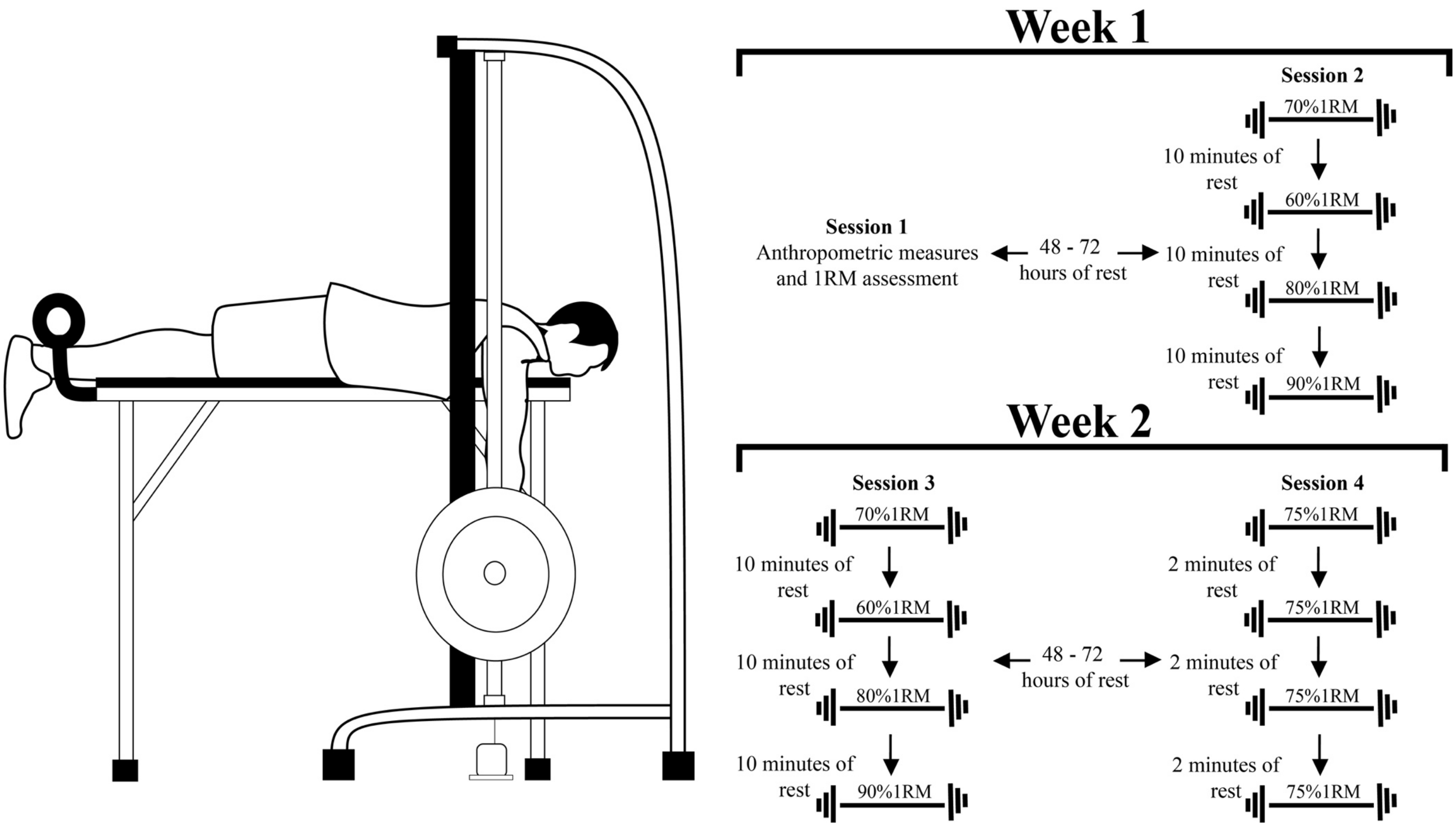


Figure 5*. Overview of the experimental design from Study 2.*

The PBP technique involved the subjects lying down in a prone position, the chin in contact with the bench, elbows fully extended, and a prone grip of the barbell slightly wider than shoulder width[16]. From that position, subjects were instructed to pull the barbell as fast as possible until it contacted with the underside of the bench. If the barbell did not contact the underside of the bench (thickness of 5.2 cm), the repetition was not considered valid. The legs were held during all repetitions by the same researcher and the chin always remained in contact with the bench. The range of movement was individualized using the mechanical brakes of the SM.

Determination of RTF-velocity relationships (Sessions 2-3)

The second and third sessions were identical. Prior to the first set of the RTF, subjects completed a standardized warm-up that included jogging, dynamic stretching, upper-body joint-mobilization exercises, and 1 set of 10, 3, and 1 repetitions of the PBP exercise with the 30%1RM, 70%1RM, and 90%1RM, respectively. After warming-up, subjects rested for 3 minutes and then they performed single sets of RTF against 4 loads (60%1RM, 70%1RM, 80%1RM, and 90%1RM). The 4 loads were applied in a randomized order in the second session, but the same sequence and absolute loads was maintained for individual subjects in the third session. Rest period of 10 minutes were implemented between successive sets[21].

Effect of fatigue on RTF prediction (Session 4)

The warm-up was identical to that described for sessions 2 and 3. After warming-up, subjects rested for 3 minutes and then they performed 4 sets of the RTF against the 75%1RM (same absolute load across the sets). Rest period of only 2 minutes were allowed between consecutive sets to induce fatigue. Of note is that this analysis only considered 18 subjects because 5 subjects did not attend to the last testing session.

Measurement Equipment and Data Analysis

Stature (Seca 202 Stadiometer, Seca Ltd., Hamburg, Germany) and body mass (Tanita BC 418 segmental, Tokyo, Japan) were measured at the beginning of the first session. A SM (Technogym, Barcelona, Spain) was used in all testing sessions. A linear velocity transducer (T-Force System; Ergotech, Murcia, Spain) was attached to the barbell of the SM to determine the MV and PV. The T-Force, which has been validated elsewhere[9], directly sampled velocity-time data at 1000 Hz.

Statistical Analysis

Data are presented as means and SD, while the r^2 and the SEE are presented through the median value and range. One-way repeated-measures ANOVAs with Bonferroni post-hoc tests were applied to compare the RTF and the fastest velocity and last repetition of the sets between the 4 loads (60%1RM, 70%1RM, 80%1RM, and 90%1RM). The Greenhouse-Geisser correction was applied when the Mauchly's sphericity test was violated ($P < 0.05$). Simple linear regression models with the $MV_{fastest}$ or $PV_{fastest}$ as predictor variables were constructed to predict the RTF (from 1RTF to 15RTF)[21]. A generalized RTF-velocity relationship was constructed considering all data points from the third session (23 subjects × 4 sets = 92 data points), while the individualized RTF-velocity relationships of the second and third sessions were computed separately considering the 4 sets of each session. The goodness-of-fit of the generalized and individualized RTF-velocity relationships was assessed by the r^2 and SEE.

The between-sessions reliability of the MVfastest and PVfastest of the set associated with each RTF (from 1RTF to 15RTF) were assessed by the within-subjects CV (standard error of measurement / subjects' mean score × 100) and the ICC model 3.1 with their respective 95%CI. A high and acceptable reliability was deemed when the CV was lower than 5% and 10%, respectively[21]. The between-subjects CV (between-subjects SD / subjects' mean score × 100) was also computed to report the between-subjects variability in the $MV_{fastest}$ and $PV_{fastest}$ associated with each RTF.

Finally, one-way repeated-measures ANOVAs with Bonferroni post-hoc tests were applied to compare the RTF of the 4 sets against 75%1RM, the velocity of the fastest and the last repetitions of the set, and the raw and absolute errors obtained when predicting the RTF using the different regression models. The reliability analyses were performed by means of a customized 2019 Microsoft Excel spreadsheet (version 16.32, Microsoft Corporations, Redmond, Washington, USA)[32], while the software package SPSS (IBM SPSS version 25.0, Chicago, IL, USA) was used for the remaining analyses. Alpha was set at 0.05.

Results

The increment in the relative load was associated with a reduction in RTF and in the $MV_{fastest}$ fand $PV_{fastest}$, while no significant differences were generally observed for the velocity of the last repetition (**Table 3**). The goodness-of-fit of the generalized RTF-velocity relationships was strong and comparable for $MV_{fastest}$ (r^2 = 0.70; SEE = 3.6 repetitions) and $PV_{fastest}$ (r^2 = 0.67; SEE = 3.7 repetitions) (**Figure 6**). However, the goodness-of-fit of the individualized RTF-velocity relationships was always stronger for both $MV_{fastest}$ (r^2 = 0.96 [0.83, 1.00]; SEE = 1.7 repetitions [0.3, 4.7]) and $PV_{fastest}$ (r^2 = 0.97 [0.84, 1.00]; SEE = 1.4 repetitions [0.2, 4.7]) (**Figure 7**).

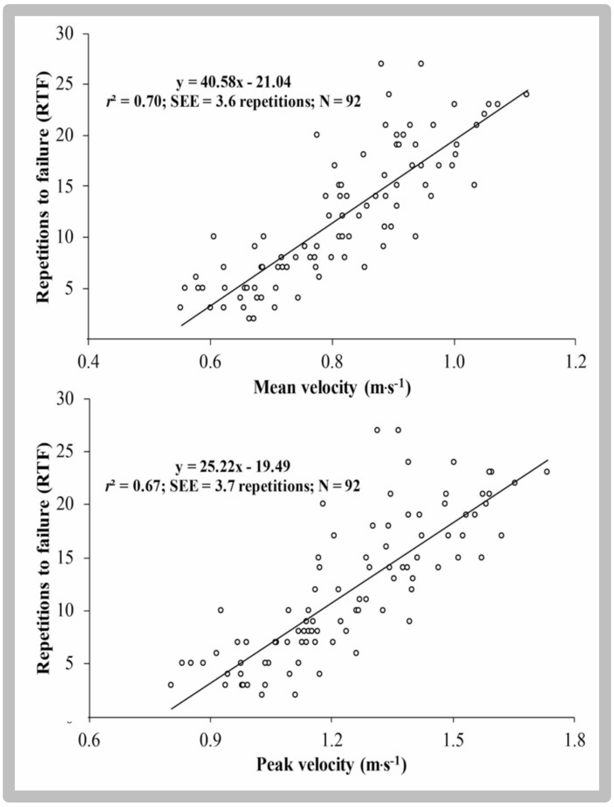


Figure 6. *Generalized relationship between the maximum number of repetitions to failure (RTF) and the fastest mean velocity (upper panel) or peak velocity (lower panel) of the set during the prone bench pull exercise. N, numbers of trials included in the regression analysis.*

Table 3. *Comparison of the number of repetitions completed before reaching muscular failure and the velocity of the fastest and last repetitions of sets performed against 4 loads.*

	ANOVA	60%1RM	70%1RM	80%1RM	90%1RM
RTF	$F = 450.6$; $P < 0.001$	20.7 ± 3.1	14.0 ± 2.4[a]	8.2 ± 1.6[a,b]	4.3 ± 1.4[a,b,c]
Fastest MV ($m \cdot s^{-1}$)	$F = 345.6$; $P < 0.001$	0.96 ± 0.07	0.87 ± 0.06[a]	0.75 ± 0.07[a,b]	0.65 ± 0.05[a,b,c]
Fastest PV ($m \cdot s^{-1}$)	$F = 376.7$; $P < 0.001$	1.49 ± 0.12	1.32 ± 0.09[a]	1.14 ± 0.09[a,b]	1.00 ± 0.10[a,b,c]
Last MV ($m \cdot s^{-1}$)	$F = 2.5$; $P = 0.064$	0.57 ± 0.08	0.58 ± 0.10	0.56 ± 0.06	0.54 ± 0.06
Last PV ($m \cdot s^{-1}$)	$F = 3.6$; $P = 0.037$	0.89 ± 0.14	0.90 ± 0.13	0.87 ± 0.08	0.84 ± 0.09[b]

Values are presented as mean ± standard deviation. 1RM, 1-repetition maximum; MV, mean velocity; PV, peak velocity; ANOVA, analysis of variance; *F*, Snedecor's *F*; *P*, *P*-value; [a], significantly different than 60%1RM; [b], significantly different than 70%1RM; [c], significantly different than 80%1RM.

Table 4. *Reliability of the fastest mean velocity (MV) and peak velocity (PV) of the set associated with different RTF.*

Fastest MV						Fastest PV				
RTF	**Session 1 ($m·s^{-1}$)**	**Session 2 ($m·s^{-1}$)**	**Within-subjects CV**	**ICC**	**Between-subjects CV**	**Session 1 ($m·s^{-1}$)**	**Session 2 ($m·s^{-1}$)**	**Within-subjects CV**	**ICC**	**Between-subjects CV**
1	0.60 ± 0.07	0.60 ± 0.07	5.4 (4.1, 7.7)	0.78 (0.54, 0.90)	11.1	0.92 ± 0.08	0.91 ± 0.10	6.7 (5.1, 9.5)	0.58 (0.21, 0.80)	10.1
2	0.62 ± 0.07	0.62 ± 0.06	4.9 (3.8, 7.1)	0.79 (0.56, 0.91)	10.5	0.95 ± 0.08	0.94 ± 0.10	5.9 (4.6, 8.5)	0.62 (0.28, 0.82)	9.5
3	0.64 ± 0.06	0.64 ± 0.06	4.5 (3.5, 6.5)	0.80 (0.58, 0.91)	9.9	0.98 ± 0.08	0.97 ± 0.10	5.3 (4.1, 7.6)	0.67 (0.36, 0.85)	9.0
4	0.66 ± 0.06	0.66 ± 0.06	4.2 (3.2, 6.1)	0.81 (0.60, 0.91)	9.4	1.01 ± 0.07	1.00 ± 0.09	4.7 (3.6, 6.8)	0.72 (0.44, 0.87)	8.7
5	0.68 ± 0.06	0.67 ± 0.06	4.0 (3.0, 5.7)	0.82 (0.62, 0.92)	9.1	1.05 ± 0.08	1.03 ± 0.10	4.2 (3.2, 6.1)	0.77 (0.52, 0.89)	8.5
6	0.71 ± 0.06	0.70 ± 0.06	3.8 (2.9, 5.4)	0.83 (0.63, 0.92)	8.8	1.08 ± 0.08	1.06 ± 0.10	3.8 (2.9, 5.5)	0.81 (0.59, 0.91)	8.4
7	0.72 ± 0.06	0.71 ± 0.06	3.6 (2.8, 5.2)	0.83 (0.64, 0.92)	8.6	1.11 ± 0.09	1.09 ± 0.10	3.5 (2.7, 5.0)	0.84 (0.65, 0.93)	8.4
8	0.75 ± 0.06	0.74 ± 0.06	3.6 (2.7, 5.1)	0.83 (0.64, 0.92)	8.4	1.15 ± 0.09	1.13 ± 0.10	3.2 (2.5, 4.6)	0.86 (0.70, 0.94)	8.5
9	0.77 ± 0.06	0.76 ± 0.06	3.5 (2.7, 5.1)	0.83 (0.64, 0.92)	8.4	1.18 ± 0.10	1.16 ± 0.10	3.1 (2.4, 4.4)	0.88 (0.74, 0.95)	8.6
10	0.79 ± 0.07	0.78 ± 0.07	3.6 (2.7, 5.1)	0.83 (0.63, 0.92)	8.3	1.22 ± 0.11	1.19 ± 0.10	3.0 (2.3, 4.3)	0.89 (0.76, 0.95)	8.8
11	0.81 ± 0.07	0.80 ± 0.07	3.6 (2.8, 5.2)	0.82 (0.63, 0.92)	8.4	1.25 ± 0.12	1.22 ± 0.11	3.0 (2.3, 4.3)	0.89 (0.76, 0.95)	9.0
12	0.83 ± 0.07	0.82 ± 0.07	3.7 (2.8, 5.3)	0.82 (0.62, 0.92)	8.5	1.28 ± 0.12	1.25 ± 0.11	3.1 (2.4, 4.5)	0.89 (0.77, 0.95)	9.3
13	0.85 ± 0.08	0.83 ± 0.07	3.8 (2.9, 5.5)	0.81 (0.60, 0.92)	8.6	1.32 ± 0.13	1.28 ± 0.12	3.2 (2.5, 4.7)	0.89 (0.76, 0.95)	9.5
14	0.87 ± 0.08	0.85 ± 0.07	3.9 (3.0, 5.7)	0.81 (0.59, 0.91)	8.7	1.35 ± 0.14	1.31 ± 0.12	3.4 (2.6, 4.9)	0.89 (0.75, 0.95)	9.8
15	0.90 ± 0.08	0.87 ± 0.07	4.1 (3.1, 5.9)	0.80 (0.58, 0.91)	8.9	1.38 ± 0.15	1.34 ± 0.13	3.6 (2.8, 5.2)	0.88 (0.74, 0.95)	10.1

Values are presented as means ± standard deviations. CV, coefficient of variation; ICC, intraclass correlation coefficient; 95% CI, 95% confidence interval.

Table 5. *Comparison between the 4 sets performed to failure and the raw and absolute errors obtained when predicting the RTF using the different regression models.*

	ANOVA	Set 1	Set 2	Set 3	Set 4
RTF	F = 37.4; P < 0.001	11.4 ± 2.8	8.9 ± 1.8[a]	7.5 ± 1.5[a,b]	7.4 ± 1.8[a,b]
Fastest MV ($m \cdot s^{-1}$)	F = 18.5; P < 0.001	0.84 ± 0.08	0.81 ± 0.08	0.78 ± 0.08[a,b]	0.78 ± 0.08[a,b]
Fastest PV ($m \cdot s^{-1}$)	F = 21.1; P < 0.001	1.28 ± 0.10	1.23 ± 0.1[a]	1.19 ± 0.11[a,b]	1.18 ± 0.10[a,b]
Last MV ($m \cdot s^{-1}$)	F = 1.6; P = 0.181	0.56 ± 0.08	0.58 ± 0.07	0.59 ± 0.08	0.59 ± 0.08
Last PV ($m \cdot s^{-1}$)	F = 2.6; P = 0.062	0.86 ± 0.11	0.89 ± 0.10	0.91 ± 0.10	0.91 ± 0.10
Raw error (repetitions)					
Individualized RTF-MV	F = 4.2; P = 0.010	-1.2 ± 2.5	-2.5 ± 2.3	-2.5 ± 1.7	-2.6 ± 1.6
Individualized RTF-PV	F = 5.2; P = 0.003	-1.0 ± 2.2	-2.2 ± 2.3	-2.4 ± 1.6[a]	-2.1 ± 2.0[a]
Generalized RTF-MV	F = 8.2; P < 0.001	-1.4 ± 3.9	-3.0 ± 4.0[a]	-3.2 ± 3.3[a]	-3.3 ± 3.5[a]
Generalized RTF-PV	F = 11.6; P < 0.001	-1.2 ± 3.5	-2.4 ± 3.5[a]	-3.0 ± 2.6[a]	-2.9 ± 2.6[a]
Absolute error (repetitions)					
Individualized RTF-MV	F = 0.7; P = 0.535	2.3 ± 1.5	2.9 ± 1.8	2.6 ± 1.5	2.7 ± 1.5
Individualized RTF-PV	F = 0.6; P = 0.606	2.1 ± 1.0	2.5 ± 1.5	2.2 ± 1.4	2.4 ± 1.3
Generalized RTF-MV	F = 1.9; P = 0.131	3.4 ± 2.4	4.3 ± 2.3	4.0 ± 2.2	4.1 ± 2.4
Generalized RTF-PV	F = 2.5; P = 0.103	2.8 ± 2.4	3.8 ± 1.7	3.6 ± 1.6	3.4 ± 1.7

Values are presented as means ± standard deviations. ANOVA, analysis of variance; MV, mean velocity; PV, peak velocity; RTF, number of repetitions performed before reaching muscular failure. [a], significantly different than 60%1RM; [b], significantly different than 70%1RM; [c], significantly different than 80%1RM.

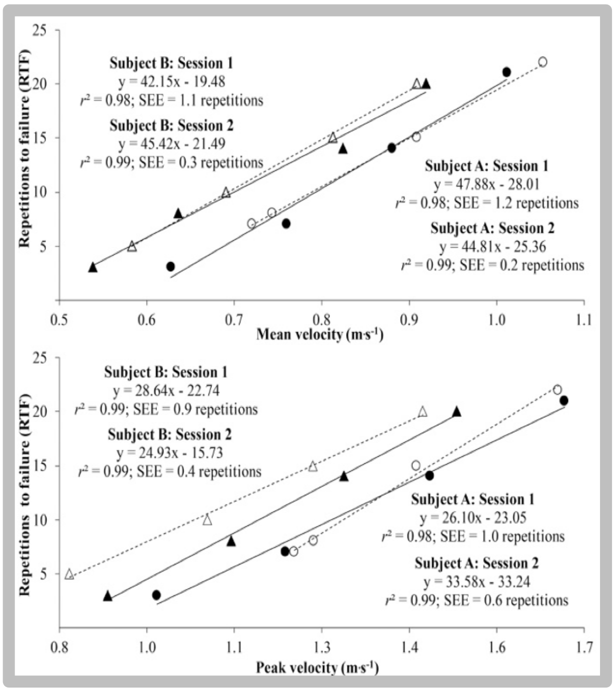


***Figure** 7. Relationship between the RTF and the $MV_{fastest}$ (upper panel) and $PV_{fastest}$ (lower panel) of the set for 2 representative subjects. Filled dots (first testing session) and empty dots (second testing session).*

The reliability of the $MV_{fastest}$ and $PV_{fastest}$ associated with each RTF was generally high and comparable for both MV (CV = 4.01% [3.50%, 5.40%]) and PV (CV = 3.98% [3.00%, 6.70%]). The within-subjects CV was only higher than 5% in 4 instances: 1RM for both $MV_{fastest}$ and $PV_{fastest}$, 2RM for $PV_{fastest}$, and 3RM for $PV_{fastest}$. The within-subjects CV was at least twice lower than the between-subjects CV (**Table 4**).

The completion of 4 consecutive sets against the 75%1RM was associated with a reduction in both the RTF and the $MV_{fastest}$ and $PV_{fastest}$ of the set, whereas no significant differences across the sets were observed for the MV and PV of the last repetition. The analysis of the raw errors indicates that the 4 prediction equations overestimated the RTFs and this overestimation was slightly higher for sets 2-4 compared to the first set. The absolute errors were lower for the individualized RTF-velocity relationships compared to the generalized RTF-velocity relationships and they were comparable for the 4 sets (**Table 5**).

Discussion

This study was designed to elucidate whether the fastest velocity of the set can be used as an accurate predictor of the RTF during the PBP exercise performed in a SM. The main findings of this study revealed that (i) individualized RTF-velocity relationships presented a higher goodness-of-fit and a greater accuracy in the prediction of the RTF than generalized RTF-velocity relationships, (ii) the $MV_{fastest}$ and $PV_{fastest}$ values associated with different RTFs were generally highly reliable, and (iii) the error in the prediction of the RTF increased by ≈ 1 repetition under fatigue (*i.e.,* set 1 *vs.* sets 2-4). These results collectively suggest that the individualized RTF-velocity relationship can be used with an acceptable precision to prescribe the loads to match a specific XRM during the PBP exercise. However, the larger overestimation of the RTF under fatigue also suggests that the individualized RTF-velocity relationship should preferably be evaluated under conditions that closely resemble typical RT sessions (*e.g.,* using inter-set rest periods of similar duration).

One of the main applications of VBT is the possibility of estimating the 1RM daily to prescribe the loads based on the athletes' readiness to train[90]. However, given the high between-subjects variability in the RTF for a given %1RM[25,72], to ensure a more homogeneous training stimulus researchers have proposed to stop the sets when subjects experience a given velocity loss instead of performing a pre-determined fixed number of repetitions[25,91]. Of note is that a high between-subjects variability

(CV ≈ 18.9-67.5%) exists for the number of repetitions that can be completed before reaching different VLTs[66], while several methodological factors could also influence the actual number of repetitions performed when using VLTs for prescribing the repetitions volume: the reference repetition used for calculating the VLT (first vs. fastest), the velocity variable considered (MV *vs.* MPV velocity *vs.* PV), and the criterion used for terminating a set (after one or more repetitions exceeded the VLT)[21]. In this regard, another approach for prescribing the repetitions volume was proposed by García-Ramos et al.[21] who confirmed that lifting velocity can be used to predict the RTF during the BP exercise. The confirmation of these results in other exercises would enable the training prescription based on the XRM (*i.e.,* selecting a load and then deciding the number of repetitions to perform depending on the desired proximity to failure) without the need to frequently perform sets to failure during a training cycle. In concordance with this previous study[21], the present study also suggests that lifting velocity can be used as an accurate predictor of the RTF during the PBP exercise.

In line with García-Ramos et al.[21], the goodness-of-fit of the individualized RTF-velocity relationships was markedly stronger than for the generalized RTF-velocity relationships, regardless of the variable considered (MV or PV). This result is also in line with a previous study that compare the goodness-of-fit between individualized and generalized load-velocity relationships[75]. In addition, in this study we also confirmed a high reliability of both $MV_{fastest}$ and $PV_{fastest}$ values associated with different RTFs (mean CV of 4.01% and 3.98%, respectively). These reliability parameters are slightly higher than the previously reported for the BP (average CV = 6.14%)[21]. Morán-Navarro et al.[61] also revealed similar reliability scores (CV = 4.4-8.0%) for the absolute velocities associated with stopping a set before failure, leaving a certain number of repetitions (2, 4, 6, or 8) in reserve, during the BP, BS, PBP and shoulder press. These results collectively suggest that lifting velocity can be used as an objective method to estimate the proximity to muscle failure and quantify the level of effort without the need of register all repetitions from all sets facilitating the implementation of VBT in team sports[29].

Performing multiple sets of 1 or more exercises during a RT session inevitably causes metabolic, neuromuscular, and perceptual fatigue[91]. The decrease in the ability to produce force (*i.e.,* fatigue) can be manifested by a decrease in both the RTF against a given load and the fastest repetition velocity of a set[22]. Therefore, in case the fatigue induced by performing multiple sets has different effects on the RTF and the fastest velocity of a set, it is plausible that the precision of the RTF-velocity relationships could be compromised. This study explored this issue for the first time and revealed that the execution of consecutive sets to failure separated by 2 minutes affected more the RTF than the fastest velocity of the set. Consequently, the RTF-velocity relationships overestimated the RTF by ≈ 1 repetition more in fatigue (sets 2-4) than at rest (set 1). Although it should be noted that the training protocol was too exhausting and likely not common when implementing VBT, it is useful for illustrating that RTF-velocity relationships should be preferably evaluated under fatigue conditions typically incurred in training.

It is noteworthy that regardless of whether the RTFs were estimated under fatigued or non-fatigue conditions, individualized RTF-velocity relationships always provided a more accurate estimate than generalized RTF-velocity relationships. Finally, it is important to keep in mind that this is the second study that has explored the RTF-velocity relationship. Although the results are so far promising, more studies are definitely needed to explore the accuracy of the RTF-velocity relationship in other RT exercises, refine the RTF-velocity relationship testing procedures (number and magnitude of the loads, inter-set rest periods, etc.), identify the impact of different equipment (FW *vs.* SM) or execution mode (only concentric *vs.* eccentric-concentric), and analyze its accuracy for subjects with different strength training backgrounds.

Conclusions

The individualized RTF-velocity relationships revealed a higher goodness-of-fit and greater accuracy in the prediction of the RTF than generalized RTF-velocity relationships. These results, together with the very high reliability of both $MV_{fastest}$ and $PV_{fastest}$ values associated with different RTF, suggest that the individualized RTF-velocity relationship can be used for prescribing the loads to match a specific XRM during the PBP exercise performed in a SM. However, the systematic overestimation in the prediction of the RTF under fatigued conditions requires more scientific attention to further refine the testing procedure of the individualized RTF-velocity relationship.

Practical Applications

The individualized RTF-velocity relationship can be assessed by a linear regression model by instructing athletes to perform sets to failure at maximal intended velocity against different loads. Once this relationship has been established, in practice coaches only need to record the fastest velocity of the set (first one-three repetitions are usually the fastest) and can be used to estimate in real-time the RTF. Although this approach is promising because it would allow to prescribe the loads to match a specific XRM daily without the need of performing sets to failure once the individualized RTF-velocity relationship has been determined, we need more studies exploring the accuracy of this approach in different exercises and training conditions.

3. Lifting Velocity Predicts the Maximum Number of Repetitions to Failure With Comparable Accuracy During the Smith Machine and Free-Weight Prone Bench Pull Exercises.

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Brief Overview

Free-weight exercises are generally preferred in the context of sports performance due to their greater similarity with sport-specific actions and greater involvement of stabilizer muscles[27,81,82]. However, most applications of VBT, including the ability to predict RTF from lifting velocity, have been mainly explored during exercises performed in a SM[21,59,72,73]. This is because the available velocity/linear position transducers do not discriminate the direction of the movement (vertical, lateral, or anteroposterior) and the use of a SM restricts the displacement of the barbell to the vertical direction potentially maximizing the accuracy of these velocity recordings[62]. In this regard, the goodness-of-fit of general load-velocity relationships seems to be slightly stronger when the PBP is performed in a SM (r^2 = 0.95–0.96; SEE = 5.31–5.90%1RM)[78] compared to FW (r^2 = 0.90–0.91; SEE = 6.27–6.56%1RM)[16,50]. To date, no study has directly compared the accuracy of lifting velocity to predict RTF between SM and FW exercises.

In previous studies subjects were asked to perform sets to failure against multiple loads to determine the individualized RTF-$MV_{fastest}$ relationships[21,59]. However, due to the high linearity of individualized RTF-$MV_{fastest}$ relationships in the range of repetitions analyzed (from 1 to 20 repetitions), it seems reasonable to suggest that the two-point method could also be valuable for this VBT application[18,57]. To date, only one study has explored the accuracy of RTF-$MV_{fastest}$ relationships under various levels of fatigue (four sets to failure of the SM PBP exercise against the 75%1RM) and demonstrated that RTF tends to be progressively overestimated with increased levels of fatigue[59]. Summing up, it is not only necessary to explore the accuracy of RTF-$MV_{fastest}$ relationships during FW exercises, but also to elucidate whether the testing procedure could be further simplified by asking subjects to perform sets to failure against only two distant loads (*i.e.,* two-point method) and to determine whether the effect of fatigue on the overestimation of RTF from velocity recordings is maintained when greater (85%1RM) and lower (65%1RM) loads are lifted.

This study expanded the information regarding the potential application of lifting velocity to predict RTFs. Specifically, the objectives of this study were: (i) to compare the goodness-of-fit between the generalized and individualized RTF-$MV_{fastest}$ relationships obtained during the SM and FW variants of the PBP exercise, (ii) to compare and associate the $MV_{fastest}$ values associated with each RTF (from 1 to 15 RTFs) between both individual estimation methods (multiple-point *vs.* two-point) and PBP exercises (SM *vs.* FW), and (iii) to explore whether the accuracy in the prediction of RTFs is affected by fatigue (set 1 *vs.* set 2), the type of RTF-$MV_{fastest}$ relationships (generalized *vs.* multiple-point *vs.* two-point), and PBP exercise (SM *vs.* FW). We hypothesized: (i) a higher goodness-of-fit for individualized compared to generalized RTF-$MV_{fastest}$ relationships[21,59] and for SM compared to FW PBP, (ii) the $MV_{fastest}$ associated with each RTF would be comparable for the multiple- and two-point methods, but higher for the SM compared to FW PBP[50], and (iii) both individualized RTF-$MV_{fastest}$ relationships (multiple-point and two-point) would present lower errors in the prediction of RTF than generalized RFT-$MV_{fastest}$ relationship, although all of them would overestimate the RTF in fatigue conditions[59].

Methods

Design

A crossover design was used to investigate the possibility of predicting RTF from the recording of lifting velocity during the SM and FW PBP exercises. After a preliminary SM PBP 1RM testing session, subjects undertook four experimental sessions, twice a week with at least 48 hours of rest, over two consecutive weeks. In a counterbalanced order, subjects performed two sessions using the SM in one week, and two sessions using the FW in another week. The first weekly session consisted of single sets of RTF separated by five minutes against four relative loads that were applied in the following fixed order: 60%1RM, 90%1RM, 70%1RM, and 80%1RM. The second weekly session consisted of four sets of RTF (two randomized sets against the 65%1RM and two sets against the 85%1RM) separated by two minutes of rest. Subjects were always instructed to lift the barbell as fast as possible and received MV feedback from the first to the last repetition[89]. All sessions were conducted at the University's research laboratory, at the same time of the day for each subject (± 3 hours), and under similar environmental conditions (~22ºC and ~60% humidity) (**Figure 8**).

Subjects

Twenty-three resistance-trained males (age = 25.0 ± 7.3 years [range: 18-45 years]; body height = 1.78 ± 0.07 m; body mass = 82.6 ± 22.7 kg; SM PBP 1RM = 84.8 ± 12.9 kg [1.06 ± 0.17 normalized per kg of body mass]) participated in this study (data presented as means ± SD). All subjects had 5.0 ± 4.7 years of RT experience and reported using the PBP in their regular training. No physical limitations or musculoskeletal injuries that could compromise testing were reported. Subjects were required to avoid any strenuous exercise over the course of the study. They were informed of the study procedures and signed a written informed consent form before the study onset. The study protocol adhered to the tenets of the Declaration of Helsinki and was approved by the Institutional Review Board (approval no: 2046/CEIH/2021).

Testing procedures

1RM assessment (preliminary session)

The warm-up consisted of jogging, dynamic stretching, upper-body joint mobilization exercises, and two sets of five repetitions of the SM PBP against 20 and 30 kg. The initial load of the incremental loading test was set at 40 kg, and it was progressively increased in 10 kg increments until the MV was lower than 0.80 $m \cdot s^{-1}$. From that moment, the load was increased in steps of five to one kg until the 1RM was directly achieved.

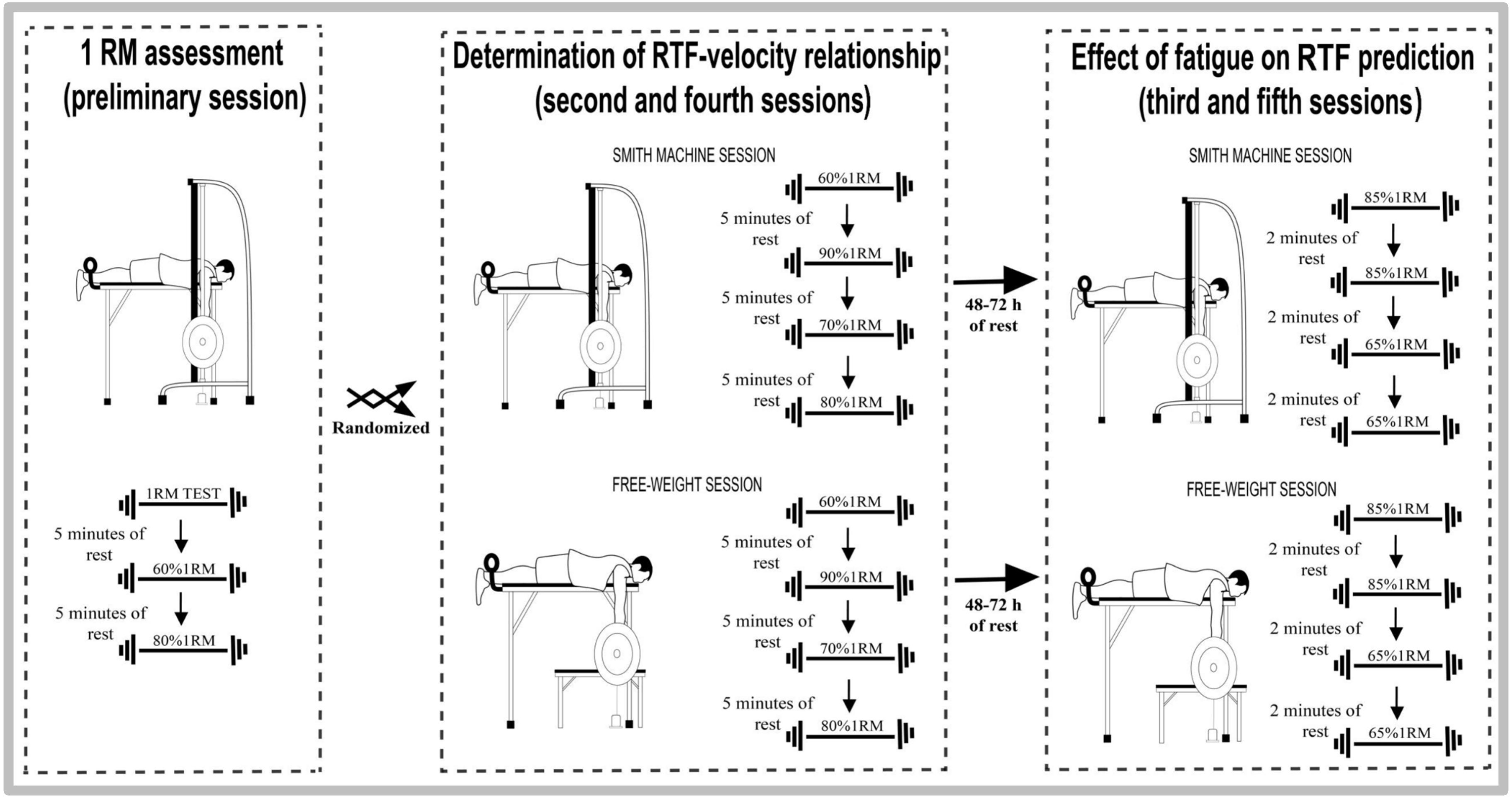

Figure 8. *Overview of the experimental design from study 3.*

Recovery time was set to three minutes for light-moderate loads and five minutes for heavier loads. Finally, subjects completed two sets of repetitions to failure separated by five minutes against the 60%1RM and 80%1RM for familiarization purposes[59].

Determination of RTF-$MV_{fastest}$ relationships (first weekly session)

The second and fourth sessions were identical, but a single PBP exercise (SM or FW) was used in each session. The warm-up consisted of jogging, dynamic stretching, and upper-body joint-mobilization exercises, followed by one set of 10, three, and one repetition of the tested PBP with the 40%1RM, 60%1RM, and 80%1RM, respectively. After warming-up, subjects rested for three minutes, and then they performed single sets of repetitions to failure against four different loads in the following order: 60%1RM, 90%1RM, 70%1RM, and 80%1RM. Rest periods of five minutes were implemented between successive sets.

Effect of fatigue on RTF prediction (second weekly session)

Each session began with the same warm-up described for the second and fourth sessions. Subjects performed two sets of RTFs against the 65%1RM and another two sets against the 85%1RM. The loads were applied in randomized order, but the same sequence and absolute loads were maintained for individual subjects during both sessions. To ensure fatigue, rest periods of only two minutes were implemented between successive sets[59]. This analysis only included 22 subjects because one subject did not attend to the fifth testing session.

PBP technique

The PBP exercise was performed in a SM (Multipower Fitness Line, Peroga, Murcia, Spain) or with a standard Olympic barbell (Rockstrong Bar, Ruster Fitness, Jaén, Spain). Subjects lied down in a prone position, with their chins touching the bench, and their elbows fully extended with a prone grip of the barbell slightly wider than shoulder width[59]. The telescopic holders of the SM were positioned so that the barbell stopped exactly when both elbows were in full extension. The barbell was stopped on a bench during the FW PBP to maintain the same range of motion. From that initial position, subjects were instructed to pull the barbell as fast as possible until it contacted with the underside of the bench. When the barbell did not contact the underside of the bench (thickness of 11.0 cm) for two consecutive repetitions, the test ended and both repetitions were not considered[59]. The legs were held with a rigid strap on the calves. A validated linear velocity transducer (T-Force System version 3.70; Ergotech, Murcia, Spain) was used to determine the MV[9]. Specifically, the MV of the fastest and last repetitions of the sets were used for subsequent analyses.

Statistical Analysis

Data are presented as means and SD, while the r^2 and SEE are presented through the median values and range. The normal distribution of the data was confirmed using the Shapiro-Wilk test ($P > 0.05$). One-way repeated-measures ANOVA were applied to compare RTF, $MV_{fastest}$ and MV_{last} between the sets performed against four relative loads (60%-90-70-80%1RM) separately for each PBP exercise. Least-square linear regression models were used to determine the relationship between RTF and $MV_{fastest}$ using the data of the first weekly sessions[21,59]. Generalized RTF-

$MV_{fastest}$ relationships were obtained by pooling together the data from all subjects (23 subjects × 4 sets = 92 data points)[21,59], while individualized RTF-$MV_{fastest}$ relationships were computed separately for each subject considering the data points acquired from the four loads (*i.e.,* multiple-point method [60-90-70-80%1RM]) or only the two most distant loads (*i.e.,* two-point method [60-90%1RM]). The goodness-of-fit of generalized and individualized RTF-$MV_{fastest}$ relationships were evaluated through the r^2 and SEE[21,59].

A two-way repeated-measures ANOVA (method [multiple-point *vs.* two-point] × PBP exercise [SM *vs.* FW]) was used to compare the $MV_{fastest}$ associated with each predicted RTF[21,59]. The *r* was used to quantify the association of the $MV_{fastest}$ attained at each RTF between both methods and PBP exercises. The criteria for interpreting the magnitude of the *r* coefficients were as follows: *trivial* (0.00–0.09), *small* (0.10–0.29), *moderate* (0.30–0.49), *large* (0.50–0.69), *very large* (0.70–0.89), *nearly perfect* (0.90-0.99), and *perfect* (1.00)[31]. The magnitude of the differences was also assessed by the Cohen's *d* effect size (ES), which was interpreted using the following scale: *trivial* (< 0.20), *small* (0.20–0.59), *moderate* (0.60–1.19), *large* (1.20–1.99), and *very large* (≥ 2.00)[31].

Finally, a three-way repeated-measures ANOVA (method [generalized *vs.* multiple-point *vs.* two-point] × PBP exercise [SM *vs.* FW] × set [set 1 *vs.* set 2]) was applied to compare the raw and absolute errors obtained for the prediction of RTF separately for the 65%1RM and 85%1RM loads. The Greenhouse-Geisser correction was used when the Mauchly's sphericity test was violated and pairwise differences were identified using Bonferroni post-hoc corrections. The analyses were performed by the software package SPSS (IBM SPSS version 25.0, Chicago, IL, USA). Alpha was set at $P \leq 0.05$.

Results

Regardless of the PBP exercise, the increase in the load was accompanied by a decrease in RTF and $MV_{fastest}$, but no significant differences were found for MV_{last} (**Table 6**). The goodness-of-fit of the generalized RTF-$MV_{fastest}$ relationship was stronger for the SM PBP (r^2 = 0.79; SEE = 5.4 repetitions) than for the FW PBP (r^2 = 0.67; SEE = 6.6 repetitions). The individualized were always stronger than generalized RFT-$MV_{fastest}$ relationships. The goodness-of-fit was comparable for the SM PBP (r^2 = 0.96 [0.86, 1.00]; SEE = 2.8 repetitions [0.6, 7.8 repetitions]) and FW PBP (r^2 = 0.94 [0.79, 1.00]; SEE = 3.0 repetitions [0.5, 9.5 repetitions]) (**Figure 9**).

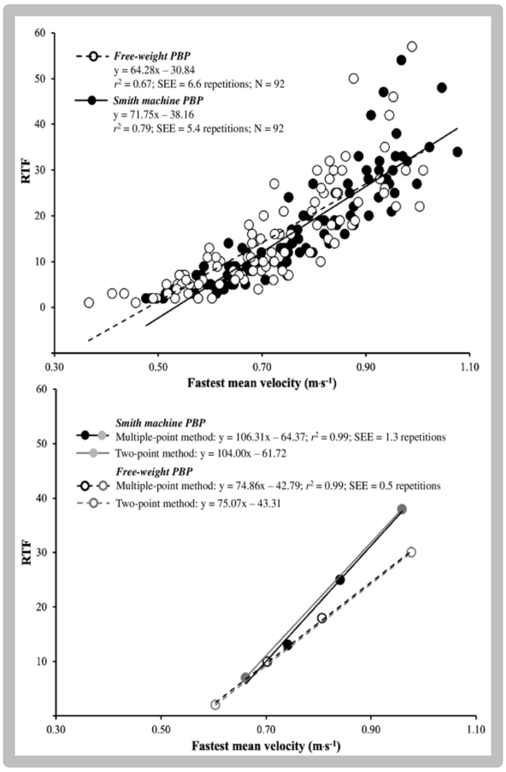

Figure 9. *Upper panel represents the generalized RTF-velocity relationships during the SM (filled dots and straight lines) and FW (open dots and dashed lines). Lower panel represents the individualized RTF-velocity relationships.*

Table 6. *Comparison of the number of repetitions performed before to failure (RTF) and mean velocity of the fastest ($MV_{fastest}$) and last (MV_{last}) repetition of in Smith machine and free-weight exercises.*

Variable	PBP exercise	60%1RM	70%1RM	80%1RM	90%1RM	ANOVA
RTF	Smith machine	32.1 ± 9.0	19.3 ± 5.0^{a}	10.0 ± 3.0^{b,c}	4.7 ± 2.3^{a,b,c}	F = 242.0; P < 0.001
	Free-weight	30.6 ± 9.8	17.3 ± 5.4^{a}	8.8 ± 3.0^{b,c}	4.1 ± 2.1^{a,b,c}	F = 167.7; P < 0.001
$MV_{fastest}$ ($m·s^{-1}$)	Smith machine	0.95 ± 0.06	0.81 ± 0.06^{a}	0.70 ± 0.07^{b,c}	0.60 ± 0.07^{a,b,c}	F = 528.2; P < 0.001
	Free-weight	0.88 ± 0.08	0.76 ± 0.09^{a}	0.66 ± 0.09^{b,c}	0.56 ± 0.09^{a,b,c}	F = 281.8; P < 0.001
MV_{last} ($m·s^{-1}$)	Smith machine	0.52 ± 0.10	0.53 ± 0.09	0.50 ± 0.06	0.50 ± 0.05	F = 1.9; P = 0.128
	Free-weight	0.50 ± 0.11	0.51 ± 0.09	0.49 ± 0.06	0.46 ± 0.07	F = 2.5; P = 0.087

Data are presented as mean ± SD. 1RM, one-repetition maximum; ANOVA, analysis of variance; F, Snedecor's F; P, P-value; ^{a}, significantly different than 60%1RM; ^{b}, significantly different than 70%1RM; ^{c}, significantly different than 80%1RM.

Table 7. *Comparison of the fastest mean velocity of the set associated with each maximum number of repetitions to failure between methods and prone bench pull exercises.*

Smith machine			Free-weight		ANOVA		
RTF	**Multiple-point method**	**Two-point method**	**Multiple-point method**	**Two-point method**	**Method**	**PBP exercise**	**Interaction**
1	0.57 ± 0.06	0.55 ± 0.06	0.55 ± 0.08	0.52 ± 0.08	$F = 4.6$; $P = 0.043$	$F = 42.9$; $P < 0.001$	$F = 0.2$; $P = 0.600$
2	0.58 ± 0.05	0.56 ± 0.05	0.56 ± 0.07	0.54 ± 0.08	$F = 5.1$; $P = 0.034$	$F = 42.5$; $P < 0.001$	$F = 0.2$; $P = 0.615$
3	0.60 ± 0.05	0.57 ± 0.05	0.58 ± 0.07	0.55 ± 0.08	$F = 5.6$; $P = 0.027$	$F = 42.0$; $P < 0.001$	$F = 0.2$; $P = 0.631$
4	0.61 ± 0.05	0.59 ± 0.05	0.59 ± 0.07	0.56 ± 0.08	$F = 6.0$; $P = 0.022$	$F = 41.4$; $P < 0.001$	$F = 0.2$; $P = 0.648$
5	0.62 ± 0.05	0.60 ± 0.05	0.60 ± 0.07	0.58 ± 0.07	$F = 6.3$; $P = 0.019$	$F = 40.7$; $P < 0.001$	$F = 0.1$; $P = 0.668$
6	0.64 ± 0.05	0.62 ± 0.05	0.61 ± 0.07	0.59 ± 0.07	$F = 6.6$; $P = 0.017$	$F = 39.9$; $P < 0.001$	$F = 0.1$; $P = 0.668$
7	0.65 ± 0.04	0.63 ± 0.04	0.63 ± 0.07	0.60 ± 0.07	$F = 6.8$; $P = 0.016$	$F = 39.1$; $P < 0.001$	$F = 0.1$; $P = 0.710$
8	0.66 ± 0.04	0.64 ± 0.04	0.64 ± 0.07	0.62 ± 0.07	$F = 6.8$; $P = 0.016$	$F = 38.1$; $P < 0.001$	$F = 0.1$; $P = 0.734$
9	0.68 ± 0.04	0.66 ± 0.04	0.65 ± 0.07	0.63 ± 0.07	$F = 6.8$; $P = 0.016$	$F = 37.1$; $P < 0.001$	$F < 0.1$; $P = 0.759$
10	0.69 ± 0.04	0.67 ± 0.04	0.66 ± 0.07	0.64 ± 0.07	$F = 6.7$; $P = 0.017$	$F = 36.0$; $P < 0.001$	$F < 0.1$; $P = 0.785$
11	0.70 ± 0.04	0.68 ± 0.04	0.68 ± 0.07	0.66 ± 0.07	$F = 6.5$; $P = 0.018$	$F = 34.8$; $P < 0.001$	$F < 0.1$; $P = 0.812$
12	0.72 ± 0.04	0.70 ± 0.04	0.69 ± 0.07	0.67 ± 0.07	$F = 6.3$; $P = 0.020$	$F = 33.5$; $P < 0.001$	$F < 0.1$; $P = 0.840$
13	0.73 ± 0.04	0.71 ± 0.04	0.70 ± 0.07	0.68 ± 0.07	$F = 6.0$; $P = 0.022$	$F = 32.2$; $P < 0.001$	$F < 0.1$; $P = 0.868$
14	0.74 ± 0.04	0.73 ± 0.05	0.71 ± 0.07	0.69 ± 0.07	$F = 5.8$; $P = 0.024$	$F = 30.8$; $P < 0.001$	$F < 0.1$; $P = 0.896$
15	0.76 ± 0.04	0.74 ± 0.05	0.73 ± 0.07	0.71 ± 0.07	$F = 5.5$; $P = 0.028$	$F = 29.3$; $P < 0.001$	$F < 0.1$; $P = 0.925$

Data are presented as means ± standard deviations. *F*, Snedecor's F; *P*, *P*-value.

The method × PBP exercise interaction did not achieve statistical significance for any RTF ($F \leq 0.2$; $P \geq 0.600$). The main effects of the PBP exercise ($F > 0.1$; $P < 0.001$) and method ($F > 0.1$; $P \leq 0.043$) were significant for all RTFs due to higher MV values associated with each RTF for the SM PBP and multiple-point method compared to the FW PBP and two-point method, respectively (**Table 7**). The MV values associated with each RTF presented *very large* to *nearly perfect* correlations between the multiple- and two-point methods during both SM (r = 0.88 [0.87, 0.91]) and FW (r = 0.94 [0.93, 0.94]), while the magnitude of the differences were *small* (SM PBP: ES = -0.47 [-0.49, -0.41]; FW PBP: ES = -0.35 [-0.36, -0.29]). The correlations of the MV values associated with each RTF between the PBP exercises ranged from *moderate* to *very large* (multiple point-method: r = 0.75 [0.55, 0.80]; two-point method: r = 0.59 [0.32, 0.70]), and the magnitude of the differences were *moderate* to *small* (multiple-point method: ES = -0.59 [-0.69, -0.36]; two-point method: ES = -0.65 [-0.69, -0.43]) (**Figure 10**).

None of the three- or two-way interactions reached statistical significance for either absolute ($F \leq 3.0$; $P \geq 0.095$) or raw ($F \leq 4.1$; $P \geq 0.053$) errors. Regarding the absolute errors, only the main effect of set reached statistical significance against the 85%1RM (F = 16.0; P = 0.001) due to greater errors in the second compared to the first set (**Figure 11**). Regarding the raw errors, only the main effect of set reached statistical significance against both the 65%1RM and 85%1RM ($F \geq 13.3$; $P \leq 0.001$) due to greater overestimation of RTF in the second compared to the first set (**Figure 11**).

Discussion

The present study attempts to gather information about the potential use of lifting velocity to predict RTFs using different methods (generalized *vs.* multiple-point *vs.* two-point) and PBP exercises (SM *vs.* FW) under various levels of fatigue. The main findings of the study revealed that (i) individualized RTF-$MV_{fastest}$ relationships presented a higher goodness-of-fit than the generalized RTF-$MV_{fastest}$ relationship being the differences between the methods more accentuated during the FW PBP than during the SM PBP, (ii) the $MV_{fastest}$ associated with different RTFs were greater for the SM PBP and multiple-point method compared to the FW PBP and two-point method, respectively, (iii) the raw and absolute errors when predicting RTFs during sets performed against the 65%1RM and 85%1RM were comparable for the three methods and two PBP variants, and (iv) all RTF-$MV_{fastest}$ relationships overestimated the RTF under fatigue conditions. These results suggest that RTF-$MV_{fastest}$ relationships allow predicting RTFs with comparable accuracy during SM and FW exercises, while the RTF-$MV_{fastest}$ relationship should preferably be determined under fatigue conditions resembling those experienced during RT.

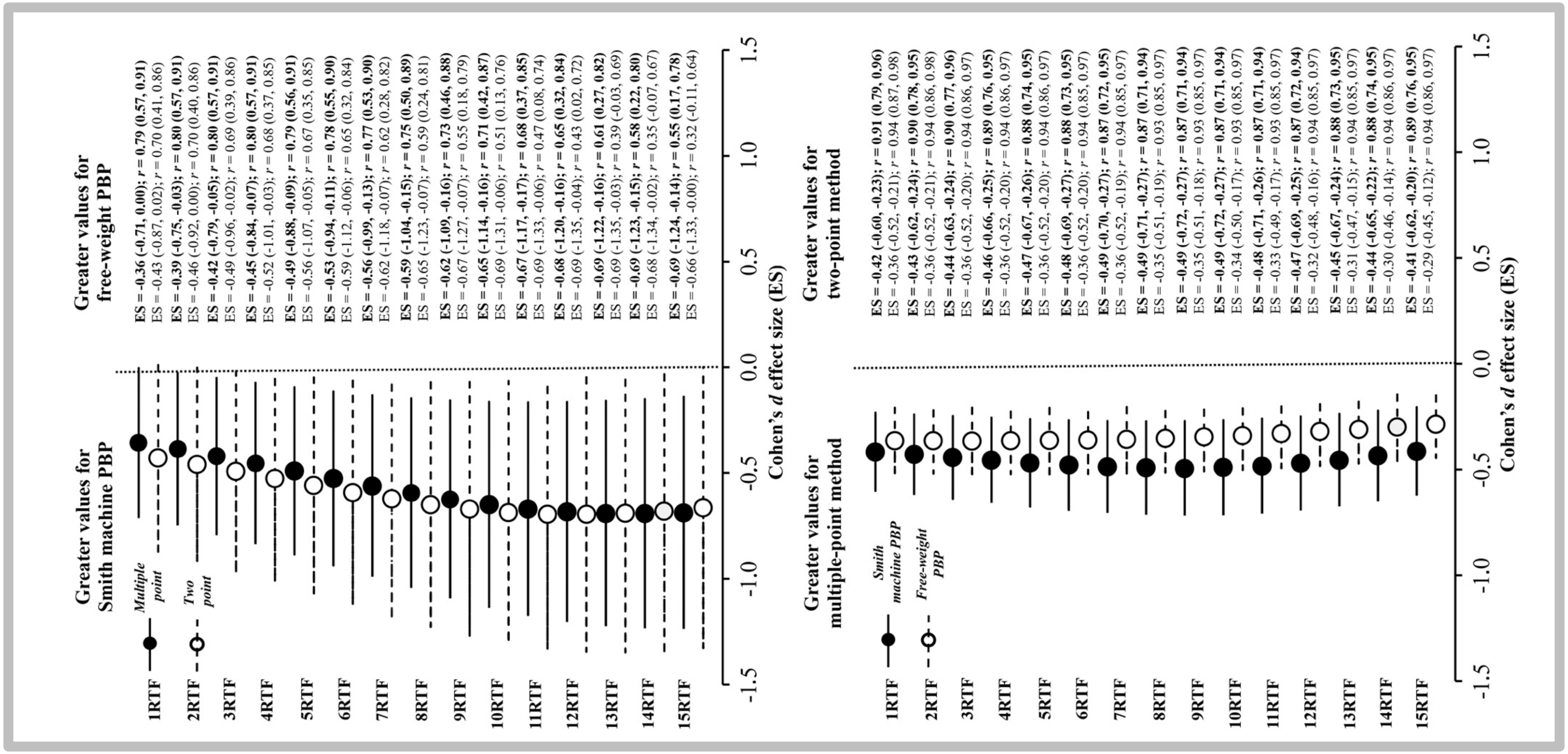

Figure 10. *Comparisons and associations of the fastest mean velocity of the set associated with each maximum number of repetitions between methods (multiple-point vs. 2-point; upper-panel) and exercises (SM vs. FW).*

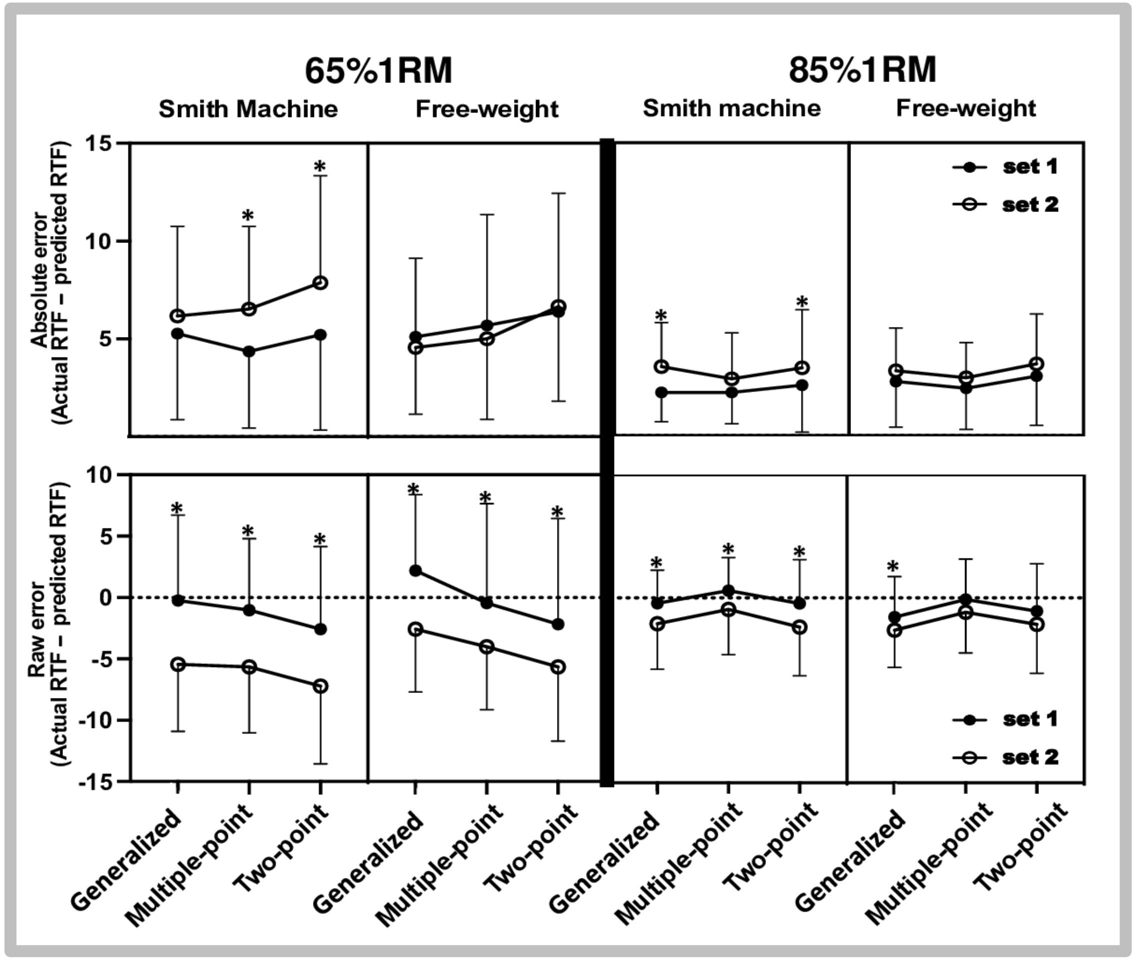

Figure 11. *Comparison of the raw and absolute errors when predicting the maximum number of between different methods (generalized vs. multiple-point vs. 2-point), exercises (SM vs. FW) and sets (1 vs. 2).*

Our first hypothesis was confirmed because both PBP exercises always showed greater goodness-of-fit for individualized compared to generalized RTF-$MV_{fastest}$ relationships. These findings are in line with Miras-Moreno et al.[59] who reported during the SM PBP a lower goodness-of-fit for the generalized (r^2 = 0.70; SEE = 3.6 repetitions) compared to individualized RTF-$MV_{fastest}$ relationships (r^2 = 0.96 [0.83–1.00]; SEE = 1.7 repetitions [0.3–4.7]). The increased differences between generalized and individualized RTF-$MV_{fastest}$ relationships for the FW PBP compared to SM PBP suggests that the inter-individual variability is larger for FW exercises. However, contrary to our hypothesis and the general belief that VBT applications are compromised with FW exercises, the goodness-of-fit of individualized RTF-$MV_{fastest}$ relationships was comparable for both PBP variants. This finding suggests that the accuracy of individualized RTF-$MV_{fastest}$ relationships is similar for SM and FW exercises.

Supporting our second hypothesis, the $MV_{fastest}$ associated with each RTF was greater for the SM PBP compared to the FW PBP. This may be explained because machine-based equipment requires less inter-muscular coordination contributing to generate more force in the direction of the movement[6,8,81,82]. However, contrary to our second hypothesis, the $MV_{fastest}$ associated with each RTF was greater for the multiple-point method compared to the two-point method. Of note is that the RTF-$MV_{fastest}$ relationship was obtained with less fatigue using the two-point method (two sets to failure) than the multiple-point method (four sets to failure). Therefore, the higher $MV_{fastest}$ for each RTF using the multiple-point method is not surprising as this and previous study have shown that during the PBP exercise the increase in fatigue promotes a greater reduction in RTF than in $MV_{fastest}$[59]. These results suggest that the two-point method could be the preferred option to estimate RTFs during RT sessions with low-moderate levels of fatigue in which lifters do not generally complete sets of repetitions to failure. Therefore, in addition to estimating the 1RM through the load-velocity relationship[18] or assessing the force-velocity[14] and load-velocity relationship variables[57], the results of this study suggest that the two-point method can also be used as a quicker and less prone to free-fatigue method for assessing the RTF-$MV_{fastest}$ relationships.

The high correlations between PBP variants (SM and FW) and methods (multiple-point and two-point) for the $MV_{fastest}$ associated with each RTF suggest that RTF-$MV_{fastest}$ relationships are subject-specific. However, despite these results and the greater goodness-of-fit for individualized compared to generalized RTF-$MV_{fastest}$ relationships, contrary to our third hypothesis, the magnitude of the errors in the prediction of RTFs did not differ between the individualized (multiple-point or two-point) and generalized RTF-$MV_{fastest}$ relationships. The only significant difference regarding RTF prediction errors was that they were higher for the second set compared to the first set. These results suggest that fatigue affects more RTF than $MV_{fastest}$. In addition, the general overestimation of RTF could be explained by the greater fatigue in which the sets were performed in the second weekly session (only two minutes of inter-set rest) compared to the first weekly session in which the RTF-$MV_{fastest}$ relationships were established (five minutes of inter-set rest). Therefore, it seems logical to construct the RTF-$MV_{fastest}$ relationship that coincides as much as possible with the level of fatigue experienced during RT, being advisable to use the two-point method with a long inter-set rest period (*e.g.,* 10 minutes) when this RT prescription method is intended to be used during low to moderate fatigue RT sessions.

The main limitation of this study is that we explored the possibility of predicting RTF in a session in which the level of fatigue was greater that the experienced in the session in which the RTF-$MV_{fastest}$ relationships were assessed. This is problematic because in our sample the RTF-$MV_{fastest}$ relationship was sensitive to fatigue. Therefore, future studies should try to equalize the fatigue levels for the testing and training sessions to elucidate whether the prediction capabilities of RTF-$MV_{fastest}$ relationships are increased. Finally, it should be explored whether the effect of fatigue on the RTF-$MV_{fastest}$ relationship is observed in other RT exercises and in individuals with more RT experience.

Conclusions and Practical Applications

RTF-$MV_{fastest}$ relationships allow RTFs to be predicted with similar accuracy during the SM and FW variants of the PBP exercise, opening up the possibility of using this RT prescription method during FW RT exercises. However, it is important to note that RTF-$MV_{fastest}$ relationships are sensitive to fatigue with greater fatigue levels affecting RTF more than $MV_{fastest}$. Therefore, RTF-$MV_{fastest}$ relationships should be determined under fatigue conditions resembling those experienced during training. The assessment of RTF and $MV_{fastest}$ against only two different loads (*e.g.,* 90%1RM and 70%1RM) with long inter-set rest periods (*e.g.,* 10 minutes), is recommended to be used during RT sessions in which the level of fatigue is low or moderate (*e.g.,* sets not performed to failure). The RTF-$MV_{fastest}$ relationship should preferably be determined under fatigue conditions (*e.g.,* not considering the first two sets to failure) when is intended to be used during RT sessions with high levels of effort (*i.e.,* multiple sets performed to failure).

4. Exploring the Relationship Between the Maximum Number of Repetitions to Failure and Fastest Lifting Velocity During the Prone Bench Pull: Are They Affected by The Stretch-Shortening Cycle?

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Brief Overview

Strategic manipulation of acute training variables during RT programs, including, but not limited to intensity, volume, or type of muscular contraction, can produce different physiological adaptations that directly impact an athlete's physical performance (*e.g.,* running, jumping, or throwing)[3,45,83]. It is well documented that muscular strength underpins the general and specific performance of most skills in sport[84]. The RT intensity (*i.e.,* traditionally prescribed as %1RM) is likely the most critical factor in promoting strength gains. However, to fully optimize its effects, it is also important to carefully manipulate other acute variables, including volume (*i.e.,* number of sets and repetitions) and the type of muscular contraction (*i.e.,* eccentric-only, concentric-only, or eccentric-concentric contractions)[15,84].

Considerable research has explored the inverse linear relationship between lifting velocity and %1RM (*i.e.,* load-velocity relationship) and how it can support the prescription of intensity during upper- and lower-body RT exercises[5,15,24,90]. However, some coaches prefer to prescribe the load based on the RTF[59]. A novel VBT approach consists of using the $MV_{fastest}$ or $PV_{fastest}$ values of the set to predict the RTF allowing a more homogenous level of effort to be prescribed using individual equations (*i.e.,* if we know the RTF for a given load, we can prescribe the desired fixed repetitions within the training set and, consequently, the proximity-to-failure)[59,60]. Specifically, some researchers have shown that individualized RTF-velocity relationships present very high goodness-of-fit (r^2 = 0.96–0.97), acceptable RTF modelling accuracy (absolute errors = 2.1 repetitions), and high reliability for the velocity values associated with different RTFs ($MV_{fastest}$: mean CV = 4.01%; $PV_{fastest}$: mean CV = 3.98%) during the concentric-only PBP exercise[59,60]. However, no study has explored the effect of incorporating the eccentric phase during the PBP exercise on the individualized RTF-velocity relationship[53].

Most sporting actions involve the SSC (*i.e.,* an eccentric contraction is immediately followed by a concentric contraction; SSC)[53]. When implementing VBT, the incorporation of the SSC not only enhances the goodness-of-fit of the load-velocity relationship, but also the velocity values attained at each %1RM in a wide range of RT exercises such as BP, BP throw, BS, and jump squats[20,69]. However, since the benefits of the SSC could be exercise-specific[60], it is important to explore the effect of incorporating the SSC during the PBP exercise on the goodness-of-fit of individualized RTF-velocity relationships and the velocity values attained for each specific RTF.

The individualized RTF-velocity relationship has proven to be strong and linear (from 1 to 30 RTFs) when multiple loads are lifted to failure (*e.g.,* 60%1RM, 70%1RM, 80%1RM, and 90%1RM referred to as 'multiple-point method' in the VBT context) during the PBP[59,60], BP[21], and BS exercise[36,43]. However, the multiple-point method is time-consuming, prone to fatigue, and can compromise training adaptations or performance during subsequent sessions[36,43,59,60]. More recently and based on the high linearity of the RTF-velocity relationships, Miras-Moreno et al.[60] explored the concentric-only PBP exercise and whether this testing procedure can be simplified by lifting only two distant loads (*e.g.,* 60%1RM and 90%1RM, referred to as the 'two-point method' in the VBT literature)[14,17,18,56,57]. Specifically, the study results found that in general, the $MV_{fastest}$ values associated with each RTF were significantly higher ($F \geq 4.6$; $P \leq 0.043$) for the multiple-point method compared to the two-point method. Despite these differences, a very high association was found between both modelling procedures (median r = 0.88 [0.87, 0.91]), suggesting that the RTF-velocity relationships are subject-specific[60]. With this in mind, it is logical to provide more information not only from the overall differences (*i.e.,* inter-individuals differences) but also from measurement bias (*i.e.,* intra-individuals differences) and whether these differences may be extrapolated to eccentric-concentric PBP exercise.

So that practitioners can better estimate how many repetitions an athlete can complete at different loads, this study explores the effect of incorporating the SSC into the PBP exercise on the RTF-velocity relationship. Specifically, the objectives of this research were: (i) to compare the goodness-of-fit of individualized RTF-$MV_{fastest}$ and RTF-$PV_{fastest}$ relationships between the concentric-only and eccentric-concentric PBP exercises, and (ii) to compare the $MV_{fastest}$ and $PV_{fastest}$ values associated with different RTFs (from 1 to 15) between both PBP exercises and modelling procedures (*i.e.,* multiple-point vs. two-point). We hypothesized that: (i) the RTF-velocity relationships would show a higher goodness-of-fit for the eccentric-concentric PBP exercise and the RTF-$PV_{fastest}$ relationships compared to the concentric-only PBP exercise and the RTF-$MV_{fastest}$ relationships, respectively[20,21,59,69], and (ii) the $MV_{fastest}$ and $PV_{fastest}$ values associated with each RTF would show higher values for the eccentric-concentric and multiple-point method compared to the concentric-only and two-point method, respectively[20,60,69].

Methods

Design

A crossover design was used to compare the goodness-of-fit of the RTF-velocity relationships and the MVfastest and $PV_{fastest}$ values associated with each RTF between the concentric-only and eccentric-concentric PBP exercises. Following an initial session to determine the concentric-only PBP 1RM, the participants randomly undertook two identical experimental sessions in the same week with at least 48 hours of rest. Specifically, the experimental sessions were composed of 3 sets to failure against 3 relative loads applied in the following order: 60%1RM, 80%1RM, and 70%1RM. Participants were instructed to lift the barbell as fast as possible while receiving real-time MV feedback on each repetition to maximize mechanical performance[37,89]. Each session was held in the University's research laboratory, at the same time of day to prevent diurnal variations in strength performance (± 3 hours), and the same climatic conditions (~22ºC and ~60% humidity).

Subjects

23 resistance-trained males (age = 25.0 ± 7.3 years [range: 18-45 years]; body height = 1.78 ± 0.07 m; body mass = 82.6 ± 22.7 kg; concentric-only PBP 1RM = 84.8 ± 12.9 kg [1.06 ± 0.17 normalized per kg of body mass]; RT experience = 5.0 ± 4.7 years) participated in this study (data presented as means ± SD). None of the participants presented physical limitations that may affect the study results. Participants were informed about the purpose and procedures of the study and signed a written informed consent form prior to the onset of the study. The study protocol adhered to the tenets of the Declaration of Helsinki and was approved by the Andalusian Biomedical Research Ethics Portal (approval no: 0557-N-22).

Testing procedures

1RM assessment (preliminary session)

Body height (Seca 202; Seca Ltd., Hamburg, Germany) and body mass (TBF-300A, Tanita Corporation of America, Inc., Arlington Heights, IL) were evaluated at the beginning of the first session. Immediately afterward, participants completed a standardized warm-up consisting of 5 minutes of jogging, dynamic stretching, upper-body joint mobilization exercises, and 2 sets of 5 repetitions during the concentric-only PBP exercise against 20 and 30 kg. Once the warm-up ended, the initial load of the incremental loading test was established at 40 kg and, was progressively increased in increments of 10 kg until the MV was less than 0.80 $m \cdot s^{-1}$. From then on, the load was increased in steps from 5 to 1 kg until the 1RM was achieved directly. 2 repetitions were performed with light-to-moderate loads ($MV \geq 0.80$ $m \cdot s^{-1}$) and 1 repetition with heavier loads ($MV < 0.80$ $m \cdot s^{-1}$). The recovery period was adjusted to 3 minutes for light-to-moderate loads and 5 minutes for heavier loads. Lastly, a familiarization session was deemed unnecessary because all participants had previously participated in research projects conducted by our research group and were familiar with the intention of lifting at maximal intended velocity until reaching failure during the PBP exercise[56,57,59].

Determination of the RTF-velocity relationships (experimental sessions)

The sessions only differed in the PBP exercise employed (concentric-only or eccentric-concentric). The warm-up consisted of 5 minutes of running at a self-selected pace, dynamic stretching, and upper-body joint-mobilization exercises, which was followed by single sets of 10, 3, and 1 repetition against the 40%1RM, 60%1RM, and 80%1RM, respectively. Once the warm-up was completed, the participants rested for 3 minutes and then they performed single sets to failure against 3 relative loads in the following sequence: 60%1RM, 80%1RM, and 70%1RM. The same absolute loads obtained from the preliminary session were maintained between both PBP exercises. A 5-minute passive rest was implemented between sets[60].

PBP exercise technique

Participants lay down in a prone posture with their chins touching the bench, the elbows fully extended, a prone barbell grip approximately wider than the shoulder width at the level of the sternum, and the legs held using a rigid strap on the calves[59,60]. The entire range of movement was preserved using the SM telescoping holders (Multipower Fitness Line, Peroga, Murcia, Spain)[59,60]. Once the barbell contacted the telescopic holders for 2 seconds between each repetition, the participants were instructed to pull the barbell as fast as possible until it contacted with the bench (*i.e.,* concentric phase), while they were not allowed to stop the barbell's gravity acceleration during the downward phase (*i.e.,* eccentric phase). Alternatively, the eccentric-concentric PBP exercise technique was almost identical to the concentric-only PBP exercise technique except for the initial position and downward phase. Specifically, the initial phase of the movement started with the barbell contacting the bottom of the bench followed by a retention of the barbell's gravity acceleration until it reached the SM telescopic holders (*i.e.,* eccentric phase) and, immediately afterwards, the participants pulled the barbell as fast as possible until it contacted with the bench bottom (*i.e.,* concentric phase) (click here to see the technique on a video). Whenever the barbell did not touch the bottom of the bench (thickness: 11.0 cm) for 2 consecutive repetitions, the test was terminated, and both repetitions were not included for further analyses[59,60]. A validated linear velocity transducer (T-Force System version 3.70; Ergotech, Murcia, Spain) was used to obtain the $MV_{fastest}$ and MV_{last} repetition and, $PV_{fastest}$ and PV_{last} from all sets performed to failure[59,60].

Statistical Analysis

Data are presented as means and SD, while r^2 and SEE are presented through median values and range. The normal distribution of the data was verified using the Shapiro-Wilk test ($P > 0.05$). Two-way repeated-measures ANOVA (PBP exercise [concentric-only *vs.* eccentric-concentric]) × load [60%1RM *vs.* 80%1RM *vs.* 70%1RM]) were conducted on RTF, $MV_{fastest}$, $PV_{fastest}$, MV_{last}, and PV_{last}. Least-square linear regression models were used to determine the RTF-$MV_{fastest}$ and RTF-$PV_{fastest}$ relationships for each PBP exercise[58–60]. Generalized relationships were acquired separately for each PBP exercise by combining the data points from all the participants (23 participants × 3 sets = 69 data points)[58–60], while individual relationships were constructed independently for each participant based on the data points obtained from the 3 loads (*i.e.,* the multiple-point method [60%-80%-70%1RM]) or only the 2 most distant loads (*i.e.,* the two-point method [60-80%1RM])[60].

The goodness-of-fit of generalized and individualized RTF-$MV_{fastest}$ and RTF-$PV_{fastest}$ relationships were assessed through the r^2 and SEE[58–60]. The Fisher's Z-transformed from the r values of the individualized RTF-velocity relationships were used to compare the goodness-of-fit using a two-way repeated-measures ANOVA (PBP exercise [concentric-only *vs.* eccentric-concentric]) × velocity variable [MV *vs.* PV]). Additionally, a two-way repeated-measures ANOVA (PBP exercise [concentric-only *vs.* eccentric-concentric]) × modelling procedure [multiple-point *vs.* two-point]) was used to compare the $MV_{fastest}$ and $PV_{fastest}$ values associated with each RTF (from 1 to 15)[58–60]. The Greenhouse-Geisser correction was applied when the Mauchly's sphericity test was violated, while pairwise comparisons considered Bonferroni post-hoc corrections. The magnitude of the differences was evaluated using the Cohen's d effect size (ES), which was interpreted using the following scale: *trivial* (< 0.20), *small* (0.20–0.59), *moderate* (0.60–1.19), *large* (1.20–2.00), or *very large* (> 2.00)[31].

Least-square linear regression models were used to evaluate the existence of fixed and proportional bias for the velocity values associated with 3 RTF, 9 RTF, and 15 RTF between different PBP exercises (concentric-only *vs.* eccentric-concentric) and modelling procedure (multiple-point *vs.* two-point)[60]. Fixed bias was present when the 95% confidence interval (CI) for the intercept did not include 0, while proportional bias was present when the 95% CI for the slope did not include 1[51]. The R^2 from the Bland-Altman plots was used to assess the heteroscedasticity of the errors defined as a $R^2 > 0.1$[23,52]. The software package SPSS (version 25.0, IBM SPSS) was used for the analyses and alpha was set at $P < 0.05$.

Results

The PBP exercise × load interaction was not significant for $MV_{fastest}$, MV_{last}, $PV_{fastest}$, and PV_{last}, but it was significant for RTF ($F = 36.3$; $P < 0.001$) due to the decreasing differences in favour of the concentric-only PBP exercise with the increment in the load ($P < 0.001$) (**Table 8**). The main effect of the PBP exercise was significant for RTF and $PV_{fastest}$ due to the higher values for the concentric-only PBP exercise ($F \geq 19.6$; $P < 0.001$), $MV_{fastest}$ and MV_{last} values were greater for the eccentric-concentric PBP exercises ($F \geq 7.1$; $P \leq 0.014$), and no significant differences were observed for PV_{last}.

The goodness-of-fit of the individualized RTF-velocity relationships were very high for the concentric-only (RTF-$MV_{fastest}$: $r^2 = 0.97$; RTF-$PV_{fastest}$: $r^2 = 0.98$) and eccentric-concentric (RTF-$MV_{fastest}$: $r^2 = 0.98$; RTF-$PV_{fastest}$: $r^2 = 0.99$) PBP exercises (**Figure 12**). Regarding the comparison of goodness-of-fit, no significant interactions of PBP exercise × velocity variable or main effect of PBP exercise were detected ($F \leq 3.2$; $P \geq 0.087$), while the main effect of the velocity variable was significant ($F = 4.7$; $P = 0.041$) due to a *trivial* stronger goodness-of-fit for the RTF-$PV_{fastest}$ compared to the RTF-$MV_{fastest}$ relationships.

The PBP exercise × modelling procedure interaction did not reach statistical significance for the $MV_{fastest}$ ($F \leq 1.4$; $P \geq 0.246$) (**Table 9**) or the $PV_{fastest}$ ($F \leq 1.2$; $P \geq 0.272$) values associated with different RTFs (**Table 10**). The main effect of the PBP exercise showed statistical significance due to higher $MV_{fastest}$ values for the eccentric-concentric compared to concentric-only PBP exercise from 4 to 15 RTFs ($P \leq 0.038$; ES ≤ 2.24), whereas $PV_{fastest}$ values were lower from 1 to 2 RTFs ($P \leq 0.041$; ES ≤ -0.50) but higher from 10 to 15 RTFs ($P \leq 0.028$; ES ≤ 0.90) for the eccentric-concentric compared to concentric-only PBP exercise. The main effect of the modelling procedure never reached statistical significance ($F \leq 2.4$; $P \geq 0.131$).

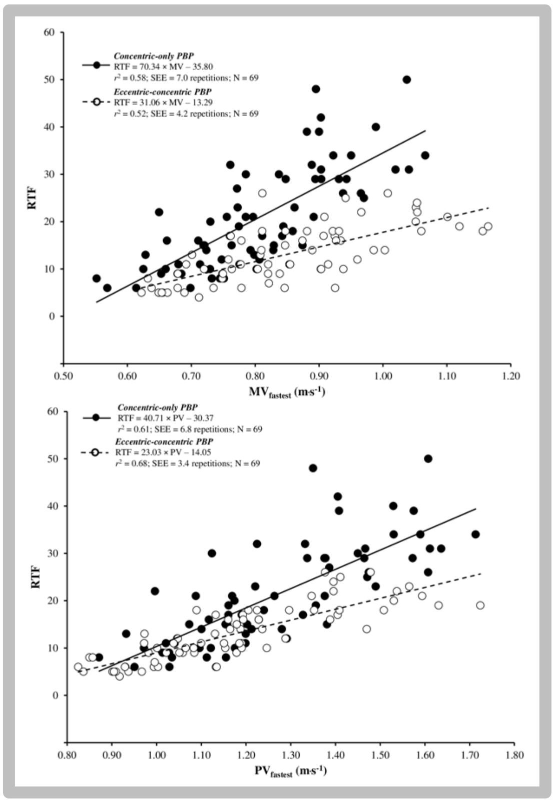

Figure 12. *Generalized RTF-velocity relationship using $MV_{fastest}$ and $PV_{fastest}$ values during concentric (filled dots) and eccentric-concentric (open dots) PBP exercises.*

Table 8. *Two-way repeated measures ANOVA comparing the RTF, the $MV_{fastest}$, $PV_{fastest}$, MV_{last}, PV_{last} against three relative loads during the concentric-only and eccentric-concentric PBP exercises.*

	PBP exercise	60%1RM	70%1RM	80%1RM	ANOVA	
					Main effects	Interaction
RTF	Concentric-only	33.0 ± 7.1	19.0 ± 5.5[a]	10.9 ± 3.7[a,b]	***PBP exercise*** ***F* = 78.6; *P* < 0.001** ***Load*** ***F* = 415.6; *P* < 0.001**	***PBP exercise × Load*** ***F* = 36.3; *P* < 0.001**
	Eccentric-concentric	19.8 ± 3.3[*]	12.5 ± 2.6[a,*]	7.0 ± 2.0[a,b,*]		
$MV_{fastest}$ ($m{\cdot}s^{-1}$)	Concentric-only	0.92 ± 0.08	0.79 ± 0.07[a]	0.70 ± 0.07[a,b]	***PBP exercise*** ***F* = 7.1; *P* = 0.014** ***Load*** ***F* = 365.3; *P* < 0.001**	*PBP exercise × Load* *F* = 0.9; *P* = 0.393
	Eccentric-concentric	0.97 ± 0.10[*]	0.84 ± 0.10[a,*]	0.74 ± 0.09[a,b]		
MV_{last} ($m{\cdot}s^{-1}$)	Concentric-only	0.52 ± 0.07	0.50 ± 0.08	0.48 ± 0.05[a]	***PBP exercise*** ***F* = 11.8; *P* = 0.002** ***Load*** ***F* = 4.2; *P* = 0.030**	*PBP exercise × Load* *F* = 0.2; *P* = 0.762
	Eccentric-concentric	0.55 ± 0.11	0.53 ± 0.08[*]	0.54 ± 0.09[*]		
$PV_{fastest}$ ($m{\cdot}s^{-1}$)	Concentric-only	1.49 ± 0.12	1.23 ± 0.10[a]	1.06 ± 0.09[a,b]	***PBP exercise*** ***F* = 19.6; *P* < 0.001** ***Load*** ***F* = 649.6; *P* < 0.001**	*PBP exercise × Load* *F* = 0.5; *P* = 0.567
	Eccentric-concentric	1.39 ± 0.16[*]	1.16 ± 0.12[a,*]	0.98 ± 0.11[a,b,*]		
PV_{last} ($m{\cdot}s^{-1}$)	Concentric-only	0.78 ± 0.12	0.78 ± 0.09	0.78 ± 0.11[b]	*PBP exercise* *F* = 0.1; *P* = 0.754 ***Load*** ***F* = 0.5; *P* = 0.022**	*PBP exercise × Load* *F* = 0.1; *P* = 0.894
	Eccentric-concentric	0.78 ± 0.16	0.79 ± 0.12	0.75 ± 0.10		

Data presented as mean ± SD. 1RM, one-repetition maximum; *F*, Snedecor's F; *P*, *P*-values. [a], significant differences compared to 60%1RM; [b], significant differences compared to 70%1RM; [*], significant differences compared to concentric-only PBP exercise (*P* < 0.05; ANOVA with Bonferroni's correction).

Table 9. *Comparison of the $MV_{fastest}$ with each RTF different PBP exercises and modelling procedures.*

	Concentric-only		Eccentric-concentric		ANOVA		
RTF	**Multiple-point method**	**Two-point method**	**Multiple-point method**	**Two-point method**	**Exercise variant**	**Modelling procedure**	**Interaction**
1	0.61 ± 0.06	0.61 ± 0.06	0.62 ± 0.09	0.62 ± 0.09	$F = 0.3$; $P = 0.540$	$F = 0.3$; $P = 0.588$	$F = 1.4$; $P = 0.246$
2	0.62 ± 0.06	0.62 ± 0.06	0.64 ± 0.09	0.64 ± 0.08	$F = 1.2$; $P = 0.278$	$F = 0.2$; $P = 0.653$	$F = 1.3$; $P = 0.261$
3	0.63 ± 0.06	0.63 ± 0.06	0.66 ± 0.09	0.66 ± 0.08	$F = 2.6$; $P = 0.115$	$F = 0.1$; $P = 0.727$	$F = 1.2$; $P = 0.279$
4	0.64 ± 0.06	0.64 ± 0.06	0.68 ± 0.09	0.68 ± 0.08	**$F = 4.8$; $P = 0.038$**	$F < 0.1$; $P = 0.809$	$F = 1.1$; $P = 0.299$
5	0.65 ± 0.06	0.65 ± 0.06	0.70 ± 0.08	0.70 ± 0.08	**$F = 7.9$; $P = 0.010$**	$F < 0.1$; $P = 0.899$	$F = 1.0$; $P = 0.322$
6	0.66 ± 0.06	0.66 ± 0.06	0.72 ± 0.08	0.72 ± 0.08	**$F = 11.9$; $P = 0.002$**	$F < 0.1$; $P = 0.998$	$F = 0.9$; $P = 0.350$
7	0.67 ± 0.06	0.67 ± 0.06	0.74 ± 0.08	0.74 ± 0.08	**$F = 17.0$; $P < 0.001$**	$F < 0.1$; $P = 0.896$	$F = 0.7$; $P = 0.382$
8	0.68 ± 0.06	0.68 ± 0.06	0.76 ± 0.08	0.76 ± 0.08	**$F = 23.3$; $P < 0.001$**	$F < 0.1$; $P = 0.785$	$F = 0.6$; $P = 0.419$
9	0.69 ± 0.06	0.69 ± 0.06	0.78 ± 0.08	0.78 ± 0.08	**$F = 30.7$; $P < 0.001$**	$F = 0.1$; $P = 0.671$	$F = 0.5$; $P = 0.462$
10	0.70 ± 0.06	0.70 ± 0.06	0.80 ± 0.08	0.80 ± 0.08	**$F = 39.2$; $P < 0.001$**	$F = 0.3$; $P = 0.557$	$F = 0.4$; $P = 0.513$
11	0.71 ± 0.06	0.71 ± 0.06	0.82 ± 0.08	0.81 ± 0.08	**$F = 48.4$; $P < 0.001$**	$F = 0.5$; $P = 0.449$	$F = 0.3$; $P = 0.571$
12	0.72 ± 0.06	0.72 ± 0.06	0.83 ± 0.08	0.83 ± 0.08	**$F = 58.3$; $P < 0.001$**	$F = 0.9$; $P = 0.349$	$F = 0.2$; $P = 0.638$
13	0.73 ± 0.06	0.73 ± 0.06	0.85 ± 0.09	0.85 ± 0.09	**$F = 68.3$; $P < 0.001$**	$F = 1.3$; $P = 0.261$	$F = 0.1$; $P = 0.713$
14	0.74 ± 0.06	0.74 ± 0.06	0.87 ± 0.09	0.87 ± 0.09	**$F = 78.0$; $P < 0.001$**	$F = 1.8$; $P = 0.188$	$F < 0.1$; $P = 0.797$
15	0.75 ± 0.06	0.75 ± 0.06	0.89 ± 0.09	0.89 ± 0.09	**$F = 87.1$; $P < 0.001$**	$F = 2.4$; $P = 0.131$	$F < 0.1$; $P = 0.889$

Data are presented as means ± standard deviations. *F*, Snedecor's *F; P*, *P*-value.

Table 10. *Comparison of the $PV_{fastest}$ with each RTF different PBP exercises and modelling procedures.*

	Concentric-only		Eccentric-concentric		ANOVA		
RTF	**Multiple-point method**	**Two-point method**	**Multiple-point method**	**Two-point method**	**Exercise variant**	**Modelling procedure**	**Interaction**
1	0.86 ± 0.14	0.85 ± 0.13	0.79 ± 0.10	0.79 ± 0.10	**$F = 6.1$; $P = 0.021$**	$F < 0.1$; $P = 0.967$	$F = 1.2$; $P = 0.272$
2	0.88 ± 0.13	0.87 ± 0.12	0.82 ± 0.09	0.82 ± 0.09	**$F = 4.7$; $P = 0.041$**	$F < 0.1$; $P = 0.941$	$F = 1.2$; $P = 0.277$
3	0.90 ± 0.13	0.89 ± 0.12	0.85 ± 0.09	0.85 ± 0.09	$F = 3.2$; $P = 0.083$	$F < 0.1$; $P = 0.914$	$F = 1.2$; $P = 0.282$
4	0.92 ± 0.13	0.91 ± 0.12	0.88 ± 0.09	0.89 ± 0.09	$F = 1.9$; $P = 0.175$	$F < 0.1$; $P = 0.887$	$F = 1.1$; $P = 0.288$
5	0.94 ± 0.12	0.94 ± 0.11	0.92 ± 0.09	0.92 ± 0.09	$F = 0.8$; $P = 0.362$	$F < 0.1$; $P = 0.858$	$F = 1.1$; $P = 0.294$
6	0.96 ± 0.12	0.96 ± 0.11	0.95 ± 0.09	0.95 ± 0.09	$F = 0.1$; $P = 0.698$	$F < 0.1$; $P = 0.828$	$F = 1.1$; $P = 0.301$
7	0.98 ± 0.12	0.98 ± 0.11	0.98 ± 0.09	0.98 ± 0.09	$F < 0.1$; $P = 0.834$	$F < 0.1$; $P = 0.798$	$F = 1.0$; $P = 0.309$
8	1.00 ± 0.12	1.00 ± 0.11	1.01 ± 0.09	1.02 ± 0.09	$F = 0.7$; $P = 0.387$	$F < 0.1$; $P = 0.767$	$F = 1.0$; $P = 0.317$
9	1.02 ± 0.12	1.02 ± 0.10	1.05 ± 0.09	1.05 ± 0.09	$F = 2.5$; $P = 0.123$	$F = 0.1$; $P = 0.735$	$F = 1.0$; $P = 0.327$
10	1.04 ± 0.12	1.04 ± 0.10	1.08 ± 0.09	1.08 ± 0.10	**$F = 5.5$; $P = 0.028$**	$F = 0.1$; $P = 0.703$	$F = 0.9$; $P = 0.337$
11	1.06 ± 0.11	1.06 ± 0.10	1.11 ± 0.10	1.11 ± 0.10	**$F = 9.6$; $P = 0.005$**	$F = 0.1$; $P = 0.671$	$F = 0.9$; $P = 0.348$
12	1.09 ± 0.11	1.08 ± 0.10	1.15 ± 0.10	1.15 ± 0.10	**$F = 14.6$; $P = 0.001$**	$F = 0.2$; $P = 0.638$	$F = 0.8$; $P = 0.361$
13	1.11 ± 0.11	1.10 ± 0.10	1.18 ± 0.11	1.18 ± 0.11	**$F = 20.0$; $P < 0.001$**	$F = 0.2$; $P = 0.605$	$F = 0.8$; $P = 0.375$
14	1.13 ± 0.11	1.12 ± 0.10	1.21 ± 0.12	1.21 ± 0.12	**$F = 25.4$; $P < 0.001$**	$F = 0.3$; $P = 0.572$	$F = 0.7$; $P = 0.390$
15	1.15 ± 0.11	1.14 ± 0.10	1.24 ± 0.12	1.24 ± 0.12	**$F = 30.3$; $P < 0.001$**	$F = 0.3$; $P = 0.539$	$F = 0.4$; $P = 0.716$

Data are presented as means ± standard deviations. *F*, Snedecor's *F; P*, *P*-value.

When comparing both PBP exercises, fixed and proportional bias were observed for the $MV_{fastest}$ associated with 3RTF using the two-point method, and for the $PV_{fastest}$ associated with 3RTF and 9RTF using both modelling procedures (**Figure 13**). Bland-Altman plots revealed low systematic bias (ranging from 0.024 to 0.086 $m.s^{-1}$), moderate random errors (ranging from 0.175 to 0.217 $m.s^{-1}$), and heteroscedasticity of the errors was present for all conditions ($R^2 \geq 0.143$) except for the $PV_{fastest}$ using the multiple-point method ($R^2 = 0.097$) (**Figure 13).**

When comparing both modelling procedures, fixed and proportional bias were observed for the $MV_{fastest}$ values associated with 3RTF during the eccentric-concentric PBP and for the $PV_{fastest}$ associated with 9RTF and 15RTF during the concentric-only PBP (**Figure 14**). Bland-Altman plots revealed very low systematic bias (ranging from 0.001 to 0.004 $m.s^{-1}$), low random errors (ranging from 0.029 to 0.055 $m.s^{-1}$), and no heteroscedasticity of the errors for any condition ($R^2 \leq 0.079$) except for the $MV_{fastest}$ during the eccentric-concentric PBP exercise ($R^2 \leq 0.103$) (**Figure 14**).

Discussion

This study explored whether the goodness-of-fit of the RTF-velocity relationships and the $MV_{fastest}$ and $PV_{fastest}$ values associated with different RTFs are affected by the incorporation of the SSC into the PBP exercise. Our first hypothesis was partly rejected because the goodness-of-fit of individualized RTF-velocity relationships was comparable between concentric-only and eccentric-concentric PBP exercises, whereas, as hypothesized, the RTF-$PV_{fastest}$ relationships demonstrated slightly stronger goodness-of-fit than the RTF-$MV_{fastest}$ relationships. Our second hypothesis was also partly confirmed because the $MV_{fastest}$ and $PV_{fastest}$ values associated with different RTFs were generally higher for eccentric-concentric compared to concentric-only PBP exercise (*i.e.,* higher velocity values differences with the increment of the predicted RTFs). However, the second part of the hypothesis was rejected due to comparable and homoscedastic differences for the $MV_{fastest}$ and $PV_{fastest}$ values associated with the different RTFs between the multiple-point and two-point methods. Collectively, these findings suggest that both the multiple-point and two-point modelling procedures can be used to construct individualized RTF-velocity relationships, but the number of RTFs at each estimated velocity in the concentric-only and eccentric-concentric models do differ. Therefore, practitioners should be aware of these differences and use the most appropriate modelling procedure based on the training that is being used by their athletes (*e.g.,* eccentric-concentric).

Individualized RTF-velocity relationships showed a greater goodness-of-fit than generalized RTF-velocity relationships for both PBP variants and both velocity variables. These results are in line with previous studies that examined exercises performed in a SM[21,59] and with FW[36,43,60], establishing a common agreement on the preferred use of individualized RTF-velocity relationships. However, it should be noted that the goodness-of-fit of individualized RTF-velocity relationships can be affected by two methodological factors considered in the present study, such as the selection of the velocity variable ($MV_{fastest}$ vs. $PV_{fastest}$) and the muscle contraction type (concentric-only *vs.* eccentric-concentric).

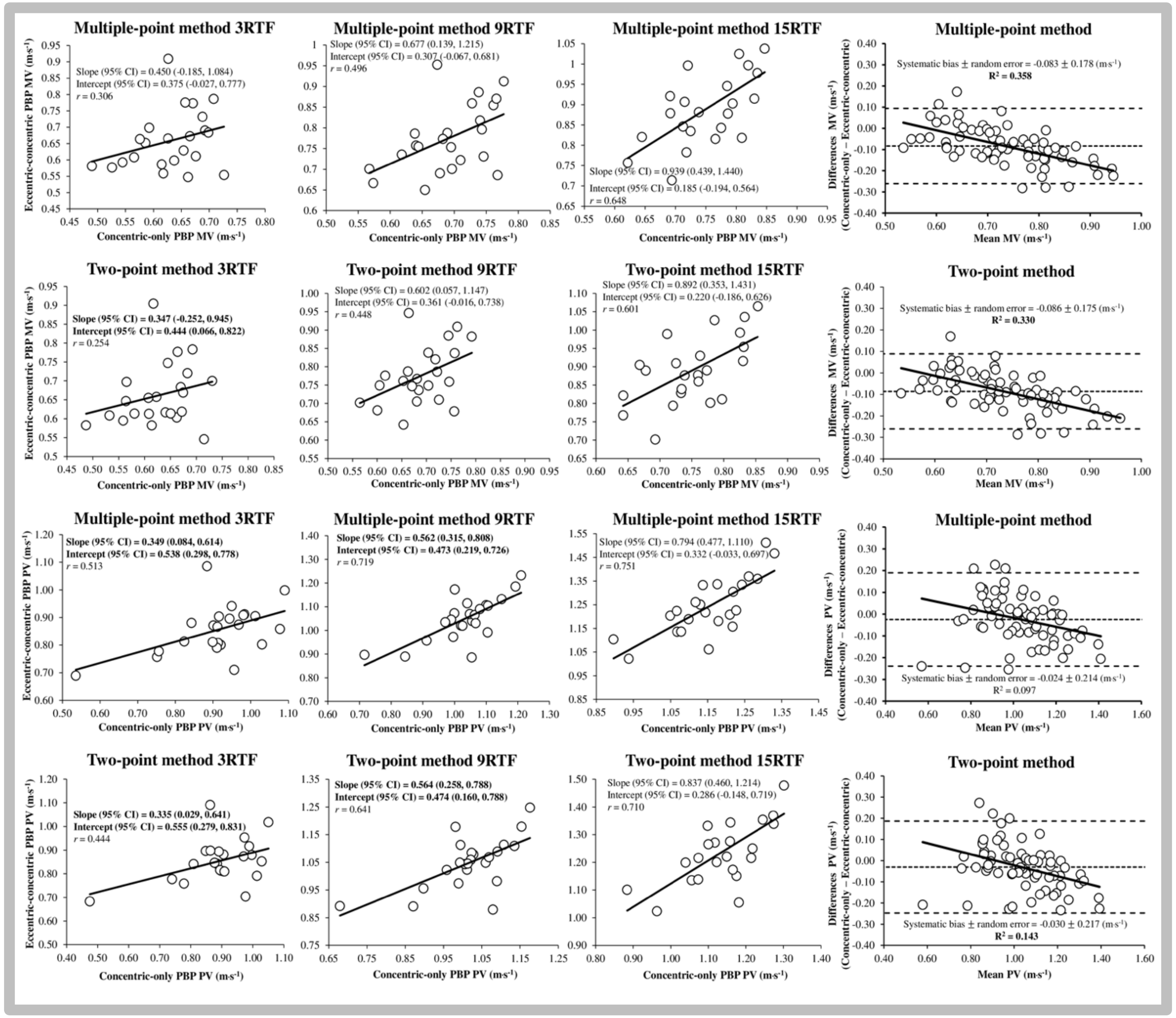

***Figure 13**. Least-square linear regression analysis and Bland–Altman plots comparing the $MV_{fastest}$ and $PV_{fastest}$ associated to the RTF between the concentric-only and eccentric-concentric PBP.*

The Bland–Altman plot depicts the systematic bias and 95% limits of agreement (±1.96; dashed lines), along with the regression line (solid line).

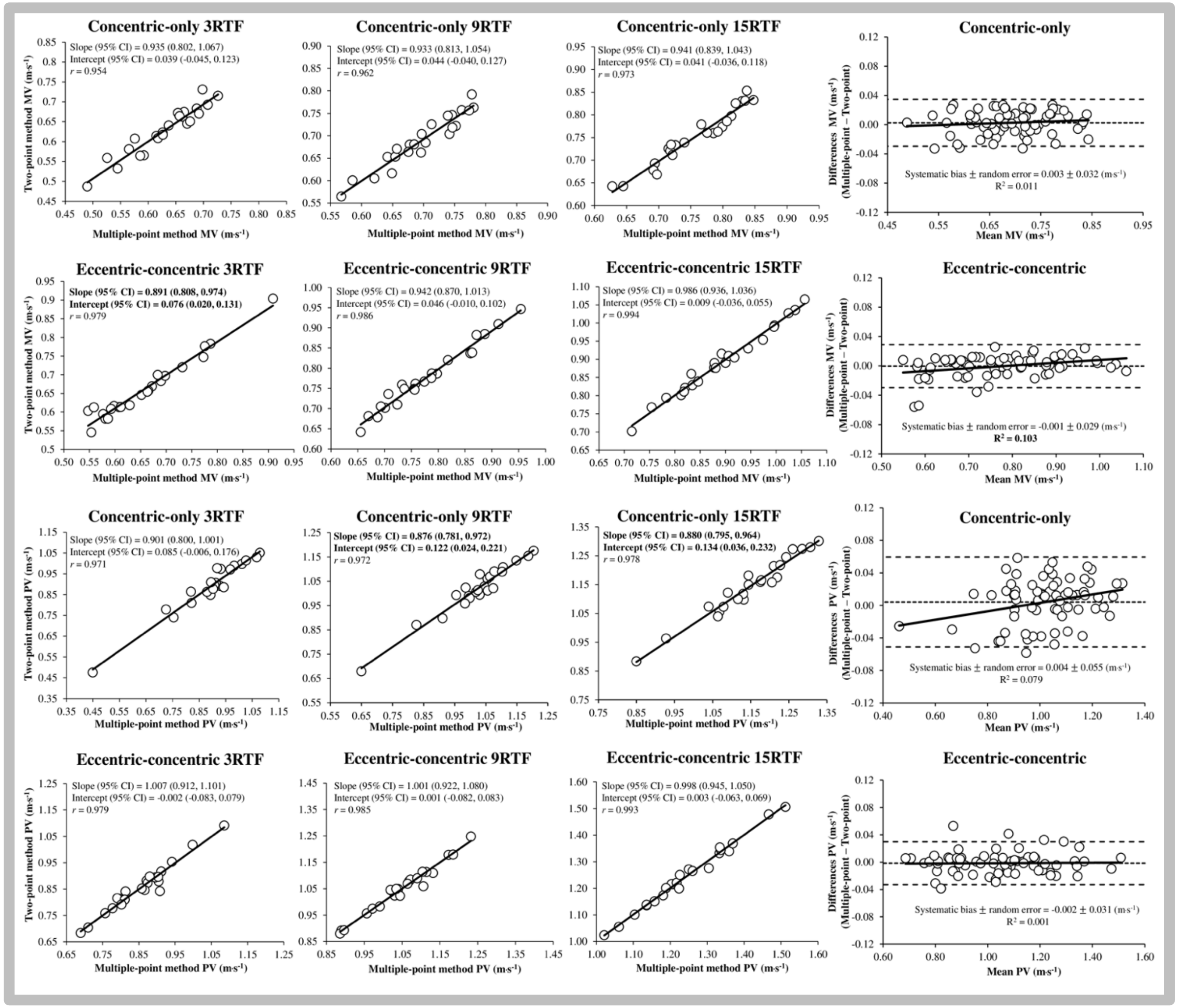

Figure 14. *Least-square linear regression analysis and Bland–Altman plots comparing the MVfastest and PVfastest associated to the RTF between the multiple-point and two-point methods.*

The Bland–Altman plot depicts the systematic bias and 95% limits of agreement (±1.96; dashed lines), along with the regression line (solid line).

The present study revealed a trivial greater goodness-of-fit for the RTF-$PV_{fastest}$ relationships compared to the RTF-$MV_{fastest}$ relationships during both the concentric-only and eccentric-concentric PBP exercises. These results align with a previous study by Miras-Moreno et al.[59] who showed slightly higher goodness-of-fit for RTF-$PV_{fastest}$ (r^2 = 0.97 [0.84,1.00]) relationships compared to RTF-$MV_{fastest}$ (r^2 = 0.96 [0.83,1.00]) relationships during the concentric-only PBP exercise. The reduced accuracy of the MV measurement may be attributed to the potential upward displacement of the bench during the PBP exercise. This displacement can occur when the barbell makes contact with the bench's underside at high velocities, leading to a slack in the linear position transducer's cable that affects MV measurements. In contrast, PV remains unaffected by this issue since it is recorded prior to the barbell's contact with the bench (*i.e.,* analyzing the velocity-time curves, the $PV_{fastest}$ is reached at approximately 50% of the concentric phase during the PBP exercise)[78]. Second, the present study showed that the incorporation of the SSC does not impact the goodness-of-fit of the RTF-velocity relationships. These findings differ from studies reporting an enhancement of the goodness-of-fit of the load-velocity relationships when incorporating the SSC[20,56,69]. Collectively, these results indicate that $PV_{fastest}$ may offer a statistically significant higher goodness-of-fit during the PBP exercise, but the magnitude of the differences is likely negligible for practical settings.

Supporting our second hypothesis, the $MV_{fastest}$ and $PV_{fastest}$ values associated with different RTFs were generally higher for the eccentric-concentric exercise compared to the concentric-only PBP exercise. These differences between the PBP exercises were increased for greater RTFs (*i.e.,* light loads are lifted). These potentiation effects (*i.e.,* faster eccentric-phase may increase the performance of the subsequent concentric-phase) agree with those reported during the load-velocity relationships[56,69]. However, the incorporation of a previous eccentric phase has revealed a greater reduction of the $MV_{fastest}$ and $PV_{fastest}$ values, along with the decrement of the RTFs (*e.g.,* a determined $MV_{fastest}$ of 0.70 $m.s^{-1}$ would predict 10RTF for concentric-only compared to 5RTF for eccentric-concentric PBP exercise) likely explained by the greater fatigue and less recovery between repetitions. This result aligns with a prior study that showed under fatigue conditions, a greater reduction in RTF than $MV_{fastest}$ or $PV_{fastest}$ during the PBP exercise[59]. Therefore, these findings indicate that practitioners should use separate equations when establishing RTF-velocity relationships when the SSC is incorporated into the PBP exercise.

Given the very high linearity of the RTF-velocity relationships, Miras-Moreno et al.[60] recently stated that the testing procedure can be simplified by performing sets to failure against only 2 distant loads (*i.e.,* two-point method). Specifically, Miras-Moreno et al.[60] revealed greater velocity values for each RTF using the multiple-method compared to the two-point method. However, contrary to our hypothesis, the present study did not find significant differences between the modelling procedures (very-low systematic bias, very-low random errors, and homoscedasticity of the errors) despite the same RT exercise being analyzed. This discrepancy could be attributed to the lower number of sets performed to failure in this study (*i.e.,* 3 sets) compared to the 4 sets performed in the study of Miras-Moreno et al.[58]. Therefore, it is recommended that the RTF-velocity relationships be obtained under fatigue conditions similar to those experienced during training (*e.g.,* one set performed to failure before the testing procedure may be performed when moderate levels of fatigue are intended).

Although this study presents new insights into the effect of SSC on the RTF-velocity relationships, it is important to acknowledge several limitations. First, the ecological validity of our results may be limited, as most athletes typically use FW in their daily routines. However, the SM offers more precise control over the range of motion and cable displacement than FW (the inclination of the cable can affect the magnitude of lifting velocities)[60]. Second, this study only evaluates the goodness-of-fit of the model (*i.e.,* r^2 and SEE), while the prediction error (*i.e.,* difference between predicted and performed repetitions) may differ in practical settings. Finally, future research should determine whether these results are applicable to other populations (*e.g.,* female subjects).

Conclusions and Practical Applications

The incorporation of the SSC does not compromise the goodness-of-fit of individualized RTF-velocity relationships. However, for practitioners wanting to create RTF tables and control the proximity to failure for different athletes, RTF-velocity relationships that consider each type of muscle action should be constructed separately given the greater fatigue induced by the eccentric-concentric compared to the concentric-only PBP. The greater fatigue induced by the eccentric-concentric PBP means that there is a lower RTF for a given initial set velocity (**see Table 8 for further details**). Additionally, two other methodological factors should be considered: (i) the $PV_{fastest}$ may offer a higher goodness-of-fit during the PBP exercise, but such minor differences may not be significant from a practical standpoint, and (ii) the construction of RTF relationships can be obtained using the two-point method (*i.e.,* only a single set of 60% and 80% of 1RM performed to failure).

From a practical standpoint, practitioners only need to monitor the $MV_{fastest}$ or $PV_{fastest}$ and the RTF from 2 (*i.e.,* two-point method) or 3 (*i.e.,* multiple-point method) sets performed to failure to construct an RTF-velocity relationship. Once these relationships have been established, coaches only need to monitor the $MV_{fastest}$ or $PV_{fastest}$ of the set (commonly reached during the 1-3 repetitions of the set) to estimate the RTF against a given absolute load. This can help support the training prescription of athletes and ensure similar proximity to failure when multiple athletes are exercising.

5. The effect of Lifting Straps on The Prediction of the Maximal Neuromuscular Capabilities and 1 Repetition Maximum During the Prone Bench Pull Exercise

Miras-Moreno, S., & García-Ramos, A.

Brief overview

Velocity-based training (VBT) has emerged as a contemporary objective auto-regulatory RT method that might enhance both training and testing procedures by recording the lifting velocity of repetitions performed with maximal concentric effort[13,15,90]. Because of its methodological robustness and feasibility within an athlete's daily routine, two VBT applications have attracted significant research attention[13,15,90]: (i) the estimation of the maximal neuromuscular capacities to produce force, velocity, and power, and (ii) the prediction of the 1RM. Indeed, both VBT applications can be efficiently conducted during the same testing procedure by recording the lifting velocity against at least two submaximal loads for the construction of individual load-velocity relationships (*i.e.,* L-V relationships) through a linear regression model [13,15,18,57].

Recent research has used the L-V relationship to assess the maximal neuromuscular capacities during the BP, BS and PBP exercises[56,57,59,70,71]. The three key metrics derived from the L-V relationship represent the abilities of the neuromuscular system to produce force at low velocities (L_0), force at high velocities (v_0), and maximal power (A_{line})[57,70,71]. The L-V relationship variables (L_0, v_0, A_{line}) have demonstrated a high concurrent validity and higher reliability compared to the parameters derived from the force-velocity relationship (*i.e.,* F_0, v_0 and P_{max})[57,70]. The high linearity of the L-V relationship has contributed to the simplification of the testing procedure, from the commonly used multiple-point method (*i.e.,* data points acquired from multiple loads) to the two-point method applied in field conditions (*i.e.,* data points acquired from the lightest possible load [barbell weight] and a heavy load [~85%1RM])[14,56,57,70]. The two-point method applied in field conditions may obtain L-V relationship variables of a larger magnitude because it minimizes fatigue[14,18,57], facilizing its implementation when prescribing other RT exercises after the testing procedure.

Many studies have also explored the possibility of predicting the 1RM using both the multiple- and two-point methods in a wide variety of upper- and lower-body RT exercises[15,90]. The main problem arises when determining the appropriate MVT for the predicted 1RM[13,15]. Traditionally, two types of MVT have been used for this purpose: the general MVT (*i.e.,* averaged across the subjects' velocity of the 1RM trial) and individual MVT (*i.e.,* individual velocity of a 1RM trial). Both types of MVT have consistently revealed comparable absolute errors when predicting the 1RM across a range of exercises [4,13,34,40]. However, many studies have demonstrated their ineffectiveness in providing accurate 1RM estimations[2,26,46,48,77]. To solve this issue, García-Ramos[13] recently proposed the individual optimal MVT (*i.e.,* the velocity that eliminates the differences between the actual and predicted 1RM) to avoid the systematic error of the 1RM prediction. Of note is that the average optimal MVT (*i.e.,* the individual optimal MVT averaged across the subjects) may provide a more feasible approach because it would not require that all subjects perform 1RM trials.

Despite the extensive research on this topic, the PBP has received less attention than other RT exercises, even though it is a crucial exercise for enhancing strength and power of upper-body muscles[87]. For example, no study has explored whether the optimal MVT could provide more accurate estimations of the PBP 1RM than the general and individual MVTs. In addition, it has been recently shown that the use of lifting straps impacts the L-V relationship during the deadlift exercise[39]. However, it is unknown whether the use of lifting straps can yield a similar effect during the PBP exercise and potentially impact the prediction of maximal neuromuscular capabilities and 1RM.

The general objective of the present study was to explore the effects of lifting straps on the magnitude of the L-V relationship variables (*i.e.,* L_0, v_0 and A_{line}) and 1RM prediction accuracy (*i.e.,* difference between actual and estimated 1RM) during the SM PBP exercise. The secondary aims were: (i) to compare the L-V relationship variables between two modelling procedures (multiple-point *vs.* two-point), and (ii) to compare the 1RM prediction accuracy between two modelling procedures (multiple-point *vs.* two-point) and three types of MVT (general *vs.* individual *vs.* average optimal). We hypothesized that: (i) the individual L-V relationships would show a comparable goodness-of-fit and similar accuracy when predicting the 1RM for both execution equipment (with and without lifting straps)[40,41], but the magnitude of the L-V relationship variables would be greater using lifting straps, (ii) the magnitude of the L-V relationship variables would be greater for the two-point compared to the multiple-point method[57], but no differences in the accuracy of 1RM estimation was expected, and (iii) the average optimal MVT would provide more accurate estimations of the 1RM compared to the general and individual MVTs[16,88].

> **!**
>
> Readers should be aware that this chapter is not related to the estimation of different RTFs. The inclusion of this chapter into the present thesis was related to the null studies exploring the lifting straps effects during the PBP exercise. For this reason, the research team decided to explore first the load-velocity relationships to know which loads select for the subsequent study analyzing the RTF-velocity relationships from the next chapter.

Methods

Design

A repeated-measures design was used to explore the effects of using lifting straps during the PBP exercise on the magnitude of L-V relationship variables and 1RM prediction accuracy. Following a preliminary session to determine the PBP 1RM without lifting straps, subjects randomly undertook two identical experimental sessions (*i.e.,* with and without lifting straps). Both sessions were carried out within the same week separated by at least 48 hours. The L-V relationship was modelled in both experimental sessions using the multiple-point (*i.e.,* L1 = 14 kg [lightest load], L4 = 75.4 ± 8.9 kg [heaviest load, 85%1RM], L2 = 34.4 ± 2.9 kg, L3 = 54.7 ± 5.9 kg) and two-point method applied in field conditions (*i.e.,* only two distant loads [L1 and L4]). Afterwards, the load was increased by 5 to 1 kg until the 1RM was directly determined[16,56,57]. All the sessions were performed in the University's research laboratory under the direct supervision of the same researcher, at the same time of day for each subject (± 3 hours) and, under similar environmental conditions (~22ºC and ~60% humidity).

Subjects

Twenty resistance-trained male subjects (age = 25.1 ± 5.4 years [range: 19–42 years]; body mass = 83.6 ± 23.6 kg; body height = 1.78 ± 0.08 m; PBP 1RM = 89.9 ± 11.0 kg [1.10 ± 0.17 normalized per kg of body mass]) volunteered to participate in this study (data presented as means ± SD). All subjects had 5.8 ± 4.7 years of RT experience and were familiar with the PBP exercise. Indeed, a familiarization session was deemed unnecessary because all subjects recently participated in research projects (*i.e.,* twice a week one month before the onset of the study) conducted by our research group and were familiar with the maximal intended lifting velocity and with the PBP exercise technique. All participants did not present any physical limitations that may affect the study results. Subjects were briefed on study's objectives and methods and provided their written consent to participate. The study protocol adhered to the tenets of the Declaration of Helsinki and was approved by the Institutional Review Board (approval no: 0557-N-22). An a-priori sample size calculation conducted using G*Power 3.1.9.6 (ES of 0.20, alpha of 0.05, statistical power of 0.90, 2 number of groups [with and without lifting straps], 12 number of measurements [2 experimental groups × 2 modelling procedures × 3 MVTs types] and, a correlation among repeated measurements of 0.75 revealed a total sample size of 14 participants).

Testing procedures

1RM determination (preliminary session)

Body height (Seca 202 Stadiometer, Seca Ltd) and body mass (Tanita BC 418 segmental; Tanita Corp, Tokyo, Japan) were evaluated at the beginning of the preliminary session. A standardized general warm-up consisting of 5 minutes of jogging, dynamic stretching, upper-body joint mobilization exercises, and 1 set of 5 repetitions against 14 kg, 20 kg and 30 kg were performed without lifting straps during the PBP exercise[56,57]. After 5 minutes of rest, subjects executed an incremental loading test to directly determine their PBP 1RM. The 1RM test started with an external load of 20 kg for all subjects and progressively increased in 10 kg increments until the MV was lower than 0.80 $m.s^{-1}$. Once the MV was lower than 0.80 $m.s^{-1}$, the load was increased from 5 to 1 kg until the 1RM was directly achieved. Two repetitions were performed with light–moderate loads (MV ≥ 0.80 $m.s^{-1}$) and 1 repetition with heavier loads (MV < 0.80 $m.s^{-1}$). Recovery time was set to 3 minutes for light–moderate loads and 5 minutes for heavier loads[56,57,59].

Determination of the L-V relationships and 1RM (experimental sessions)

Each experimental session started with the same general warm-up previously described for the preliminary session. The specific warm-up consisted of 1 set of 10, 5, and 2 repetitions at 40%, 60%, and 80% of 1RM, respectively. After warming-up, subjects rested for 3 minutes and then, they performed the experimental protocol. The experimental protocol consisted of lifting four loads in a fixed sequence (L1-L4-L2-L3). Only the first two loads (L1-L4) were considered by the two-point method, whereas the multiple-point method also considered L2 and L3. Three (L1-L2) and two (L3-L4) repetitions were performed for each load and 3 minutes of inter-set rest was established. After 5 minutes of rest, subjects lifted the 95% of the 1RM determined in the preliminary session and afterwards, the load was increased from 5 to 1 kg until the 1RM was directly reached. Participants were always encouraged to lift the barbell as fast as possible while receiving real-time MV feedback on each repetition to maximize mechanical performance and 1RM prediction accuracy[37].

Measurement Equipment, Exercise Technique and Data Analysis

The PBP exercise was performed in a SM (Multipower Fitness Line, Peroga, Murcia, Spain) using a standard barbell (14 kg and 10 cm diameter) and calibrated technique plates (Ruster Fitness, Jaén, Spain). The PBP technique performed in this study was extensively explained elsewhere[56,59,72]. Subjects were instructed to lift the barbell, which rested on the SM's telescopic holders for at least 2 seconds, as fast as possible until it made contact with the bottom of the bench with an overhand grip (*i.e.,* concentric phase). Subjects were not allowed to stop the barbell's gravity acceleration during the downward phase (*i.e.,* eccentric phase)[57,59]. All participants used the same lifting straps (RDX Sports; material: flat nylon; padding: gel integrated neoprene; length: 58.5 cm; width: 3.8 cm). A validated linear velocity transducer at a sampling frequency of 1000 Hz (T-Force System version 3.70; Ergotech, Murcia, Spain) was used to obtain the MV of all repetitions[9]. Only the repetition with the $MV_{fastest}$ values for each load was considered for the L-V relationship modelling[57,59].

The MV collected under four (multiple-point: L1-L4-L2-L3) and two (two-point: L1-L4) loads were used to determine the L-V relationships through a least-square linear regression model $L(V) = L_0 - slope \times V$. Three variables were derived from the L-V relationship: L_0 (*i.e.,* theorical load at 0 $m \cdot s^{-1}$), v_0 (*i.e.,* $v_0 = L_0 / slope$) and A_{line} (*i.e.,* $A_{line} = L_0 \times v_0 / 2$). The same L-V relationships were used to estimate the 1RM considering three types of MVT: (i) general: selecting a fixed MV exercise for all subjects (0.47 $m \cdot s^{-1}$); (ii) individual: MV obtained during the 1RM trial for each subject, and (iii) average optimal: MV that eliminates the differences between the actual and predicted 1RM, calculated as follows: Optimal MVT = (Actual 1RM – load-intercept)/*slope* from L-V relationship[16,18,90]. We employed a leave-one-out cross-validation method for calculating the average optimal MVT, excluding the subject intended for 1RM prediction.

Statistical Analyses

Data are presented as means and SD, while r^2 is presented through median values and range. The normal distribution of the data was verified using the Shapiro-Wilk test ($P > 0.05$). The goodness-of-fit of the individual L-V relationship modelled by the multiple-point method was assessed through the r^2 [56,57]. Two-way repeated-measures ANOVA (execution equipment [with straps *vs.* without straps] × modelling procedure [multiple- *vs.* two-point method]) were used to compare the magnitude of the L-V relationship variables[56,57]. A three-way repeated-measures ANOVA (execution equipment × modelling procedure × MVT [general *vs.* individual *vs.* average optimal]) was used to compare the absolute and raw errors of the predicted 1RM, whereas the percentage values were presented for descriptive purposes in **Figure 15**[59]. A two-way repeated-measures ANOVA (execution equipment × MVT [individual *vs.* multiple-point average optimal *vs.* two-point average optimal]) was used to compare different MVTs to estimate the 1RM during the PBP performed with and without lifting straps. The Greenhouse-Geisser correction was applied when the Mauchly's sphericity test was violated, while pairwise comparisons considered Bonferroni post-hoc corrections.

The magnitude of the differences was evaluated using the Cohen's *d* ES, which was interpreted using the following scale: *trivial* (< 0.20), *small* (0.20–0.59), *moderate* (0.60–1.19), *large* (1.20–2.00), or *very large* (> 2.00)[31]. The software package SPSS (version 25.0, IBM SPSS) was used for the analyses and alpha was set at $P < 0.05$.

Results

The goodness-of-fit of the individual L-V relationships was very high for the PBP exercise performed with (r^2 = 0.97 [0.94–0.99]) and without (r^2 = 0.97 [0.95–0.99]) lifting straps. No significant interaction (execution equipment × modelling procedure) or execution equipment effect was observed for any L-V relationship variables ($F \leq 2.6$; $P \geq 0.123$; **Table 11**). However, the main effect of the modelling procedure reached statistical significance for all L-V relationship variables ($F \geq 183.4$; $P < 0.001$) due to significant higher values for two- compared to multiple-point method for the PBP exercise performed with ($P \leq 0.001$; ES range = 0.36–0.59) and without ($P \leq 0.001$; ES range = 0.35–0.64) lifting straps.

Regarding the ANOVAs conducted on the absolute and raw errors when predicting the 1RM, the three-way interaction was only significant for the raw errors (F = 45.1; $P < 0.001$). Considering all the two-way interactions, only the modelling procedure × MVT interaction reached statistical significance for both type of errors ($F \geq 64.4$; $P < 0.001$) because the errors were comparable for the multiple- and two-point methods using the average optimal MVT, but greater errors were observed for multiple- compared to two-point method using general or individual MVTs (**Figure 15**). The main effect of execution equipment never reached statistical significance ($F \leq 0.387$; $P \geq 0.541$). A significant main effect of modelling procedure was observed due to lower raw errors ($P < 0.001$, ES = 0.53; small differences) and absolute errors ($P < 0.001$, ES = 0.68; moderate differences) for two- compared to multiple-point method. The main effect of MVT was also significant due to lower raw errors ($P < 0.001$, ES = 1.20-1.34; large differences) and absolute errors ($P < 0.003$; ES = 1.00-1.26; moderate to large differences) for average optimal MVT compared to individual and general MVTs.

Regarding the different MVTs used to estimate the 1RM, the execution equipment × MVT interaction failed to reach statistical significance (F = 2.1; P = 0.131) (**Table 12**). The main effect of execution equipment was significant due to lower MVT obtained using lifting straps ($P < 0.001$; ES = 0.25; small differences). The main effect of MVT was significant due to higher velocities for individual MVT compared to multiple-point average optimal MVT ($P < 0.001$; ES = 3.04; very large differences) and two-point average optimal MVT ($P < 0.001$; ES = 1.23; large differences), whereas the two-point optimal MVT was greater than the multiple-point average optimal MVT ($P < 0.001$; ES = 1.81; large differences).

Table 11. *Two-way repeated-measures ANOVA comparing the load-velocity (L-V) relationship variables between different modelling procedures during the PBP performed with and without lifting straps.*

L-V relationship variable	Modelling procedure	PBP		ANOVA	
		Without lifting straps	**With lifting straps**	**Main effects**	**Interaction**
L_0 (kg)	Multiple-point	110 ± 11 [80–132]	109 ± 10 [83–124]	***Modelling procedure:*** ***F* = 183.4; *P* < 0.001** *Execution equipment:* *F* = 0.1; *P* = 0.696	*Modelling procedure × Execution equipment:* *F* = 2.6; *P* = 0.123
	Two-point	115 ± 12 [84–140]	115 ± 11 [87–130]		
v_0 ($m \cdot s^{-1}$)	Multiple-point	2.02 ± 0.15 [1.81–2.34]	2.01 ± 0.15 [1.73–2.27]	***Modelling procedure:*** ***F* = 471.2; *P* < 0.001** *Execution equipment:* *F* = 0.2; *P* = 0.595	*Modelling procedure × Execution equipment:* *F* < 0.1; *P* = 0.777
	Two-point	2.07 ± 0.16 [1.86–2.42]	2.06 ± 0.16 [1.76–2.33]		
A_{line} ($kg \cdot m \cdot s^{-1}$)	Multiple-point	111 ± 13 [86–146]	110 ± 14 [83–141]	***Modelling procedure:*** ***F* = 205.9; *P* < 0.001** *Execution equipment:* *F* = 0.8; *P* = 0.363	*Modelling procedure × Execution equipment:* *F* = 1.3; *P* = 0.262
	Two-point	119 ± 16 [92–159]	118 ± 16 [88–151]		

Descriptive values are presented as mean ± standard deviation [range]. L_0, load-axis intercept; v_0, velocity-axis intercept; A_{line}, area under the L-V relationship line; F, Snedecor's F; P, P-value.

Table 12. *Two-way repeated-measures analysis of variance (ANOVA) comparing different minimum velocity thresholds (MVT) to estimate the one-repetition maximum (1RM) during the prone bench pull exercise (PBP) performed with and without lifting straps.*

Modelling procedure	**PBP (m·s^{-1})**		**ANOVA**
	Without lifting straps	**With lifting straps**	
Individual MVT	0.47 ± 0.05 [0.40–0.55]	0.46 ± 0.05 [0.36–0.55]	***MVT: F* = 148.9; *P* < 0.001**
Multiple-point optimal MVT	0.33 ± 0.00 [0.32–0.34]	0.31 ± 0.00 [0.30–0.31]	***Execution equipment: F* = 35.2; *P* < 0.001**
Two-point optimal MVT	0.41 ± 0.00 [0.41–0.42]	0.40 ± 0.00 [0.39–0.41]	*MVT × Execution equipment: F* = 2.1; *P* = 0.131

Descriptive values are presented as mean ± standard deviation [range]. F, Snedecor's F; P, P-value

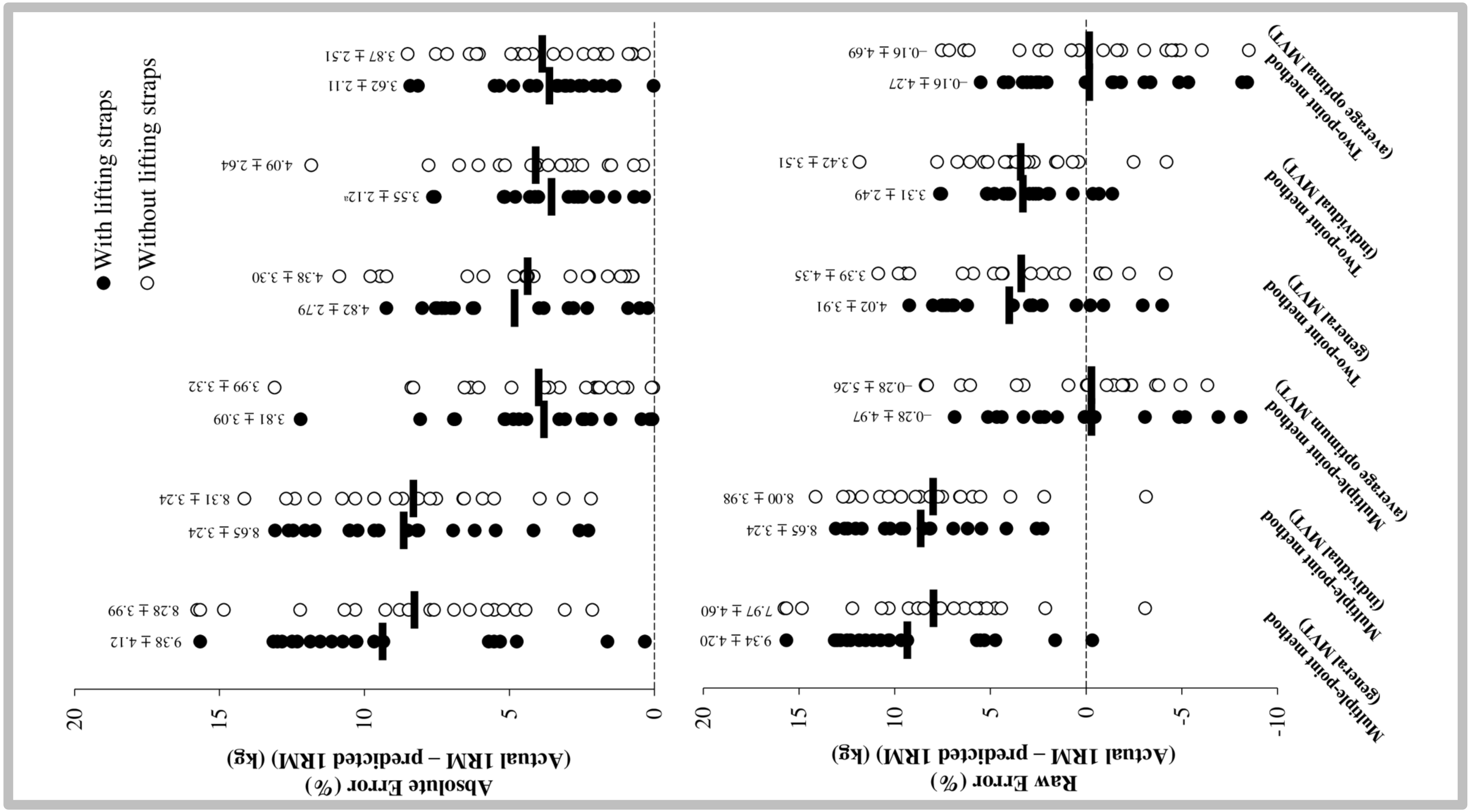

Figure 15. Descriptive values of the absolute errors and raw errors when estimating the 1RM between different modelling procedures (multiple- and two-point method) and MVT: general, individual and average optimal, performed with and without lifting straps.

Table 13. Relationship between different minimum velocity thresholds (MVT) to estimate the one-repetition maximum (1RM) during the prone bench pull exercise (PBP) performed with and without lifting straps.

		Individual MVT		**Optimal MVT (multiple-point)**		**Optimal MVT (two-point)**
		With straps	Without straps	With straps	Without straps	With straps
Individual MVT	Without straps	**0.693****				
Optimal MVT (multiple-point)	With straps	**0.556***	0.336			
	Without straps	0.409	0.442	**0.614****		
Optimal MVT (two-point)	With straps	**0.724****	**0.485***	**0.919****	**0.539***	
	Without straps	**0.497***	**0.545***	**0.559***	**0.899****	**0.511***

Data are presented as Pearson's product-moment correlation coefficient (*r*). *Correlation coefficient is significant at $P < 0.05$; **Correlation coefficient is significant at $P < 0.01$.

Discussion

The current study explored the impact of using lifting straps on the magnitude of L-V relationship variables and 1RM prediction accuracy during the PBP exercise, using various modelling procedures (multiple- and two-point) and types of MVT (general, individual, and average optimal). The goodness-of-fit of the L-V relationship, magnitude of L-V relationship variables, and 1RM prediction accuracy were comparable for both PBP exercises. The magnitude of the L-V relationship variables and 1RM prediction accuracy were greater for two- compared to multiple-point method. The average optimal MVT combined with the two-point method revealed the greatest accuracy in the 1RM prediction. These results reinforce the two-point method applied in field conditions and the average optimal MVT for the routine testing of the L-V relationship, whereas the use of lifting straps during single PBP repetitions presents negligible effect regardless of the load lifted.

Grip strength may limit performance during pulling exercises performed against heavy loads[7]. In this regard, lifting straps can assist in transferring part of the load from the fingers to the wrist, which in turn could potentially enable to lift heavier loads[7,86]. Considering that lifting straps are most effective during heavy lifts, it is plausible that their use may influence the shape of the L-V relationship[7,86]. However, recent research observed that although lifting straps allowed for a greater 1RM and steeper slope of the L-V relationship (*i.e.,* greater increase in load for a given reduction in velocity) during the deadlift, the linearity of the relationship remained unaffected[39]. Our findings support the high linearity of the L-V relationship regardless of whether the PBP exercise was performed with (r^2 = 0.97 [0.99–0.94]) or without (r2 = 0.97 [0.99–0.95]) lifting straps. Since the use of lifting straps did not affect the linearity of L-V relationships, it is reasonable to examine their impact on predicting the maximal neuromuscular capacities and 1RM during the PBP exercise[40].

Jukic et al.[39] revealed a greater ergogenic effect of lifting straps as the load increased during the deadlift exercise. In contrast, our results found that lifting straps do not affect performance at low velocities (L_0), high velocities (v_0) or maximal work rate (A_{line}) during the PBP exercise. Our findings align with those of Valério et al.[88] who did not obtain significant differences in the lat-pull down 1RM (*i.e.,* note that 1RM is highly correlated with L_0) when the exercise was performed with or without using lifting straps. These conflicting findings may stem from the specific demands of each exercise. It is worth mentioning that the benefits of using lifting straps might be more pronounced in the deadlift as opposed to the PBP or lat-pull down exercises, as the former involves lifting heavier loads, thus emphasizing the significance of grip strength[7,88]. Therefore, unlike the deadlift exercise, the use of lifting straps does not affect the estimation of the maximal neuromuscular capacities during the PBP exercise.

Regardless of the execution equipment used, the two-point method applied in field conditions revealed significant higher L-V relationships variables compared to the multiple-point method. These results are in concordance with previous studies from Miras-Moreno et al.[56,57] who observed higher values of L-V relationships variables for the two-point compared to the multiple-point method during the

PBP exercise. The differences between modelling procedures may be explained by the lower fatigue induced by the two-point method testing protocol[56,57]. While previous studies have generally revealed a comparable 1RM prediction accuracy for the multiple- and two-point methods[15], our results surprisingly indicated a higher 1RM prediction accuracy for two- compared to multiple-point method when using general and individual MVTs. These findings can be elucidated by the systematic underestimation of the actual 1RM values, caused by both general and individual MVTs. As a result, the increased 1RM values derived from the two-point method effectively mitigated the extent of this underestimation.

The 1RM estimation is probably the most researched application of VBT[13]. In this sense, García-Ramos[13] recently introduced the optimal MVT allowing a higher 1RM prediction accuracy than individual or general MVTs during the BP exercise. The primary benefit of the optimal MVT lies in its ability to minimize the systematic differences compared to the actual 1RM. In the same line, our study effectively demonstrated that regardless of the execution equipment and method used, the raw differences between actual and predicted 1RMs consistently remained under 1 kg when the average optimal MVT was employed. It is worth highlighting that the average optimal MVT was found to be lower than individual MVT, aligning with previous research indicating that relying solely on the velocity achieved during the 1RM trial may systematically lead to overestimations or underestimations of the actual 1RM[15]. Furthermore, the significant positive correlations observed for the optimal MVT for both PBP exercises hint its potential subject-specific nature (see **Table 13**). This implies that using an individual optimal MVT could yield a more accurate 1RM prediction compared to the average optimal MVT. Nevertheless, a drawback of the individual optimal MVT is that requires a preliminary session to determine the optimal MVT for each subject. Although the most suitable procedure is yet to be determined, it is evident that practitioners should prioritize identifying the optimal MVT over the individual MVT when their objective is to predict the 1RM through the individual L-V relationship.

Despite the encouraging results for the use of the two-point method and optimal MVT, readers should be aware of several limitations. First, the use of a SM in our study may: (i) restrict the ecological validity of our findings because lifting straps may demonstrate greater benefits during FW exercises, and (ii) alter the accuracy of the force-velocity relationships variables. However, the SM allows for a more accurate control of the range of motion as well as cable displacement (*e.g.,* the cable sometimes slightly is inclined during FW exercises and may affect to the lifting velocity obtained)[60]. Second, the effectiveness of lifting straps may be influenced by the individual's grip strength and, barbell diameter. Finally, while the present study suggests a greater 1RM prediction accuracy for the optimal MVT, future research should elucidate whether the average optimal MVT reported in this study also provides a greater accuracy in other training conditions (*e.g.,* female participants, other velocity monitoring device or free-weight exercises are used).

Conclusions and practical applications

The use of lifting straps during the PBP exercise does not impact the magnitude of the maximal neuromuscular capacities (L_0, v_0, and A_{line}) or the 1RM prediction when constructed from the individual L-V relationship. Therefore, athletes should decide about their use mainly based on their personal preferences. Our results also indicate that the two-point method applied in field conditions (*i.e.,* using only two loads), not only yields L-V relationship variables of greater magnitude but also offers a more precise estimation of the 1RM compared to the multiple-point method. The 1RM prediction accuracy was generally enhanced when using the average optimal MVT compared to general and individual MVTs. These results emphasize the relevance of the two-point method applied in field conditions and the average optimal MVT for routine L-V relationship testing, while also highlighting the negligible effect of using lifting straps during single PBP repetitions. A MVT of 0.40 $m \cdot s^{-1}$, significantly lower than the velocity of the 1RM trial (≈ 0.47 $m \cdot s^{-1}$), should be taken into account when applying the two-point method to prevent a systematic underestimation of the true 1RM.

6. Impact of Lifting Straps on the Relationships Between Maximum Repetitions to Failure and Lifting velocity During the Prone Bench Pull Exercise

Miras-Moreno, S., García-Ramos, A., Rojas-Ruiz, FJ., & Pérez-Castilla, A.

Brief overview

The $MV_{fastest}$ and $PV_{fastest}$ of the set has recently been used to predict the RTF during the SM PBP exercise[59]. These authors also showed that individualized RTF–velocity relationships provided a higher goodness-of-fit (r^2 = 0.96–0.97 *vs.* 0.67–0.70) and accuracy in the prediction of the RTF (absolute errors = 2.1–2.9 repetitions *vs.* 2.8–4.3 repetitions) than generalized RTF–velocity relationships. Importantly, the SM PBP exercise was conducted without lifting straps. This could make an individual's grip strength a limiting factor, potentially causing early fatigue and exercise interruption[7,42]. Briefly, lifting straps allow for a greater perceived security and power feeling, as well as greater mean and peak velocity when performing four sets of four repetitions against the 80%1RM load[38,42]. These benefits may be somewhat explained by part of the weight lifted is transferred from the fingers to the wrist[7,88]. However, other authors did not report any effect of using lifting straps on mean and peak power, mean and peak velocity recorded at a range of fixed loads (from 20% to 80% 1RM) during the deadlift exercise[41], nor on the 1RM value, RTF against the 70%1RM, and muscle activation during the lat pull-down exercise[88]. These conflicting findings highlight the important methodological issue of whether the RTF-velocity relationships are influenced by using lifting straps during the SM PBP exercise.

Strong and linear RTF-velocity relationships have been reported for each subject during the SM PBP exercise (r^2 = 0.97 [0.83–1.00])[59]. Specifically, the individualized RTF-velocity relationships were modelled by applying a linear regression model to data obtained from sets to failure performed against four loads (60%1RM, 70%1RM, 80%1RM, and 90%1RM)[21,59]. This testing procedure, which incorporates more than two experimental points in the modelling, has been referred to as "multiple-point method" in the VBT literature[18,57,90]. However, from a more practical perspective, this multiple-point method used to create the individualized RTF-velocity relationship is time consuming and prone to fatigue[18,57,90]. Given the high linearity reported for the individualized RTF-velocity relationships, a more efficient approach would involve performing sets to failure against only two distant loads (*e.g.,* 60%1RM and 80%1RM) (*i.e.,* “two-point method”)[60]. However, no study has examined the feasibility of the two-point method to predict velocity values ($MV_{fastest}$ and $PV_{fastest}$) associated with each RTF. The expected findings should provide novel and valuable information for refining the testing procedure used to construct RTF-velocity relationships.

To shed light on the gaps identified in the literature, the objectives of this study were: (i) to compare the goodness-of-fit between the generalized and individualized RTF-$MV_{fastest}$ and RTF-$PV_{fastest}$ relationships obtained during the SM PBP exercise performed with and without lifting straps, and (ii) to compare the $MV_{fastest}$ and $PV_{fastest}$ associated with different RTFs (from 1 to 15) between both execution equipment (*i.e.,* with *vs.* without lifting straps) and prediction methods (*i.e.,* multiple-point *vs.* two-point). We hypothesized that: (i) the goodness-of-fit would be higher for individualized compared to generalized RTF-velocity relationships and comparable for both execution equipment[21,43,59] and (ii) the velocity values ($MV_{fastest}$ and $PV_{fastest}$) associated with each RTF would be comparable between execution equipment and prediction methods[14,41,42,88].

Methods

Design

The possibility of predicting RTF from the monitoring of lifting velocity during the SM PBP exercise performed with and without lifting straps was investigated using a randomized crossover design, as observed in **Figure 16**. Following an initial SM PBP 1RM testing session, subjects rest for 72 hours and participated into two experimental sessions separated by at least 48 hours of rest throughout the same week. Both experimental sessions consisted of single sets of RTFs separated by five minutes of rest against three relative loads performed in the following order: 60%1RM, 80%1RM, and 70%1RM. Subjects were asked to lift the barbell as fast as possible for as many repetitions as possible while receiving real-time velocity performance feedback to maximize performance in each repetition[37]. Each subject's session was held in the University's research facility at the same time of day (± 3 hours) and under identical climatic conditions (~22ºC and ~60% humidity).

Subjects

Twenty resistance-trained males (age = 25.1 ± 5.4 years [range: 19-42 years]; body height = 1.78 ± 0.08 m; body mass = 83.6 ± 23.1 kg; SM PBP 1RM with lifting straps = 88.9 ± 11.0 kg [1.10 ± 0.17 normalized per kg of body mass]) participated in this study (data presented as means ± SD). All subjects had 5.8 ± 4.7 years of RT experience and reported using the PBP exercise in their regular training. No physical limitations or musculoskeletal injuries that could compromise testing were reported. Before the study, they were informed of the study procedures, signed a written informed consent form, and were asked to refrain from vigorous activity. The study protocol adhered to the tenets of the Declaration of Helsinki and was approved by the Andalusian Biomedical Research Ethics Portal (approval no: 0557-N-22).

Testing procedures

1RM assessment with lifting straps (preliminary session)

Jogging, dynamic stretching, upper-body joint mobilization exercises, and two sets of five repetitions of the SM PBP against 20 and 30 kg comprised the warm-up. Initial load for the incremental loading test was 40 kg, and it was raised by 10 kg increments until the MV fell below 0.80 $m \cdot s^{-1}$. From that point on, the load was adjusted in increments of five to one kg in consensus between the subject and an experienced researcher until the 1RM was attained. Two repetitions with light-to-moderate loads (MV ≥ 0.80 $m \cdot s^{-1}$) and one repetition with heavier loads (MV < 0.80 $m \cdot s^{-1}$) were conducted[57,59]. Recovery time was set to three minutes for light-moderate loads and five minutes for heavier loads[57,59].

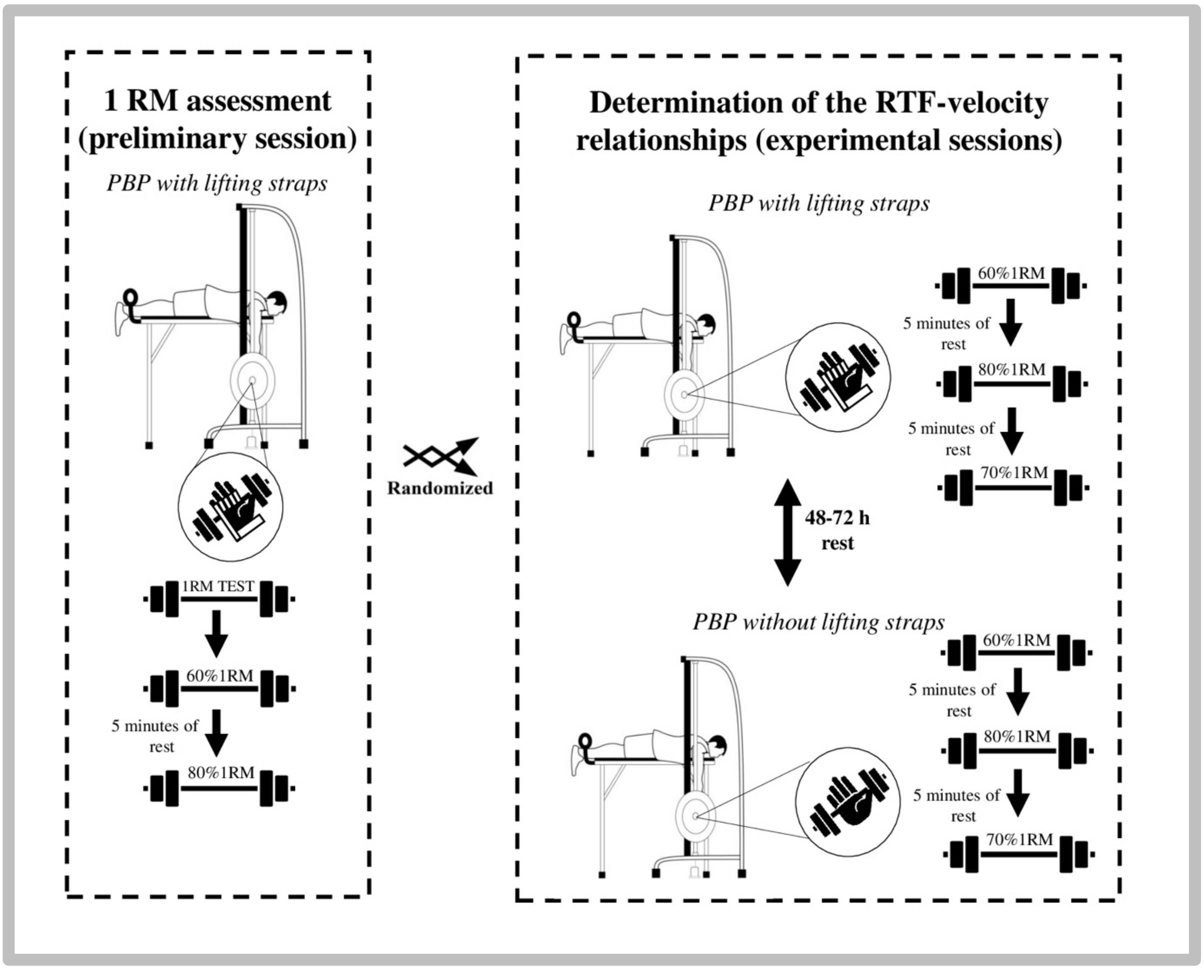

Figure 16. *Overview of the experimental design from study 6.*

Determination of RTF-velocity relationships (experimental sessions)

The entire experimental session was performed separately with or without lifting straps according to each condition. Jogging, dynamic stretching, and upper-body joint-mobilization exercises comprised the warm-up, which was followed by one set of 10, three, and one repetition of the tested PBP with the 40%1RM, 60%1RM, and 80%1RM, respectively[59,60]. After warming up, subjects rested for three minutes before doing single sets of repetitions to failure against three relative loads performed in the following order: 60%1RM, 80%1RM, and 70%1RM. Five-minute pauses were taken between repetition to failure sets[60]. The same sequence and absolute loads were maintained for both sessions.

PBP technique

The PBP exercise was performed in a SM (Multipower Fitness Line, Peroga, Murcia, Spain). Subjects assumed a prone posture with their chins resting on the bench, elbows fully extended, and a barbell grip approximately broader than shoulder width[56,57,59]. The SM's telescopic holders were positioned such that the barbell stopped precisely when both elbows were fully extended allowing to maintain the same range of motion[56,57,59]. The individuals were asked to pull the barbell as fast as possible until it contacted with the bottom of the bench with an overhand grip. The test was terminated and neither repetition was counted when the barbell failed to hit the bottom of the bench (11.0 cm thickness) for two consecutive repetitions[59]. The calves of the legs were secured with a stiff strap to avoid the legs movements and facilitate the upper-limbs force application[56,57,59]. All participants were able to wrap the same lifting straps (RDX Sports; material: flat nylon; padding: gel integrated neoprene; length: 58.5 cm; width: 3.8 cm) during all the experimental sessions. A validated linear velocity transducer (T-Force System version 3.70; Ergotech, Murcia, Spain)[9] was used for velocity monitoring. The RTF, $MV_{fastest}$, $PV_{fastest}$, MV_{last}), and PV_{last} were used for subsequent analyses[59].

Statistical Analysis

Data are presented as means and SD, while the r^2 and SEE are presented through the median value and range. The normal distribution of the data was confirmed using the Shapiro-Wilk test ($P > 0.05$). Two-way repeated-measures ANOVA (execution equipment [with *vs.* without lifting straps]) × load [60%1RM *vs.* 80%1RM *vs.* 70%1RM]) were conducted on RTF, $MV_{fastest}$, $PV_{fastest}$, MV_{last}, and PV_{last}. Least-square linear regression models were used to determine the RTF-$MV_{fastest}$ and RTF-$PV_{fastest}$ relationships for each execution equipment[59,60]. Generalized relationships were obtained separately for each execution equipment by pooling together the data from all subjects (20 subjects × 3 sets = 60 data points)[21,59,60], while individualized relationships were computed separately for each subject considering the data points acquired from the three loads (*i.e.,* multiple-point method [60%-80%-70%1RM]) or only the two most distant loads (*i.e.,* two-point method [60-80%1RM])[60]. The goodness-of-fit of generalized and individualized RTF-$MV_{fastest}$ and RTF-$PV_{fastest}$ relationships were evaluated through the r^2 and SEE[59,60]. Additionally, a two-way repeated-measures ANOVA (execution equipment [with *vs.* without lifting straps]) × prediction method [multiple-point *vs.* two-point]) was used to compare the $MV_{fastest}$ and $PV_{fastest}$ values associated with each predicted RTF[59,60]. The Greenhouse-Geisser correction was used when the Mauchly’s sphericity test was violated and pairwise differences were identified using

Bonferroni post-hoc corrections. The magnitude of the differences was assessed by the Cohen's *d* ES, which was interpreted using the following scale: *trivial* (< 0.20), *small* (0.20–0.59), *moderate* (0.60–1.19), *large* (1.20–2.00), or *very large* (> 2.00)[31]. The software package SPSS (version 25.0, IBM SPSS) was used for the analyses. Alpha was set at 0.05.

Results

The execution equipment × load interaction did not achieve any statistical significance for RTF, $MV_{fastest}$, MV_{last}, $PV_{fastest}$, or PV_{last} ($F \leq 1.2$; $P \geq 0.283$) (**Table 14**). The main effect of execution equipment only reached statistical significance for MV_{last} due to the higher values obtained with lifting straps compared to without lifting straps ($F = 5.2$; $P = 0.033$). The main effect of load was significant for RTF, $MV_{fastest}$, and $PV_{fastest}$ ($F \geq 152.0$; $P < 0.001$) as they decreased with the increment in the load.

The goodness-of-fit and accuracy of the generalized RTF-$MV_{fastest}$ and RTF-$PV_{fastest}$ relationships were comparable with lifting straps ($r^2 = 0.57$ and 0.66; SEE = 7.5 and 6.7 repetitions, respectively) and without lifting straps ($r^2 = 0.52$ and 0.59; SEE = 7.9 and 7.3 repetitions, respectively) (**Figure 17**). The individualized RTF-velocity relationships were always stronger than the generalized RTF-velocity relationships, but comparable with lifting straps ($MV_{fastest}$: $r^2 = 0.95$ [0.87, 0.99]; SEE = 2.7 repetitions [0.1, 9.6 repetitions]; $PV_{fastest}$: $r^2 = 0.97$ [0.88, 1.00]; SEE = 2.3 repetitions [0.1, 10.3 repetitions]) and without lifting straps ($MV_{fastest}$: $r^2 = 0.95$ [0.82, 1.00]; SEE = 2.7 repetitions [0.1, 10.4 repetitions]; $PV_{fastest}$: $r^2 = 0.97$ [0.89, 0.99]; SEE = 2.3 repetitions [0.2, 8.0 repetitions]).

Neither the execution equipment × prediction method interaction nor the main effect of the execution equipment achieved statistical significance for the $MV_{fastest}$ ($F \leq 0.1$ and 1.6; $P \geq 0.703$ and 0.217, respectively) (**Table 15**) or $PV_{fastest}$ ($F \leq 0.5$ and 0.6; $P \geq 0.455$ and 0.432, respectively) (**Table 16**) values associated with the different RTFs. However, the main effect of the prediction method was always significant for $MV_{fastest}$ ($F \geq 17.0$; $P \leq 0.001$) (**Table 15**) and $PV_{fastest}$ ($F \geq 21.5$; $P < 0.001$) (**Table 16**) due to slightly higher velocity values associated with each RTF for the multiple-point method compared to the two-point method for $MV_{fastest}$ ($P < 0.001$; ES ≤ 0.25) and $PV_{fastest}$ ($P < 0.001$; ES ≤ 0.24).

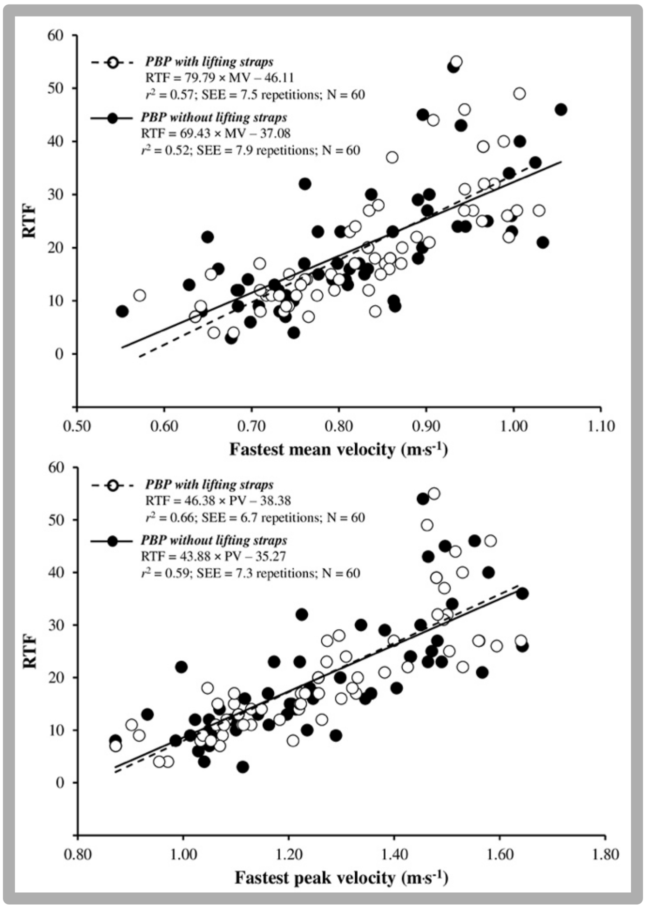

Figure 17. Generalized RTF-velocity relationships during the SM PBP performed with (open dots) and without lifting straps (filled dots).

Table 14. Two-way repeated measures ANOVA comparing the RTF, $MV_{fastest}$, $PV_{fastest}$, MV_{last}, PV_{last}) performed against three relative loads during the PBP performed with and without lifting straps.

	Execution equipment	**60%1RM**	**70%1RM**	**80%1RM**	**ANOVA**	
					Main effects	**Interaction**
RTF	With lifting straps	32.5 ± 10.0	17.1 ± 5.0[a]	10.2 ± 3.3[a,b]	*Execution equipment* *F* = 0.4; *P* = 0.531 ***Load*** ***F* = 152.0; *P* < 0.001**	*Execution equipment × Load* *F* = 0.2; *P* = 0.783
	Without lifting straps	32.5 ± 9.2	16.6 ± 3.8	9.5 ± 3.1		
$MV_{fastest}$ ($m{\cdot}s^{-1}$)	With lifting straps	0.95 ± 0.06	0.82 ± 0.06[a]	0.72 ± 0.06[a,b]	*Execution equipment* *F* = 3.5; *P* = 0.074 ***Load*** ***F* = 283.3; *P* < 0.001**	*Execution equipment × Load* *F* = 0.9; *P* = 0.415
	Without lifting straps	0.94 ± 0.07	0.80 ± 0.07	0.70 ± 0.06		
MV_{last} ($m{\cdot}s^{-1}$)	With lifting straps	0.53 ± 0.07	0.52 ± 0.08	0.50 ± 0.06	***Execution equipment*** ***F* = 5.2; *P* = 0.033** *Load* *F* = 1.0; *P* = 0.350	*Execution equipment × Load* *F* = 1.2; *P* = 0.283
	Without lifting straps[*]	0.48 ± 0.11	0.51 ± 0.08	0.48 ± 0.07		
$PV_{fastest}$ ($m{\cdot}s^{-1}$)	With lifting straps	1.49 ± 0.09	1.23 ± 0.09[a]	1.05 ± 0.09[a,b]	*Execution equipment* *F* = 0.5; *P* = 0.452 ***Load*** ***F* = 384.6; *P* < 0.001**	*Execution equipment × Load* *F* = 0.4; *P* = 0.665
	Without lifting straps	1.48 ± 0.10	1.23 ± 0.09	1.04 ± 0.08		
PV_{last} ($m{\cdot}s^{-1}$)	With lifting straps	0.79 ± 0.11	0.78 ± 0.12	0.75 ± 0.10	*Execution equipment* *F* = 2.0; *P* = 0.173 *Load* *F* = 1.0; *P* = 0.376	*Execution equipment × Load* *F* = 0.5; *P* = 0.602
	Without lifting straps	0.75 ± 0.13	0.76 ± 0.11	0.73 ± 0.11		

Data are presented as mean ± SD. 1RM, one-repetition maximum; *F*, Snedecor's F; *P*, *P*-values. [a], significantly lower values than 60%1RM; [b], significantly lower values than 70%1RM; [*], significantly lower values than with lifting straps ($P < 0.05$; ANOVA with Bonferroni's correction).

Table 15. Comparison of the $MV_{fastest}$ associated with each RTF between both execution equipment (with and without lifting straps) and prediction methods (multiple-point and two-point).

	Without lifting straps		With lifting straps		ANOVA		
RTF	**Multiple-point method**	**Two-point method**	**Multiple-point method**	**Two-point method**	**Execution equipment**	**Method**	**Interaction**
1	0.62 ± 0.06	0.61 ± 0.05	0.63 ± 0.05	0.62 ± 0.06	$F = 1.2$; $P = 0.270$	$F = 22.3$; $P < 0.001$	$F = 0.1$; $P = 0.708$
2	0.63 ± 0.06	0.62 ± 0.05	0.64 ± 0.05	0.63 ± 0.05	$F = 1.3$; $P = 0.255$	$F = 22.0$; $P < 0.001$	$F = 0.1$; $P = 0.707$
3	0.64 ± 0.06	0.63 ± 0.05	0.65 ± 0.05	0.64 ± 0.05	$F = 1.4$; $P = 0.242$	$F = 21.7$; $P < 0.001$	$F = 0.1$; $P = 0.707$
4	0.65 ± 0.06	0.64 ± 0.05	0.66 ± 0.05	0.65 ± 0.05	$F = 1.5$; $P = 0.232$	$F = 21.4$; $P < 0.001$	$F = 0.1$; $P = 0.707$
5	0.67 ± 0.06	0.65 ± 0.05	0.68 ± 0.05	0.66 ± 0.05	$F = 1.5$; $P = 0.224$	$F = 21.1$; $P < 0.001$	$F = 0.1$; $P = 0.706$
6	0.68 ± 0.06	0.66 ± 0.05	0.69 ± 0.05	0.67 ± 0.05	$F = 1.6$; $P = 0.219$	$F = 20.8$; $P < 0.001$	$F = 0.1$; $P = 0.706$
7	0.69 ± 0.06	0.68 ± 0.06	0.70 ± 0.05	0.68 ± 0.05	$F = 1.6$; $P = 0.217$	$F = 20.5$; $P < 0.001$	$F = 0.1$; $P = 0.706$
8	0.70 ± 0.06	0.69 ± 0.06	0.71 ± 0.05	0.69 ± 0.05	$F = 1.6$; $P = 0.219$	$F = 20.1$; $P < 0.001$	$F = 0.1$; $P = 0.705$
9	0.71 ± 0.06	0.70 ± 0.06	0.72 ± 0.05	0.71 ± 0.05	$F = 1.5$; $P = 0.223$	$F = 19.7$; $P < 0.001$	$F = 0.1$; $P = 0.705$
10	0.72 ± 0.06	0.71 ± 0.06	0.73 ± 0.05	0.72 ± 0.05	$F = 1.5$; $P = 0.230$	$F = 19.3$; $P < 0.001$	$F = 0.1$; $P = 0.705$
11	0.73 ± 0.06	0.72 ± 0.06	0.74 ± 0.05	0.73 ± 0.05	$F = 1.4$; $P = 0.240$	$F = 18.9$; $P < 0.001$	$F = 0.1$; $P = 0.704$
12	0.74 ± 0.06	0.73 ± 0.06	0.75 ± 0.05	0.74 ± 0.05	$F = 1.3$; $P = 0.252$	$F = 18.4$; $P < 0.001$	$F = 0.1$; $P = 0.704$
13	0.75 ± 0.07	0.74 ± 0.06	0.76 ± 0.05	0.75 ± 0.05	$F = 1.3$; $P = 0.267$	$F = 18.0$; $P < 0.001$	$F = 0.1$; $P = 0.704$
14	0.76 ± 0.07	0.75 ± 0.07	0.77 ± 0.05	0.76 ± 0.05	$F = 1.2$; $P = 0.283$	$F = 17.5$; $P = 0.001$	$F = 0.1$; $P = 0.703$
15	0.78 ± 0.07	0.77 ± 0.07	0.78 ± 0.05	0.77 ± 0.05	$F = 1.1$; $P = 0.301$	$F = 17.0$; $P = 0.001$	$F = 0.1$; $P = 0.703$

Data are presented as means ± SD. ANOVA, analysis of variance; *F*, Snedecor's *F; P*, *P*-values.

Table 16. Comparison of the $PV_{fastest}$ associated with each RTF between both execution equipment (with and without lifting straps) and prediction methods (multiple-point and two-point).

	Without straps		**With straps**		**ANOVA**		
RTF	**Multiple-point method**	**Two-point method**	**Multiple-point method**	**Two-point method**	**Execution equipment**	**Method**	**Interaction**
1	0.90 ± 0.10	0.87 ± 0.09	0.88 ± 0.09	0.86 ± 0.09	$F = 0.6$; $P = 0.432$	$F = 27.9$; $P < 0.001$	$F = 0.2$; $P = 0.609$
2	0.92 ± 0.10	0.89 ± 0.09	0.90 ± 0.08	0.88 ± 0.08	$F = 0.5$; $P = 0.455$	$F = 27.6$; $P < 0.001$	$F = 0.2$; $P = 0.601$
3	0.94 ± 0.10	0.91 ± 0.09	0.93 ± 0.08	0.90 ± 0.08	$F = 0.5$; $P = 0.483$	$F = 27.2$; $P < 0.001$	$F = 0.2$; $P = 0.592$
4	0.96 ± 0.10	0.93 ± 0.09	0.95 ± 0.08	0.93 ± 0.08	$F = 0.4$; $P = 0.518$	$F = 26.9$; $P < 0.001$	$F = 0.3$; $P = 0.583$
5	0.98 ± 0.09	0.95 ± 0.09	0.97 ± 0.07	0.95 ± 0.07	$F = 0.3$; $P = 0.559$	$F = 26.5$; $P < 0.001$	$F = 0.3$; $P = 0.573$
6	1.01 ± 0.09	0.97 ± 0.08	0.99 ± 0.07	0.97 ± 0.07	$F = 0.2$; $P = 0.607$	$F = 26.2$; $P < 0.001$	$F = 0.3$; $P = 0.564$
7	1.02 ± 0.09	0.99 ± 0.08	1.01 ± 0.07	0.99 ± 0.07	$F = 0.1$; $P = 0.664$	$F = 25.8$; $P < 0.001$	$F = 0.3$; $P = 0.553$
8	1.04 ± 0.09	1.01 ± 0.08	1.03 ± 0.07	1.01 ± 0.07	$F = 0.1$; $P = 0.727$	$F = 25.3$; $P < 0.001$	$F = 0.3$; $P = 0.543$
9	1.06 ± 0.09	1.03 ± 0.09	1.05 ± 0.07	1.03 ± 0.07	$F < 0.1$; $P = 0.797$	$F = 24.9$; $P < 0.001$	$F = 0.4$; $P = 0.532$
10	1.08 ± 0.09	1.06 ± 0.09	1.07 ± 0.07	1.06 ± 0.07	$F < 0.1$; $P = 0.872$	$F = 24.4$; $P < 0.001$	$F = 0.4$; $P = 0.520$
11	1.10 ± 0.09	1.08 ± 0.09	1.09 ± 0.07	1.08 ± 0.07	$F < 0.1$; $P = 0.948$	$F = 23.9$; $P < 0.001$	$F = 0.4$; $P = 0.508$
12	1.12 ± 0.09	1.10 ± 0.09	1.11 ± 0.07	1.10 ± 0.07	$F < 0.1$; $P = 0.977$	$F = 23.3$; $P < 0.001$	$F = 0.4$; $P = 0.495$
13	1.14 ± 0.10	1.12 ± 0.09	1.14 ± 0.07	1.12 ± 0.07	$F < 0.1$; $P = 0.906$	$F = 22.7$; $P < 0.001$	$F = 0.5$; $P = 0.482$
14	1.16 ± 0.10	1.14 ± 0.10	1.16 ± 0.08	1.14 ± 0.08	$F < 0.1$; $P = 0.840$	$F = 22.1$; $P < 0.001$	$F = 0.5$; $P = 0.469$
15	1.18 ± 0.10	1.16 ± 0.10	1.18 ± 0.08	1.16 ± 0.08	$F < 0.1$; $P = 0.780$	$F = 21.5$; $P < 0.001$	$F = 0.5$; $P = 0.455$

Data are presented as means ± SD. *F*, Snedecor's *F; P*, *P*-values

Discussion

The current research aims to examine whether the use of lifting straps impacts the RTF-$MV_{fastest}$ and RTF-$PV_{fastest}$ relationships constructed from different prediction methods (multiple- and two-point method). The main findings of this study revealed that: (i) individualized RTF-velocity relationships presented a higher goodness-of-fit than the generalized RTF-velocity relationships, while the goodness-of-fit was comparable between both execution equipment, and (ii) the $MV_{fastest}$ and $PV_{fastest}$ values associated with different RTFs were comparable between both execution equipment, but greater for the multiple-point compared to the two-point method. These results suggest that, while the lifting straps do not affect the goodness-of-fit of the RTF-velocity relationships or the velocity values associated with different RTFs, caution should be taken when applying different prediction methods to create the RTF-velocity relationships during the SM PBP exercise.

Supporting our first hypothesis, both execution equipment provided a greater goodness-of-fit for individualized compared to generalized RTF-velocity relationships using both $MV_{fastest}$ and $PV_{fastest}$. These findings align with a prior study by Miras-Moreno et al.[59], which also showed a stronger goodness-of-fit for individualized compared to generalized RTF-velocity relationships for both velocity variables (median r^2 = 0.96 and 0.97 for $MV_{fastest}$ and $PV_{fastest}$, respectively). Additionally, this strong linearity is consistent with other upper-body and lower-body resistance training exercises such as the SM BP (median r^2 = 0.98 for $MV_{fastest}$)[21] or FW BS exercise (median r^2 = 0.98 for $MV_{fastest}$)[43]. Specifically, it is also crucial to note that the slope and intercept from generalized RTF-velocity relationships observed in this study vary from those established by Miras-Moreno et al.[59] (RTF-axis intercept = 69.43 *vs.* 40.58 and 43.88 *vs.* 25.22; *slope* = 37.08 *vs.* 21.04 and 35.27 *vs.* 19.49 for $MV_{fastest}$ and $PV_{fastest}$, respectively), despite the fact of using the same RT exercise (*i.e.,* SM PBP) and execution equipment (*i.e.,* without lifting straps). The notable differences observed between these RTF-velocity relationships under consistent experimental conditions, underscore the paramount importance of using individualized RTF-velocity[72]. This fact may be explained by the high inter-individual RTF differences against a given %1RM whereas the $MV_{fastest}$ and $PV_{fastest}$ remains consistent across individuals (*e.g.,* while $MV_{fastest}$ was 0.95 ± 0.06 $m \cdot s^{-1}$, RTF was 32.5 ± 10.0 against the 60%1RM load; see Table 1 from referenced study for further details)[72].

Supporting our second hypothesis, the goodness-of-fit of the RTF-velocity relationships and the $MV_{fastest}$ and $PV_{fastest}$ values associated with each RTF were comparable between both execution equipment. These results may be explained by the fact that no differences were found for RTF, $MV_{fastest}$, and $PV_{fastest}$ when the SM PBP exercise was performed with and without lifting straps. These findings concur with recent studies that showed no effect of lifting straps on RTF against the 70%1RM load during the lat pull-down and the 80%1RM load during the deadlift exercise[7,88]. However, it should be also emphasized that the same absolute loads were no maintained for both execution equipment, but relative to each 1RM condition[7,88]. Therefore, it may involve comparing greater loads for lifting straps in contrast to without lifting straps. In contrast, recent results showed that using lifting straps during the deadlift exercise may show greater perceived security, power feeling, mean and peak velocity when four sets of four repetitions against the same absolute load (80%1RM)[38,42]. Additionally, Jukic et al.[41] did not report any effect of using lifting straps on mean and peak velocity recorded at a range of fixed loads (from 20% to 80% 1RM) during the deadlift exercise. It should be note that these differences showed by Jukic et al.[38,41,42] appear unrelated to the participants' strength levels and experience because the same participants were involved in these studies. However, these discrepancies may be explained because during the deadlift is easier to lift heavier loads (*i.e.,* higher recruitment of the motor units from the upper and lower body) and compromise more the grip strength than lat-pull down or PBP exercises where less load is expected to be lifted[7,10]. Collectively, these results suggests that the benefits of lifting straps may be exercise dependent and it seems that there is no effect in the RTF, $MV_{fastest}$ and $PV_{fastest}$ and consequently, no affecting to the RTF-velocity relationships during the SM PBP exercise.

In the context of VBT, the two-point method has been proposed as a quicker and less prone to fatigue method to estimate the 1RM and other load-velocity relationship variables[14,18,57]. In this regard, the strong linearity observed for the individualized RTF-velocity relationship during the SM PBP[59] and SM BP[21] exercises could justify the use the two-point method to estimate the RTF. However, contrary to our second hypothesis, the $MV_{fastest}$ and $PV_{fastest}$ values associated with each RTF showed slightly greater values for the multiple-point method (*i.e.,* modelled by three sets performed to failure) compared to two-point method (*i.e.,* modelled by two sets to failure). The higher velocity values associated with each RTF for the multiple-point method may be explained by a higher fatigue experienced by subjects when starting the third set (*i.e.,* non-performed set during the two-point method) compared to the first two sets that were common for both multiple- and two-point methods. For example, when analyzing subject-by-subject each regression model obtained during the SM PBP exercise performed without straps, the two-point method slope (98.25 ± 32.5) was slightly higher than multiple-point method slope (97.09 ± 31.8), whereas the RTF-axis intercept remains perfectly stable between both prediction methods (two-point: 59.4 ± 21.5; multiple-point: 59.3 ± 21.1). In practical terms, this means that for the same $MV_{fastest}$, the RTF would result slightly higher values for the two-point method compared to the multiple-point method probably by an increment of the fatigue during the testing procedure (*e.g.,* a determined $MV_{fastest}$ of 0.70 $m.s^{-1}$ would predict a load of 9RM for two-point method and of 8RM for multiple-point method; see **Table 15** for further details). Therefore, since fatigue affects more RTF than $MV_{fastest}$ or $PV_{fastest}$[59], it seems reasonable to determine the RTF-velocity relationship under fatigue levels similar to those typically experienced during resistance training sessions.

Even though this study provides novel insights into the influence of lifting straps on the RTF-velocity relationships obtained during the SM PBP exercise, a number of limitations must be addressed. First, since most athletes commonly use FW during their daily routine, the SM may have limited ecological validity of our results. It is important to note that during the FW exercise with greater involvement of stabilizer muscles, lifting straps may show more benefits than during machine-based exercises[27,81]. Additionally, the estimation error (difference between predicted *vs.*

performed) between the multiple-point and two-point method must be proven against different level of fatigue experienced during construction of the RTF-velocity relationships when both MV and PV are monitor. Finally, since its use does not decrease performance and may improve the grip security, is only recommended if the subject feels comfortable during the Smith machine PBP exercise.

Conclusions and practical applications

The use of lifting straps during the SM PBP exercise does not affect the goodness-of-fit of the RTF-velocity relationships or the velocity values associated with different RTFs. However, some caution should be taken when applying different prediction methods to create the RTF-velocity relationships during the SM PBP exercise. Specifically, when using the same output velocity, the estimation of the RTF from the two-point method was slightly higher than from the multiple-point method due to less fatigue experienced by the subjects during the testing procedure (two *vs.* three sets to failure). From a practical standpoint, practitioners only need to monitor the fastest velocity (*e.g.,* MV or PV) during sets performed to momentary failure against at least two distant loads (*e.g.,* 60%1RM and 80%1RM). It may be also important that the different sets used for modelling the RTF-velocity relationships are initiated under fatigue conditions similar to those that will be experienced during actual resistance training sessions (*e.g.,* one set performed to failure before the testing procedure may be realized when moderate levels of fatigue are intended).

7. Stability of the Relationship Between Maximum Repetitions to Failure and Lifting Velocity Over a 6-weeks Strength Training Program

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Brief overview

Given the relevance of fatigue-free prescription methods, VBT has emerged as a contemporary objective autoregulatory RT method that might enhance both training and testing procedures by recording the lifting velocity of repetitions performed at maximal intended velocity[15,90]. Due to its strong methodology and feasibility into an athlete's daily routine, the 1RM prediction through monitoring lifting velocity have attracted significant research attention[15,90]. However, an important limitation of this variable is that does not provide any information of the RTF for a given load (*i.e.,* high-between subject's variability of the RTF for a given %1RM)[44,72].

Recent research has also explored whether the $MV_{fastest}$ and $PV_{fastest}$ within a set may be able to predict different RTFs during the BP[21], PBP[58–60], and BS[36,43] exercises. When combining the data (RTF and $MV_{fastest}$/$PV_{fastest}$ for at least two loads) for each subject (*i.e.,* individualized RTF-velocity relationships), these authors showed a high positive linear relationship ($r^2 > 0.90$; SEE < 2 repetitions)[21,36,43,58–60]. Moreover, these RTF-velocity relationships showed a high reliability (median CV < 4.01%) for the velocity values associated with each RTF (from 1 to 15RTF) but, were measured within the same testing week[59]. Since the RTF-velocity relationships are based on RTF for at least two loads, a major problem of this approach is its feasibility within athlete's daily routine. This problem can be easily solved by showing a long stability (*i.e.,* no differences between long-term comparisons) of the individualized RTF-velocity relationships, reducing the times of testing evaluation within a season. However, to date, no previous study has explored how the RTF-velocity relationships change over long-term in real-conditions (*i.e.,* after a training protocol).

This research aimed to assess the stability of the RTF-$MV_{fastest}$ and RTF-$PV_{fastest}$ relationships after the completion of a 6-weeks strength-training during both BP and PBP exercises. Specifically, this study aimed to compare the time effect (1st *vs.* 2nd *vs.* 3rd *vs.* 4th testing session) on: (i) the goodness-of-fit (r^2 and SEE) of the RTF-$MV_{fastest}$ and RTF-$PV_{fastest}$ relationships and, (ii) the consistency of the predicted $MV_{fastest}$ and $PV_{fastest}$ values associated with 3, 9 and 15RTFs. We hypothesized that: (a) the individualized RTF-velocity relationships would show a comparable goodness-of-fit over time (r^2 and SEE) but, slightly higher for RTF-$PV_{fastest}$ compared to RTF-$MV_{fastest}$ and, (b) the $MV_{fastest}$ and $PV_{fastest}$ values associated with each RTF would show non-significant differences over time but, the $MV_{fastest}$ would show a higher stability compared to $PV_{fastest}$ values[59].

Methods

Design

A longitudinal design (3 posttests) was used to compare the stability of the individualized RTF-velocity relationships obtained during the BP and PBP exercises. The study protocol included a total of 14 sessions conducted over a 7-weeks period: 1 familiarization session + 1 pretest (week 1), 2 strength-training sessions (week 2, 4, and 6) and, 1 strength training session + 1 posttest (week 3, 5 and 7) (**Figure 18**). Both testing and training sessions were separated by at least 48 hours. The testing sessions consisted of single sets of repetitions to failure (85%1RM, 75%1RM, and 65%1RM [fixed order]) separated by five minutes of rest[58–60]. The strength training sessions consisted of 4 sets against 75%1RM, with the load weekly adjusted and varying the resting time (1-5 minutes). All the repetitions were performed with maximal intended velocity, while receiving real-time velocity performance feedback to maximize performance in each repetition[37,89]. Each session was held in the University's research laboratory, at the same time of day to prevent diurnal variations in strength performance (± 3 hours), and approximately same climatic conditions (~22ºC and ~60% humidity).

Subjects

Twenty-one (14 males and 7 females) sports science students (age = 24.9 ± 6.2 years, body mass = 73.5 ± 13.3 kg, body height = 1.73 ± 0.11 m) volunteered to participate in this study. Subjects had 4.1 ± 4.8 years of experience (1RM relative to body mass = 0.88 ± 0.30 kg [males: 1.04 ± 0.14 kg; females: 0.55 ± 0.25 kg]) of BP exercise, while 1.2 ± 2.3 years of experience (1RM relative to body mass = 0.96 ± 0.15 kg [males: 1.04 ± 0.09 kg; females: 0.76 ± 0.06 kg]) of PBP exercise ('Tier 1: Recreationally Active' based on the Mckay et al.[55] performance caliber). Although most participants were already familiar with the maximal intended lifting velocity (13 out of 21), all underwent a familiarization session with a researcher experienced in VBT methods (>3 years). No physical limitations or musculoskeletal injuries that could compromise testing were reported. Before the study, they were informed of the study procedures, signed a written informed consent form, and were asked to refrain from vigorous activity. The study's objectives were deliberately withheld to avoid any possible influence on the outcomes being examined. The study protocol adhered to the tenets of the Declaration of Helsinki and was approved by the Institutional Review Board (approval no: 0557-N-22). To quantify the stability of the RTF-velocity relationship, an *a-priori* sample size calculation conducted using G*Power 3.1.9.6 (ES = 0.20, alpha = 0.05, statistical power = 0.95, 2 number of groups, 4 number of measurements and, a correlation among repeated measurements of 0.90 revealed a total sample size of 14 subjects).

Testing procedures

Body composition and familiarization (preliminary session)

Stature (Seca 202 Stadiometer, Seca Ltd) and body mass (Tanita BC segmental; Tanita Corp, Tokyo, Japan) were measured at the beginning of the preliminary session. Afterwards, a standardized general warm-up consisted of jogging, dynamic stretching, upper- and lower-body joint-mobilization exercises, and 2 sets (one for each exercise) of 5 repetitions with an external load of 20kg were performed. Then, in a randomized order, a specific warm-up based on progressive increments of 10 kg until reaching a $MV_{fastest}$ below 0.50 $m \cdot s^{-1}$ and 0.80 $m \cdot s^{-1}$ for the BP and PBP exercises, respectively[58–60].

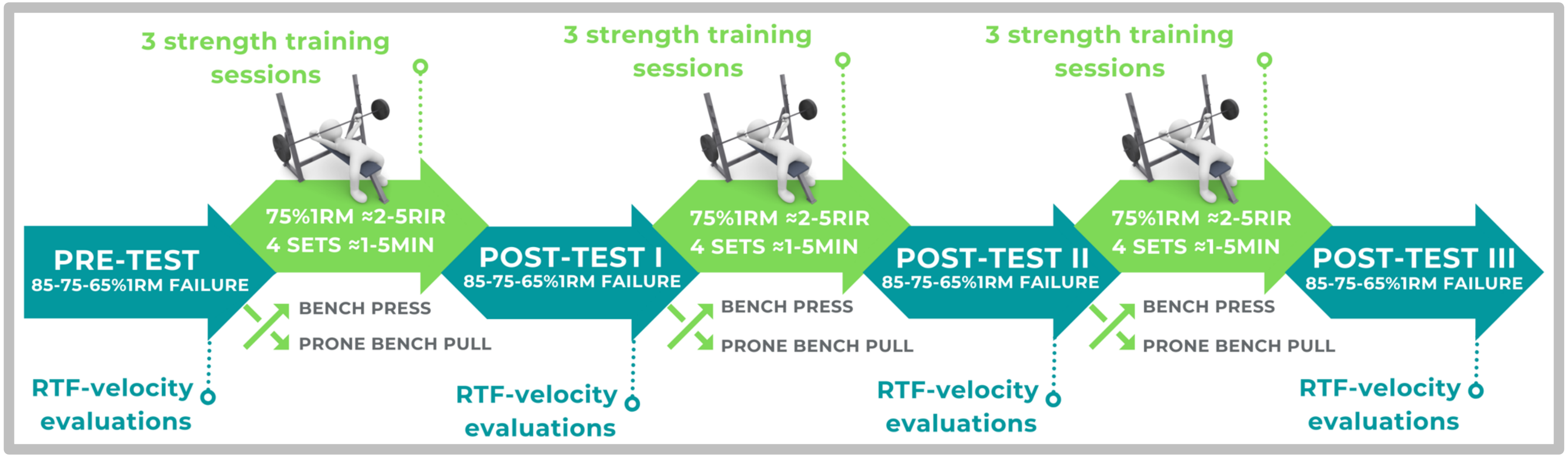

Figure 18. Overview of the experimental design from study 7.

In that moment, smaller increments from 5 to 1 kg were applied until the 1RM was directly achieved[21,58–60]. From that point on, in a randomized exercise order, 3 sets reaching momentary failure (85-75-65%1RM) and separated by 5 minutes were performed[58,60].

The BP and PBP exercises were performed using a SM (Multipower Fitness Line, Peroga, Murcia, Spain) and calibrated technique plates (Ruster Fitness, Jaén, Spain). During the BP exercise, subjects initiated the task using the standard five-point body contact position technique (head, upper back, and buttocks placed firmly on the bench with both feet flat on the floor). Subjects used a self-selected grip width, with their elbows fully extended and, they were not allowed to bounce the barbell off their chests[21,37]. During the PBP exercise, subjects lied down in a prone position, the chin in contact with the bench, elbows fully extended, and a prone grip of the barbell slightly wider than shoulder width[58,60]. From that position, subjects were instructed to pull the barbell as quickly as possible until it contacted the underside of the bench (thickness of 5.2 cm). The legs were held during all repetitions by using a rigid strap on the calves, strap to avoid the legs movement and facilitate the upper-limbs force application[58,60].

1RM and RTF-velocity assessment (4 testing sessions)

The same abovementioned general and specific warm-up was performed for determining the 1RM on each testing session. After 5 minutes of resting, in a randomized order, subjects performed the same abovementioned procedure of sets to momentary failure (fixed order: 85-75-65%1RM) for constructing the individualized RTF-$MV_{fastest}$ and RTF-$PV_{fastest}$ relationships (**Figure 19 and 20**)[58,60]. Rest periods of 5 minutes were implemented between sets and exercises. On each repetition, verbal performance feedback (*i.e.,* $MV_{fastest}$ on each repetition) and verbal encouragement (*e.g.,* 'Come on, push it!') was provided to encourage maximal effort[37]. The velocity values were provided by a validated linear position transducer (GymAware RS, Kinetic Performance Technologies, Canberra, Australia) that directly sampled the displacement-time data which automatically calculate the $MV_{fastest}$ and $PV_{fastest}$[33].

Strength training sessions (training sessions)

The same abovementioned general and specific warm-up was performed for determining the 1RM on each testing session. Subjects were allowed to rest for 10 min between 1RM determination and the initiation of the first set of the training. To attempt to replicate training under real-world conditions, the intensity was daily adjusted (75%1RM [strength-training]) but, it was randomly combined with different MVT (BP: 0.35 $m \cdot s^{-1}$ or 0.45 $m \cdot s^{-1}$; PBP: 0.55 $m \cdot s^{-1}$ or 0.65 $m \cdot s^{-1}$) and inter-set resting time (1, 3, or 5 minutes) (undulating programming). Please, note that during the: (i) BP exercise: $MV_{fastest} < 0.45$ $m \cdot s^{-1}$ subjects are able to perform 6 additional repetitions, while $MV^{fastest} < 0.35$ $m \cdot s^{-1}$ subjects can complete on average 4 more repetitions before reaching failure; (ii) PBP exercise: $MV_{fastest} < 0.55$ $m \cdot s^{-1}$ subjects are unlikely to perform any more successful repetitions, while $MV < 0.65$ $m \cdot s^{-1}$ subjects can complete on average 2-3 more repetitions before reaching failure [21,72].

Statistical Analysis

The data's normal distribution was confirmed using the Shapiro-Wilk test ($P > 0.05$). Least square linear regression models were used to determine the RTF-$MV_{fastest}$ and RTF-$PV_{fastest}$

relationships for each exercise[21,36,43,58–60]. The goodness-of-fit of the individualized RTF-velocity relationships was evaluated through the r^2 and SEE, presented as range values. Two-way ANOVA (time [1st, 2nd, 3rd, and 4th session] × velocity variable [$MV_{fastest}$ vs. $PV_{fastest}$]) were conducted on the Fisher's *Z*-transformed from the *r* values and SEE to assess the stability of the goodness-of-fit over time from the RTF-velocity relationships[58].

Two-way repeated-measures ANOVA (time [1st, 2nd, 3rd, and 4th session] × RTF [3RTF *vs.* 9RTF *vs.* 15RTF]) were conducted on the $MV_{fastest}$ and $PV_{fastest}$ associated to 3RTF, 9RTF and 15RTF to assess the stability of the velocities predicted. The Greenhouse-Geisser correction was applied when Mauchly's sphericity test was violated, while pairwise comparisons considered Bonferroni post-hoc corrections. To avoid overestimation, the magnitude of the differences was evaluated using the Hedges's *g* ES calculated as the means difference divided by the pooled SD, which was interpreted according to conventions of Cohen: *trivial* (< 0.20), *small* (0.20–0.59), *moderate* (0.60–1.19), *large* (1.20–2.00), or *very large* (> 2.00)[31]. The *r* depicted through the range values were used to quantify the association between pre–post (1st *vs.* 2nd, 1st *vs.* 3rd, and 1st *vs.* 4th session) for the predicted velocity values associated to each RTF. The criteria for interpreting the magnitude of the *r* coefficients were as follows: *trivial* (0.00–0.09), *small* (0.10–0.29), *moderate* (0.30–0.49), *large* (0.50–0.69), *very large* (0.70–0.89), *nearly perfect* (0.90–0.99), and *perfect* (1.00)[31].

The R^2 from the Bland-Altman plots with the 95% limits of agreement (*LoA*) technique (bias ±1.96×SD) was used to assess the heteroscedasticity of the errors defined as a $R^2 > 0.1$[23,52]. Statistical analyses were performed using the software package SPSS (IBM SPSS version 28.0, Chicago, IL). The graphs were made using a custom spreadsheet in Microsoft Excel together with R version 4.4.1 and RStudio version 2024.04.2+764 using the *ggplot2* package[31,93]. Statistical significance was set at $P < 0.05$.

Results

The goodness-of-fit of the individualized RTF-velocity relationships were very high for BP (RTF-$MV_{fastest}$ relationship: range r^2 = 0.96–0.99 and range SEE = 0.60–1.02 repetitions; RTF-$PV_{fastest}$ relationship: range r^2 = 0.91–0.96 and range SEE = 0.76–1.31 repetitions) and PBP exercises (RTF-$MV_{fastest}$ relationship: range r^2 = 0.96–0.98 and range SEE = 1.42–1.89 repetitions; RTF-$PV_{fastest}$ relationship: range r^2 = 0.96–0.98 and range SEE = 1.26–1.58 repetitions), irrespective of time or velocity variables used (**Figure 21**).

Regarding the comparison of the goodness-of-fit, no significant interactions of time × velocity variable were showed ($F \leq 2.5$; $P \geq 0.064$), regardless of the RT exercise (**Figure 22**). The time effect did not show statistical significance, except for the SEE values for the BP exercise ($F = 3.8$; $P = 0.03$) due to moderate higher SEE values of session 4, compared to session 2 ($P = 0.04$; ES = -0.74 [-1.38, -0.10]) and session 3 ($P < 0.01$; ES = -0.90 [-1.55, -0.25]).

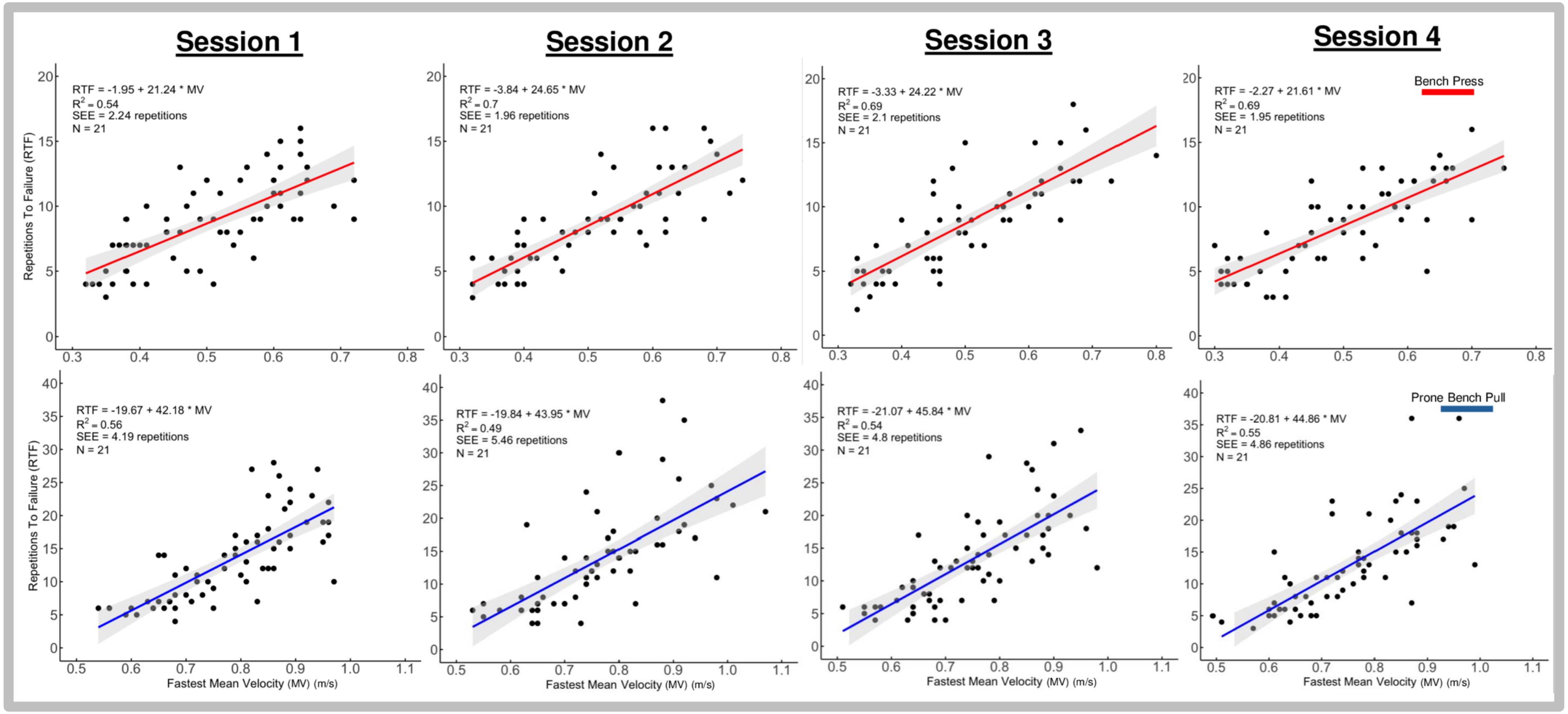

Figure 19. Generalized RTF-$MV_{fastest}$ relationships along the time with their respective upper and lower 95% confidence intervals (shaded area).

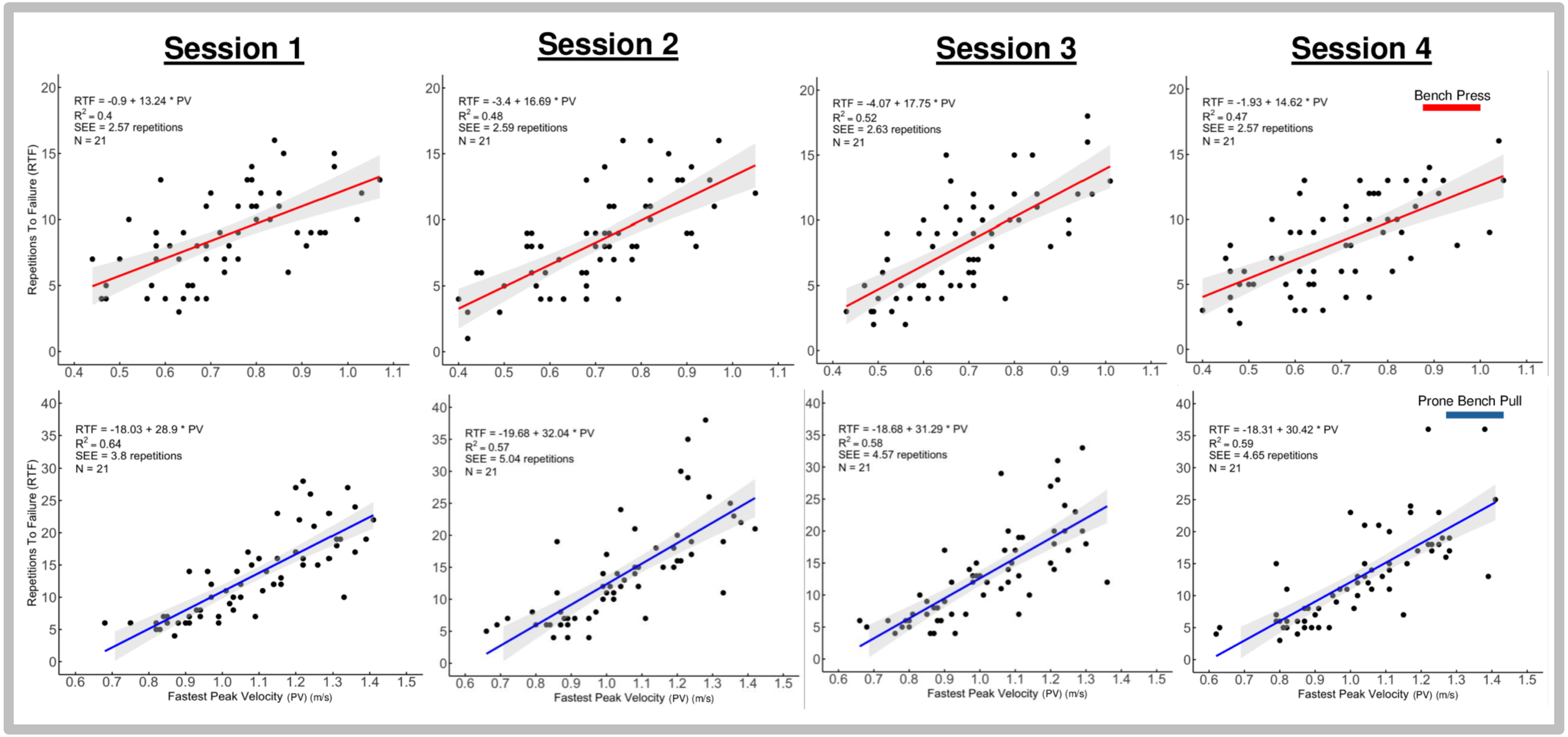

Figure 20. Generalized RTF-PV$_{fastest}$ relationships along the time with their respective upper and lower 95% confidence intervals (shaded area).

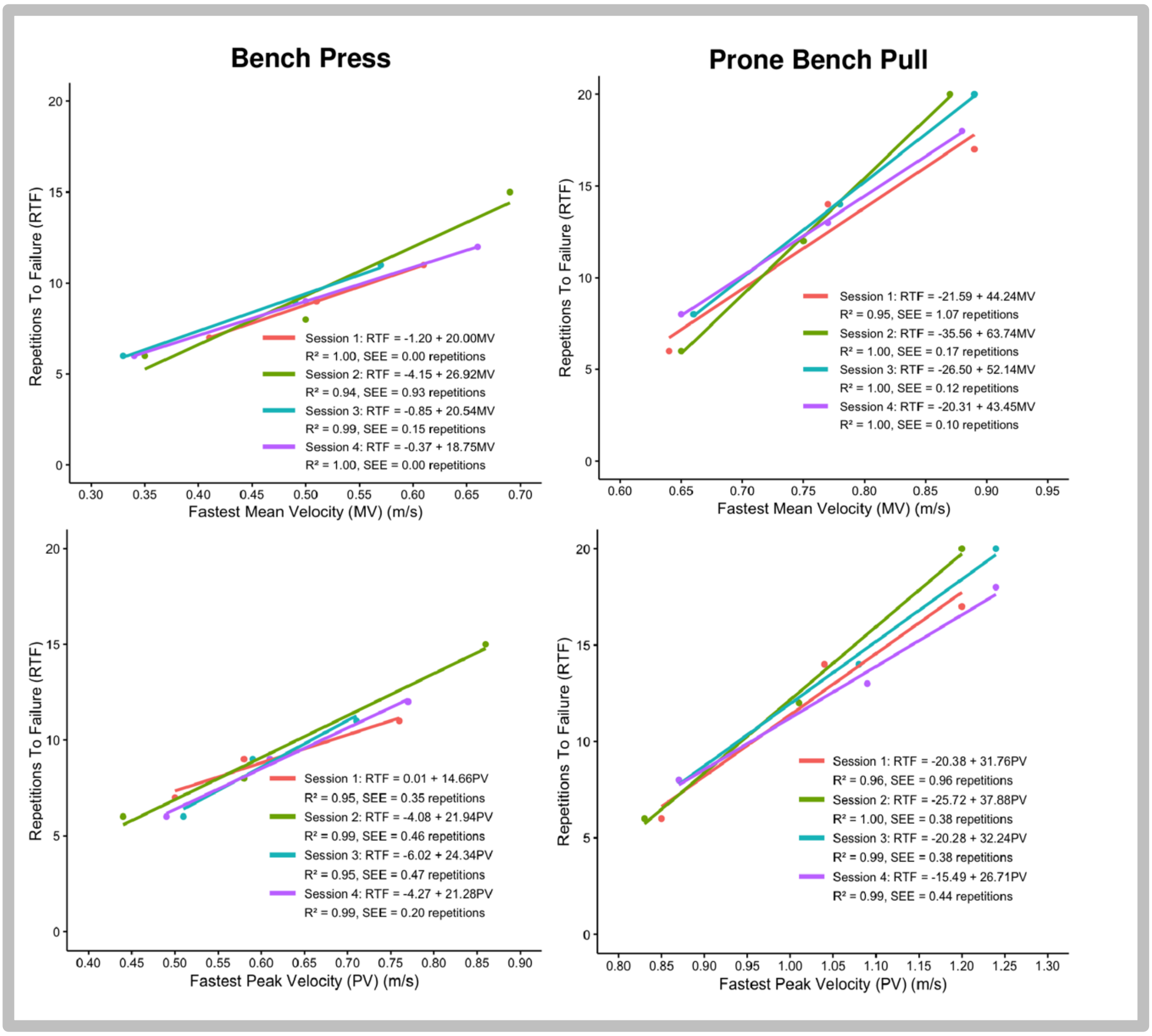

Figure 21. Individualized RTF-velocity relationships along the time from a representative subject.

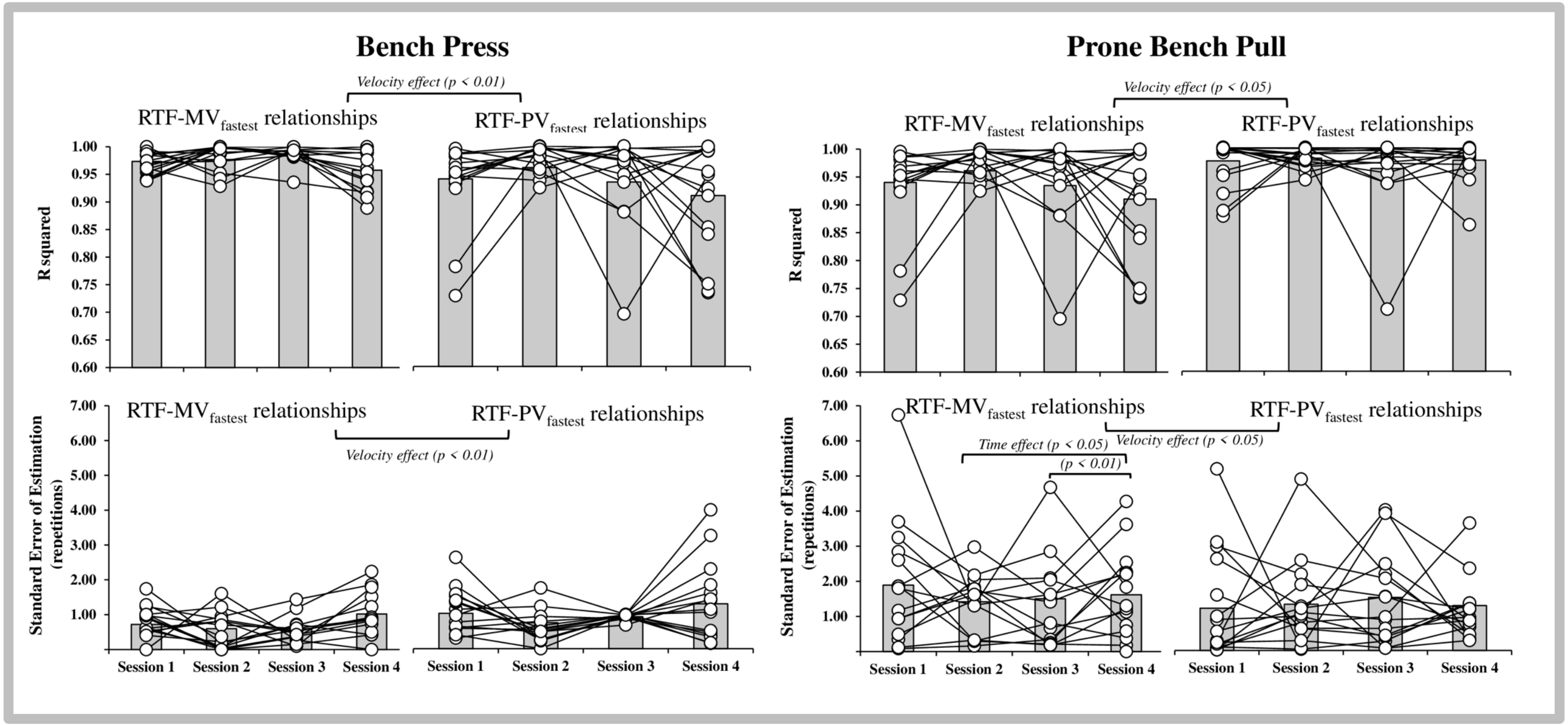

Figure 22. Two-way repeated measures ANOVA time (1st, 2nd, 3rd, and 4th session) × velocity variable ($MV_{fastest}$ and $PV_{fastest}$), comparing the goodness-of-fit through the r^2 and SEE along 6 weeks of strength-training.

The velocity variable effect showed significant differences for all the r^2 and SEE values for both exercises ($F \geq 4.5$; $P \leq 0.047$), due to a higher goodness-of-fit for BP exercise when using the $MV_{fastest}$ (r^2: $P < 0.01$, ES = 0.58 [0.27,0.89]; SEE: $P < 0.01$, ES = -0.44 [-0.75,-0.13]) whereas the $PV_{fastest}$ provided a higher goodness-of-fit for the PBP exercise (r^2: $P < 0.01$, ES = -0.15 [-0.46,0.15]; SEE: $P < 0.01$, ES = 0.15 [-0.15, 0.46]).

Regarding the comparison of the $MV_{fastest}$ and $PV_{fastest}$ associated to 3RTF, 9RTF and 15RTF, no significant interactions of time × RTF value were showed ($F \leq 0.7$; $P \geq 0.637$), regardless of the RT exercise (**Figure 23**). The time effect showed only significant differences for PBP exercise ($F \geq 5.7$; $P \leq 0.002$), due to small higher $MV_{fastest}$ ($P < 0.001$; ES ≤ 0.25) and $PV_{fastest}$ values ($P < 0.001$; ES ≤ 0.32) from session 1 compared to other sessions. The RTF effect showed significant ($F \geq 154.1$; $P < 0.001$) for all the RT exercises and velocities, due to higher velocities of 15RTF compared to 9RTF or 3RTF ($P < 0.001$; range ES = 1.33–4.13). Most of the associations (32 out of 36) between the velocities obtained during the 1st session and other sessions, revealed significant moderate to nearly perfect positive associations (range r = 0.470–0.930) (**Figure 23**).

When comparing the predicted $MV_{fastest}$ values to different RTFs over time (1st *vs.* 2nd, 1st *vs.* 3rd and, 1st *vs.* 4th sessions), Bland-Altman plots revealed a very low systematic bias (ranging from 0.003 to 0.039 $m.s^{-1}$), from low to moderate random errors (PBP: ranging from 0.028 to 0.074 $m.s^{-1}$; BP: ranging from 0.053 to 0.122 $m.s^{-1}$) and, heteroscedasticity of the errors was presented for 9RTF and 15RTF ($R^2 \geq 0.115$) during BP exercise (**Figure 24**).

When comparing the predicted $PV_{fastest}$ values to different RTFs over time (1st *vs.* 2nd, 1st *vs.* 3rd and, 1st *vs.* 4th sessions), Bland-Altman plots revealed low systematic bias (ranging from 0.002 to 0.072 $m.s^{-1}$), from low to moderate random errors (PBP: ranging from 0.036 to 0.099 $m.s^{-1}$; BP: ranging from 0.059 to 0.135 $m.s^{-1}$) and, heteroscedasticity of the errors was presented for 3RTF and 9RTF ($R^2 \geq 0.100$) during BP exercise (**Figure 25**).

Discussion

The current study explored the impact of time during a 6-weeks strength-training protocol on the stability of: (i) the goodness-of-fit from individualized RTF-velocity relationships and, (ii) the predicted velocity values associated for a given RTF. The main's study findings revealed that: a) the goodness-of-fit from individualized RTF-velocity relationship showed to be high and stable over time, b) the goodness-of-fit appears to be influenced by the interaction of the lifting velocity variable with exercise type (the highest fit for $MV_{fastest}$ was observed during BP, while the highest fit for $PV_{fastest}$ was shown during PBP) and, c) the predicted $MV_{fastest}$ and $PV_{fastest}$ values remained stable over time for BP and PBP exercise, except for a velocity decreasing trend when the 1st session is compared with others sessions during PBP exercise. Collectively, our results suggests that the goodness-of-fit of individualized RTF-velocity relationships and the predicted $MV_{fastest}$/$PV_{fastest}$ values are highly stable but, when the technique experience is low for a given exercise, it is recommended its periodic evaluation due to a possible RTFs overestimation.

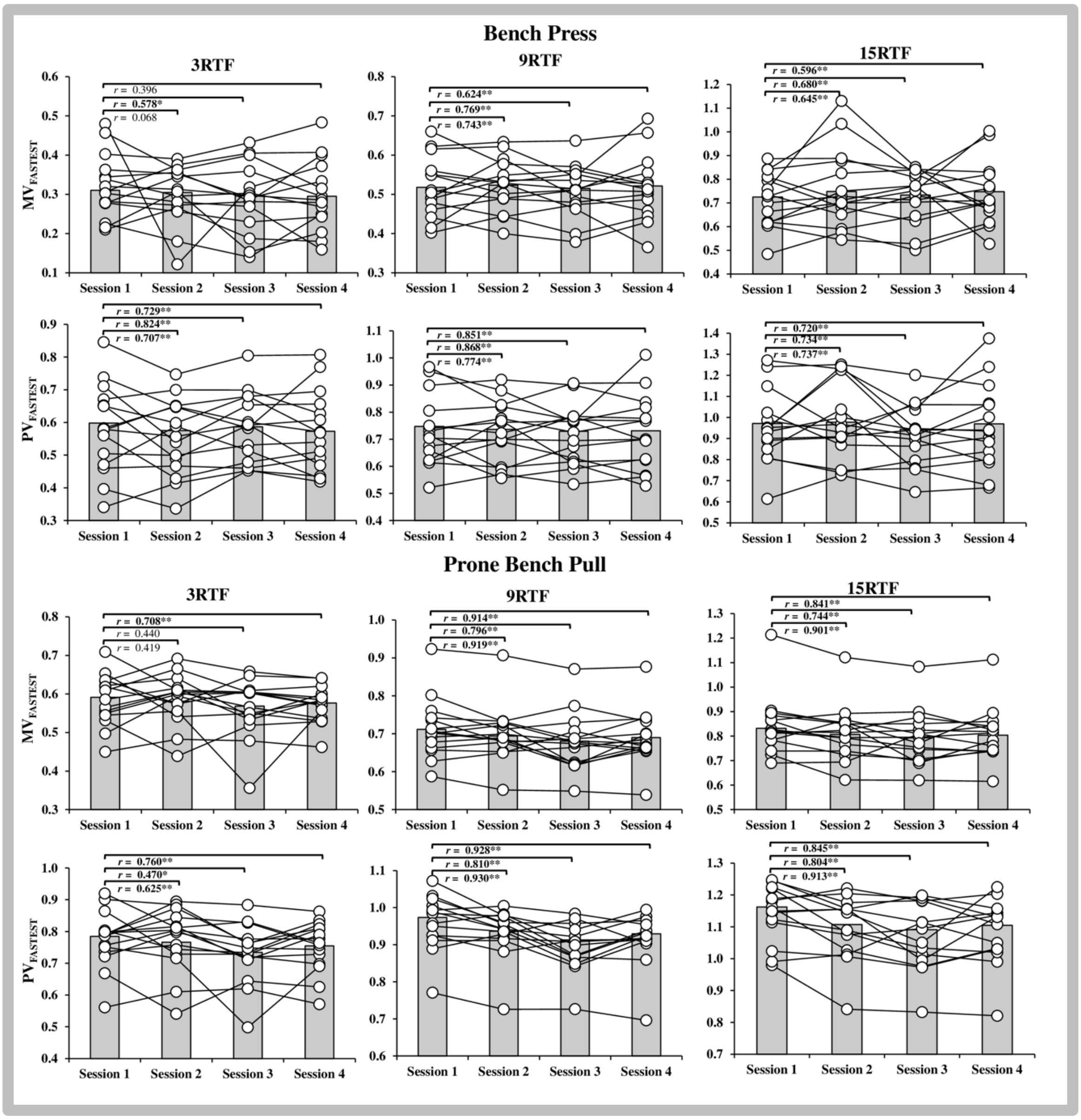

Figure 23. Comparison of the predicted $MV_{fastest}$ and $PV_{fastest}$ associated to 3RTF, 9RTF, and 15RTF during the BP and PBP along 6 weeks of strength-training.

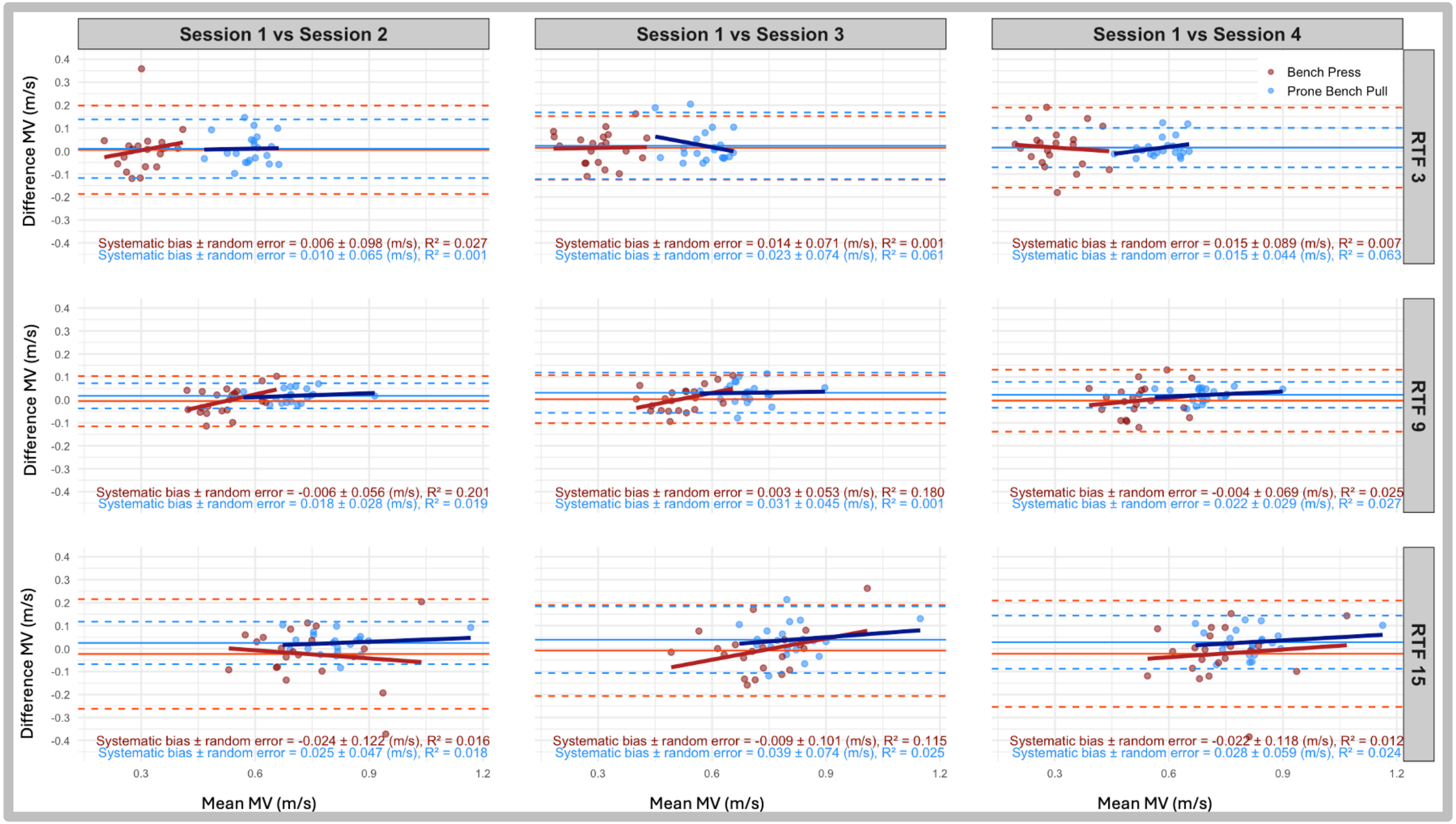

Figure 24. Bland–Altman plots comparing the $MV_{fastest}$ associated to the RTF between the sessions 1st *vs.* 2nd , 1st *vs.* 3rd and, 1st *vs.* 4th sessions. The Bland–Altman plot depicts the systematic bias and 95% limits of agreement (±1.96; dashed lines), along with the regression line (solid line). 95% CI, 95% confidence interval; R2, coefficient of determination from Bland-Altman plots.

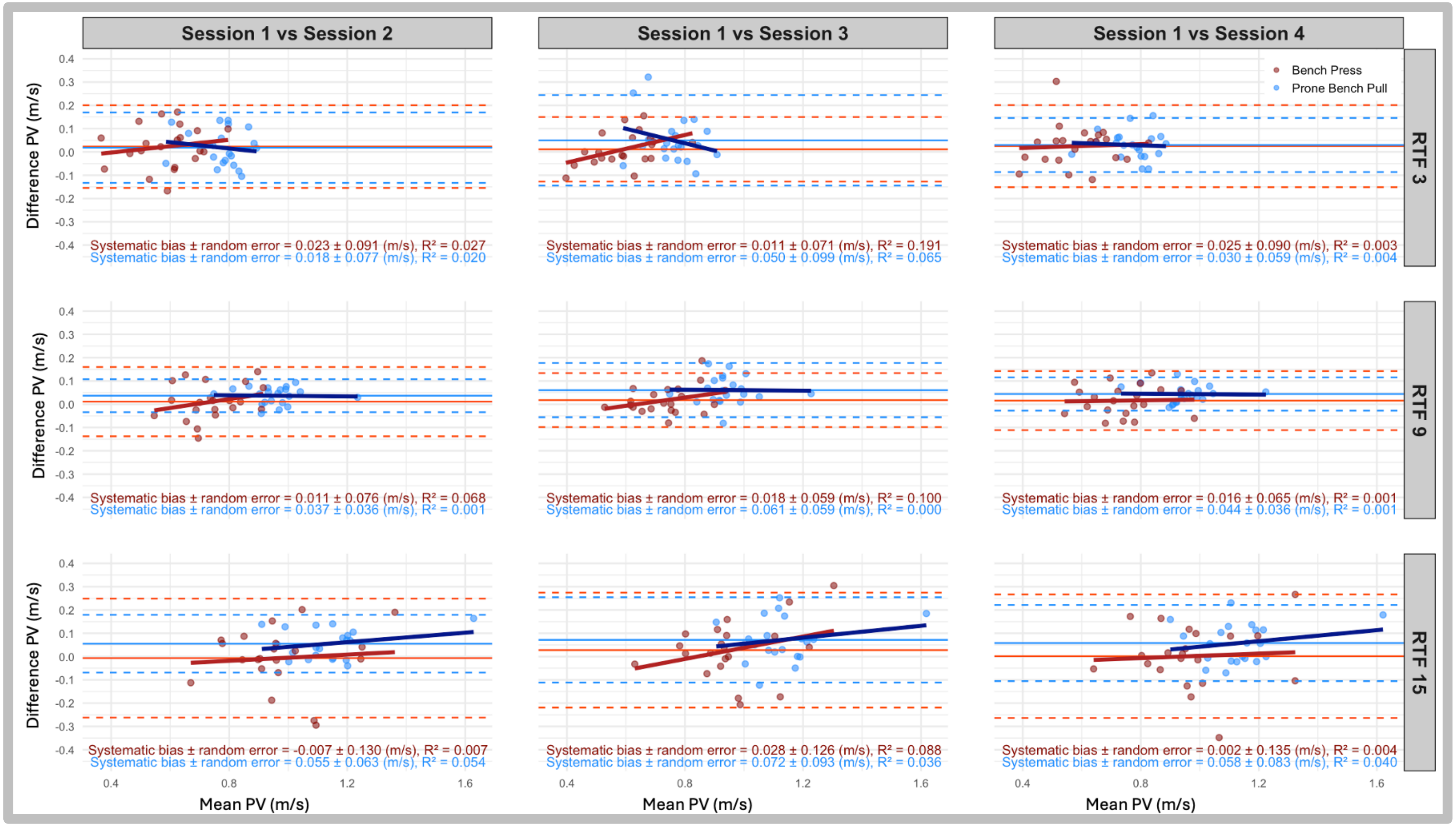

Figure 25. Bland–Altman plots comparing the $MV_{fastest}$ associated to the RTF between the sessions 1st *vs.* 2nd , 1st *vs.* 3rd and, 1st *vs.* 4th sessions. The Bland–Altman plot depicts the systematic bias and 95% limits of agreement (±1.96; dashed lines), along with the regression line (solid line). 95% CI, 95% confidence interval; R2, coefficient of determination from Bland-Altman plots.

Our first hypothesis was confirmed because the use of both velocity variables ($MV_{fastest}$ and $PV_{fastest}$) revealed an almost perfect goodness-of-fit of individualized RTF-velocity relationships which remained stable over time. These findings align with previous studies by Miras-Moreno et al.[58,59] which showed a linear (from 1 to 30 RTFs), high (*i.e.,* high r^2 and low SEE) and stable (*i.e.,* session-to-session comparisons) relationship over the same testing week, irrespective of the lifting velocity variable used. Similarly, our study extends these findings by suggesting that the goodness-of-fit of these relationships remains stable over a longer period (7 weeks) and is unaffected by a strength training protocol.

In the VBT context, a critical methodological consideration for modelling the load-velocity relationship is choosing the best lifting velocity variable which directly impact its linearity[15,19]. In this regard, there is a clear consensus that $PV_{fastest}$ is recommended for measuring the performance in ballistics movement[15,19]. The rationale behind this matter is to avoid including extra displacement of the linear encoder when the athlete is not applying any force to the barbell (*e.g.,* during a BP throw, at the moment the athlete loses contact with the barbell)[15,19]. The recent literature from the RTF-velocity relationships, revealed a comparable goodness-of-fit and between-session reliability for both $MV_{fastest}$ and $PV_{fastest}$ during the PBP exercise[58,59]. However, our results showed an interaction between the lifting velocity variable with exercise type that may affect to the fit over time (highest fit for $MV_{fastest}$ was observed for BP, while the highest fit for $PV_{fastest}$ for PBP). These results may be partially explained by the natural tendency to lift at maximum intended velocity during the PBP exercise (*i.e.,* during light-moderate loads the bench tends to slightly 'jump', including an extra displacement into the calculation of $MV_{fastest}$). Please, note that the $PV_{fastest}$ is not affected by this issue, as its value is typically monitored far away from the contact with the bench (see this study for further velocity-time curve information[78]). In contrast, the $PV_{fastest}$ during the BP exercise is generally achieved near to the end of the concentric phase, making it more sensitive to the 'trunk off the bench' effect when attempting to lift at maximum intended velocity[78]. Because of its paramount importance on the stability of these RTF-velocity relationships, further research is warranted to explore which lifting velocity variables are recommended for the main RT exercises.

Partially supporting our second hypothesis, the $MV_{fastest}$ and $PV_{fastest}$ values remained stable over time during the BP and PBP exercise, regardless of the increment in the 1RM after the 6-weeks strength training (BP: mean differences [PRE-POST3] = 14.6 ± 10.9 kg; PBP: mean differences [PRE-POST] = 7.6 ± 4.5 kg). However, it should be noted that a trend of lower velocity values was observed when comparing the 1st with the other sessions during the PBP exercise (**Figure 26 and 27**). These results are in contrast with those from Miras-Moreno et al.[59] which found a high reliability of the $MV_{fastest}$ and $PV_{fastest}$ values associated to a given RTF (median CV = 4.01% and 3.98%, respectively) within the same testing week.

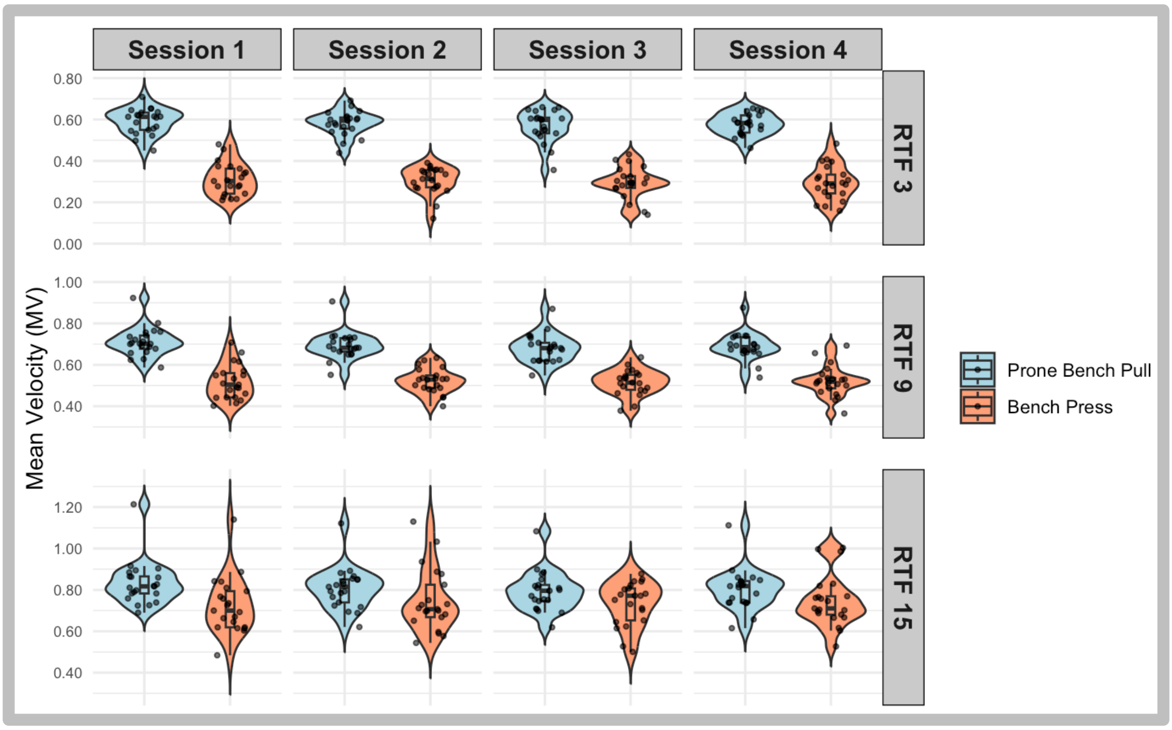

Figure 26. Violin plots depicting the predicted $MV_{fastest}$ of the set associated 3RTF, 9RTF and 15RTF during along 6 weeks of strength-training. The shape and spread of the violins represent the distribution and variability of mean velocities within each session while the embedded box plots highlight the median, interquartile range, and outliers within each group.

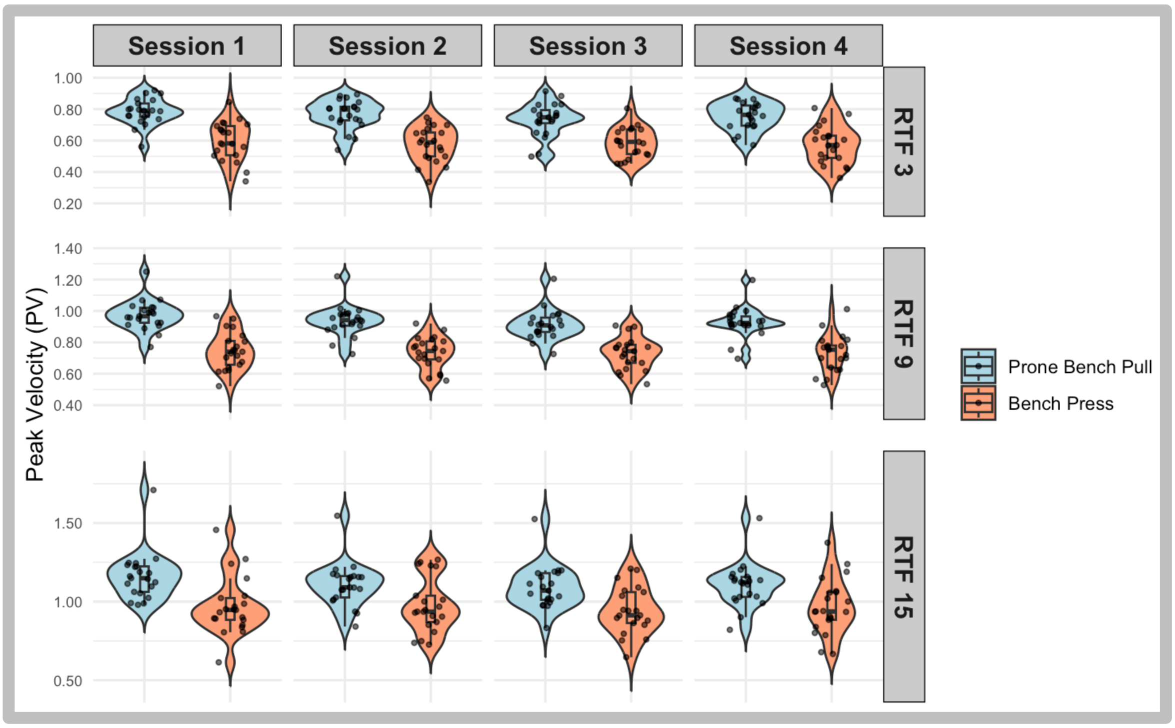

Figure 27*.* Violin plots depicting the predicted $PV_{fastest}$ of the set associated 3RTF, 9RTF and 15RTF during along 6 weeks of strength-training. The shape and spread of the violins represent the distribution and variability of mean velocities within each session while the embedded box plots highlight the median, interquartile range, and outliers within each group.

This issue can be explained by the interaction of four factors that may affect to the long-terms PBP stability when is compared to BP: (i) *degrees of freedom involved*: the back flexion included in the PBP may increase the complexity of the movement (*i.e.,* neuromuscular coordination)[28,60], (ii) *subject's grip strength*: grip strength may limit performance during pulling exercises against heavy loads leading to an early muscular failure[7], (iii) *subject's exercise and training experience:* the above mentioned complexity of the PBP exercise, together with the very low experience of the subjects (1.2 ± 2.3 years of experience) may help to explain the differences obtained during the 1st sessions compared with other sessions which remained stable (2nd *vs.* 3rd *vs.* 4th sessions). Future studies should explore these phenomena in other RT exercises and with different training protocols.

Despite the encouraging results for the great stability from individualized RTF-velocity relationships for the BP and PBP exercises, readers should be aware of several limitations and literature gaps that need further addressed. First, the use of a SM reduces the degrees of freedom and consequently, it may help to demonstrate a greater stability from the RTF-velocity relationships. Second, the estimation accuracy (difference between predicted *vs.* performed) of the RTF-velocity relationships have not assessed in this study and may differ from those found from a practical standpoint[59,60]. Complementary, despite of not being a limitation of the study, there are other points that coaches should keep in mind when analyzing the stability of the RTF-velocity relationships: (i) *number of the loads*: higher velocities associated to a given RTF have been found with the increments of the experimental points (*i.e.,* loads) included into the modelling procedure (*i.e.,* multiple- vs. two-point methods)[58,60] and, (ii) athlete's experience: it seems to be the most critical factor when assessing the RTF-velocity relationships, since a recent study revealed the lowest absolute errors observed in the current literature (~ 1 repetition) for high-level wrestlers[36].

Conclusions and practical applications

The findings of the present study revealed that individualized RTF-velocity relationships consistently demonstrated a high goodness-of-fit over time. However, it seems that the selection of an adequate lifting velocity variable for each exercise, can improve its goodness-of-fit (RTF-$MV_{fastest}$ relationships were most consistent for BP but, RTF-$PV_{fastest}$ relationships were for PBP). The predicted $MV_{fastest}$ and $PV_{fastest}$ values remained stable over time for BP and PBP exercise, except for a velocity decreasing trend when the 1st session is compared with other sessions during PBP exercise (2nd *vs.* 3rd *vs.* 4th sessions). Due to the lack of experience of the sample with PBP exercise, our results suggests that exercise experience plays a crucial role on the RTF-velocity relationships on the early stages of training.

Conclusions / Conclusiones

This doctoral thesis has been organized into seven studies based on the following conclusions:

Study I: *Can Lifting Velocity Predict Repetitions to Failure? A Systematic Review.*

Conclusion 1: Individualized RTF-velocity relationships demonstrate a higher goodness-of-fit and more accurate RTF predictions compared to generalized models. These individualized relationships also show a range from acceptable to high between-session reliability for velocity values associated with specific RTFs (from 1–15 RTF).

Conclusion 2: Although the accuracy of RTF-velocity relationships under fatigue-free conditions is generally acceptable, it is significantly compromised by varying levels of fatigue during the training sessions aimed to predict (fatigue affects more to RTF than velocity). However, it is important to note that prediction errors due to fatigue may be minimized when assessing athletes with extensive RT experience.

Conclusion 3: The basic properties of the RTF-velocity relationships seem to be unaffected using different equipment (SM *vs.* FW), lifting velocity variables ($MV_{fastest}$ *vs.* $PV_{fastest}$), magnitude of the loads analyzed (from 60% to 90%1RM), number of sets (from 3 to 4 sets), and resting time (from 5 to 10 minutes) used for the equation's construction.

Study II: *Lifting Velocity as a Predictor of the Maximum Number of Repetitions That Can Be Performed to Failure During the Prone Bench Pull Exercise.*

Conclusion 3: The individualized RTF-velocity relationships revealed a higher goodness-of-fit and greater accuracy in the prediction of the RTF than generalized RTF-velocity relationships.

Conclusion 4: The very high reliability of both $MV_{fastest}$ and $PV_{fastest}$ values associated with different RTF, suggest that the individualized RTF-velocity relationship can be used for prescribing the loads to match a specific XRM during the PBP exercise performed in a SM.

Conclusion 5: The systematic overestimation in the prediction of the RTF under fatigued conditions requires more scientific attention to further refine the testing procedure of the individualized RTF-velocity relationship.

Study III: *Lifting Velocity Predicts the Maximum Number of Repetitions to Failure With Comparable Accuracy During the Smith Machine and Free-Weight Prone Bench Pull Exercises.*

Conclusion 6: The RTF-$MV_{fastest}$ relationships allow RTFs to be predicted with similar accuracy during the SM and FW variants of the PBP exercise, opening up the possibility of using this RT prescription method during FW RT exercises.

Conclusion 7: The RTF-$MV_{fastest}$ relationships are sensitive to fatigue with greater fatigue levels affecting RTF more than $MV_{fastest}$. Therefore, RTF-$MV_{fastest}$ relationships should be determined under fatigue conditions resembling those experienced during training.

Conclusion 8: The assessment of RTF and $MV_{fastest}$ against only two different loads (*e.g.,* 90%1RM and 70%1RM) with long inter-set rest periods (*e.g.,* 10 minutes), is recommended to be used during RT sessions in which the level of fatigue is low or moderate (*e.g.,* sets not performed to failure).

Study IV: *Exploring the Relationship Between Maximum Number of Repetitions and Fastest Lifting Velocity During the Prone Bench Pull: Are They Affected by the Stretch-shortening Cycle?*

Conclusion 9: The incorporation of the SSC does not compromise the goodness-of-fit of individualized RTF-velocity relationships. However, for practitioners wanting to create RTF tables and control the proximity to failure for different athletes, RTF-velocity relationships that consider each type of muscle action should be constructed separately given the greater fatigue induced by the eccentric-concentric compared to the concentric-only PBP.

Conclusion 10: The $PV_{fastest}$ may offer a higher goodness-of-fit during the PBP exercise, but such minor differences may not be significant from a practical standpoint

Conclusion 11: The construction of RTF relationships can be obtained using the two-point method (*i.e.,* only a single set of 60% and 80% of 1RM performed to failure).

Study V: *The Effect of Lifting Straps on the Prediction of the Maximal Neuromuscular Capabilities and 1 Repetition Maximum During the Prone Bench Pull Exercise.*

Conclusion 12: The use of lifting straps during the PBP exercise does not impact the magnitude of the maximal neuromuscular capacities (L_0, v_0, and A_{line}) or the 1RM prediction when constructed from the individual L-V relationship.

Conclusion 13: The two-point method applied in field conditions (*i.e.,* using only two loads), not only yields L-V relationship variables of greater magnitude but also offers a more precise estimation of the 1RM compared to the multiple-point method. The 1RM prediction accuracy was generally enhanced when using the average optimal MVT compared to general and individual MVTs.

Study VI: *Impact of Lifting Straps on the Relationship Between Maximum Repetitions to Failure and Lifting Velocity During the Prone Bench Pull Exercise.*

Conclusion 14: The use of lifting straps during the SM PBP exercise does not affect the goodness-of-fit of the RTF-velocity relationships or the velocity values associated with different RTFs.

Conclusion 15: The estimation of the RTF from the two-point method was slightly higher than from the multiple-point method due to less fatigue experienced by the subjects during the testing procedure (two *vs.* three sets to failure).

Study VII: *Stability of the Relationship Between Maximum Repetitions to Failure and Lifting Velocity Over a 6-weeks Strength Training Program.*

Conclusion 16: The individualized RTF-velocity relationships consistently demonstrated a high goodness-of-fit over time. However, it seems that the selection of an adequate lifting velocity variable for each exercise, can improve its goodness-of-fit (RTF-$MV_{fastest}$ relationships were most consistent for BP but, RTF-$PV_{fastest}$ relationships were for PBP).

Conclusion 17: Exercise experience plays a crucial role on the RTF-velocity relationships on the early stages of training. The predicted $MV_{fastest}$ and $PV_{fastest}$ values remained stable over time for BP and PBP exercise, except for a velocity decreasing trend when the 1st session is compared with other sessions during PBP exercise (2^{nd} *vs.* 3^{rd} *vs.* 4^{th} sessions).

/

Tesis doctoral organizada en siete estudios en base a las siguientes conclusiones:

Estudio I: *¿Puede la velocidad de ejecución predecir las repeticiones hasta el fallo (RFM)? Una revisión sistemática.*

Conclusión 1: Las relaciones individualizadas RFM-velocidad demuestran una mayor bondad de ajuste y predicciones de RFM más precisas en comparación con los modelos generalizados. Estas relaciones individualizadas también muestran una fiabilidad entre sesiones que va de aceptable a alta para los valores de velocidad asociados con RFM específicas (de 1 a 15 RFM).

Conclusión 2: Aunque la precisión de las relaciones RFM-velocidad en condiciones sin fatiga es generalmente aceptable, se ve significativamente comprometida por los niveles variables de fatiga durante las sesiones de entrenamiento que se pretende predecir (la fatiga afecta más a las RFM que a la velocidad). Sin embargo, es importante señalar que los errores de predicción debidos a la fatiga pueden minimizarse al evaluar a atletas con amplia experiencia en entrenamiento de resistencia.

Estudio II: *Velocidad de ejecución como predictor del número máximo de repeticiones que se pueden realizar hasta el fallo durante el ejercicio de remo tumbado.*

Conclusión 3: Las relaciones individualizadas entre RFM-velocidad revelaron una mayor bondad de ajuste y una mayor precisión en la predicción de la RFM que las relaciones generalizadas entre RFM y velocidad.

Conclusión 4: La muy alta fiabilidad de las velocidades asociadas con diferentes RFM sugiere que la relación individualizada RFM-velocidad puede utilizarse para prescribir las cargas que coincidan con un XRM específico durante el ejercicio de remo tumbado en MS.

Conclusión 5: La a sobreestimación sistemática en la predicción de las RFM bajo condiciones de fatiga requiere más atención científica para refinar aún más el procedimiento de prueba de la relación individualizada RFM-velocidad.

Estudio III: *La velocidad de ejecución predice el número máximo de repeticiones hasta el fallo con una precisión comparable durante el ejercicio de remo tumbado en máquina Smith (MS) y con peso libre (PL).*

Conclusión 6: Las relaciones RFM-velocidad permiten predecir las RFM con una precisión similar durante las variantes MS y PL durante el ejercicio de remo tumbado, abriendo la posibilidad de utilizar este método de prescripción de entrenamiento de resistencia durante los ejercicios con peso libre.

Conclusión 7: Las relaciones RFM-velocidad son sensibles a la fatiga, con niveles mayores de fatiga afectando más a la RFM que a la velocidad máxima de la serie. Por ello, estas relaciones deberían determinarse en condiciones de fatiga que se asemejen a las experimentas durante el entrenamiento.

Conclusión 8: Se recomienda utilizar la evaluación de las RFM-velocidad contra sólo dos cargas diferentes (*e.g.,* 90-70%1RM) cuando los niveles de fatiga de la sesión sean bajos o moderados (*e.g.,* no hasta fallo muscular).

Estudio IV: *Exploración de la relación entre el número máximo de repeticiones y la velocidad de ejecución durante el ejercicio de remo tumbado: ¿Están afectadas por el ciclo de estiramiento-acortamiento?*

Conclusión 9: La incorporación del ciclo de estiramiento-acortamiento no compromete la bondad de ajuste de las relaciones individualizadas RFM-velocidad. Sin embargo, deberían construirse por separado para cada ejercicio.

Conclusión 10: La velocidad pico de la serie puede ofrecer una mayor bondad de ajuste durante el ejercicio de remo tumbado, pero tales diferencias menores pueden no ser significativas desde un punto de vista práctico.

Conclusión 11: La construcción de las relaciones RFM-velocidad puede obtenerse utilizando el método de dos puntos para ambos ejercicios (*e.g.,* solo una serie 60 y otra al 80% hasta fallo muscular).

Estudio V: El efecto de las correas de levantamiento sobre la predicción de las capacidades neuromusculares máximas y la una repetición máxima durante el ejercicio de remo tumbado.

Conclusión 12: El uso de correas de levantamientos durante el ejercicio de remo tumbado no impacta la magnitud de las capacidades neuromusculares máximas (L_0, v_0 y A_{line}) ni a la predicción del 1RM cuando se construye por medio de las relaciones carga-velocidad.

Conclusión 13: El método de dos puntos aplicado en condiciones de campo (*e.g.,* utilizando solo dos cargas) no solo produce variables de la relación carga-velocidad de mayor magnitud, sino que también ofrece una estimación más precisa del 1RM en comparación con el método de múltiples puntos. La precisión en la predicción del 1RM se mejoró generalmente al usar el umbral mínimo de velocidad óptimo promedio en comparación con los generales e individuales.

Estudio VI: Impacto de las correas de levantamiento en la relación entre repeticiones máximas hasta el fallo y la velocidad de ejecución durante el ejercicio de remo tumbado.

Conclusión 14: El uso de correas de levantamiento durante el ejercicio de remo tumbado en MS no afecta la bondad de ajuste de las relaciones RFM-velocidad ni los valores de velocidad asociados a diferentes RFM.

Conclusión 15: La estimación de las RFM mediante el método de dos puntos fue ligeramente superior a la del método de múltiples puntos debido a la menor fatiga experimentada por los sujetos durante el procedimiento de prueba (dos *vs.* tres series hasta el fallo).

Estudio VII: Estabilidad de la relación entre el número máximo de repeticiones hasta el fallo y la velocidad de levantamiento a lo largo de un programa de entrenamiento de fuerza de 6 semanas.

Conclusión 16: Las relaciones individualizadas RFM-velocidad demostraron consistentemente una alta bondad de ajuste a lo largo del tiempo. Sin embargo, parece que la selección de una variable de velocidad de levantamiento adecuada para cada ejercicio puede mejorar su bondad de ajuste (las relaciones con la velocidad media fueron más consistentes para press de banca, pero las relaciones con la velocidad pico lo fueron para el remo tumbado).

Conclusión 17: La experiencia en el ejercicio de fuerza juega un papel crucial en las relaciones RFM-velocidad en las primeras etapas del entrenamiento. Los valores predichos de velocidades se mantuvieron estables a lo largo del tiempo para ambos ejercicios, excepto por una tendencia decreciente de la velocidad cuando se compara la primera sesión con las demás sesiones durante el ejercicio de remo tumbado (2^{da} *vs.* 3^{ra} *vs.* 4^{ta} sesiones), debido a la poca experiencia con este ejercicio.

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Annexes

The following annexes are attached:

- **ANNEX 1:** Documents submitted and approved by the ethics committee CEIM/CEI Provincial of Granada.
- **ANNEX 2:** Doctoral student Curriculum Vitae

ANNEX 1:

Documents submitted and approved by the ethics committee CEIM/CEI Provincial of Granada.

JUNTA DE ANDALUCIA CONSEJERÍA DE SALUD Y FAMILIAS

DICTAMEN ÚNICO EN LA COMUNIDAD AUTÓNOMA DE ANDALUCÍA

D/Dª: ANTONIO SALMERON GARCIA como secretario/a del CEIM/CEI Provincial de Granada

CERTIFICA

Que este Comité ha evaluado la propuesta del promotor/investigador UNIVERSIDAD DE GRANADA para realizar el estudio de investigación titulado:

TÍTULO DEL ESTUDIO:	VELOCIDAD DE EJECUCIóN COMO UN INDICADOR DE INTENSIDAD Y GRADO DE ESFUERZO EN EL EJERCICIO DE REMO TUMBADO
Protocolo, Versión:	2
HIP, Versión:	2
CI, Versión:	

Y que considera que:

Se cumplen los requisitos necesarios de idoneidad del protocolo en relación con los objetivos del estudio y se ajusta a los principios éticos aplicables a este tipo de estudios.

La capacidad del/de la investigador/a y los medios disponibles son apropiados para llevar a cabo el estudio.

Están justificados los riesgos y molestias previsibles para los participantes.

Que los aspectos económicos involucrados en el proyecto, no interfieren con respecto a los postulados éticos.

Y que este Comité considera, que dicho estudio puede ser realizado en los Centros de la Comunidad Autónoma de Andalucía que se relacionan, para lo cual corresponde a la Dirección del Centro correspondiente determinar si la capacidad y los medios disponibles son apropiados para llevar a cabo el estudio.

Lo que firmo en Granada a 04/05/2022

D/Dª. ANTONIO SALMERON GARCIA, como Secretario/a del CEIM/CEI Provincial de Granada

CERTIFICA

Que este Comité ha ponderado y evaluado en sesión celebrada el 29/04/2022 y recogida en acta 4/22 la propuesta del/de la Promotor/a UNIVERSIDAD DE GRANADA, para realizar el estudio de investigación titulado:

TÍTULO DEL ESTUDIO:	VELOCIDAD DE EJECUCIóN COMO UN INDICADOR DE INTENSIDAD Y GRADO DE ESFUERZO EN EL EJERCICIO DE REMO TUMBADO
Protocolo, Versión:	2
HIP, Versión:	2
CI, Versión:	

Que a dicha sesión asistieron los siguientes integrantes del Comité:

Presidente/a

D/Dª. AURORA BUENO CAVANILLAS

Vicepresidente/a

D/Dª. Paloma Muñoz de Rueda

Secretario/a

D/Dª. ANTONIO SALMERON GARCIA

Vocales

D/Dª. Francisco Manuel Luque Martínez
D/Dª. Juan Ramón Delgado Pérez
D/Dª. Berta Gorlat Sánchez
D/Dª. José Dario Sánchez López
D/Dª. Sonia Dominguez Almendros
D/Dª. Juan Mozas Moreno
D/Dª. José Uberos Fernández
D/Dª. SALVADOR ARIAS SANTIAGO
D/Dª. MARIA ESPERANZA DEL POZO GAVILAN
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D/Dª. MARTA CUADROS CELORRIO
D/Dª. MARIA ANGELES GARCIA LIROLA
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D/Dª. MANUEL MARTIN DIAZ
D/Dª. ANGEL COBOS VARGAS
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D/Dª. RAFAEL MARIN JIMENEZ
D/Dª. JOAQUINA MARTINEZ GALAN
D/Dª. MARÍA DOLORES GARCÍA VALVERDE
D/Dª. ESTHER MOLINA RIVAS
D/Dª. ANTONIO JUAN PÉREZ FERNÁNDEZ

D/Dª. ANTONIO JIMENEZ PACHECO
D/Dª. PATRICIA GALVEZ MARTIN

Que dicho Comité, está constituido y actua de acuerdo con la normativa vigente y las directrices de la Conferencia Internacional de Buena Práctica Clínica.

Lo que firmo en Granada a 04/05/2022

COMITÉ DE ETICA CEIM/CEI PROVINCIAL DE GRANADA

SOLICITUD PARA TESIS DOCTORAL UNIVERDIDAD DE GRANADA

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INFORMACIÓN SOBRE EL PROTOCOLO EXPERIMENTAL

TÍTULO TESIS: VELOCIDAD DE EJECUCIÓN COMO INDICADOR DE INTENSIDAD Y GRADO DE ESFUERZO EN EL EJERCICIO DE REMO TUMBADO

1. INTRODUCCIÓN

El **entrenamiento de fuerza** está bien reconocido como un método eficaz para mejorar el rendimiento deportivo porque tiene el potencial de inducir adaptaciones favorables en la hipertrofia muscular, la fuerza y la potencia.[1] Sin embargo, las adaptaciones neuromusculares inducidas por los programas de entrenamiento de fuerza dependen en gran medida de la manipulación de ciertas variables, como el tipo y el orden del ejercicio, la magnitud de la carga, el volumen, los períodos de descanso entre series o la velocidad de ejecución de cada repetición.[1] En concreto, **una de las principales preocupaciones de los entrenadores cuando están diseñando los programas de entrenamiento de fuerza es decidir cuánta carga y cuántas repeticiones deben levantar sus deportistas en un ejercicio determinado**.[2] Los dos métodos más utilizados comúnmente para prescribir la intensidad de los entrenamientos de fuerza consiste en asignar una carga relativa basada en la capacidad de fuerza dinámica máxima del deportista (es decir, porcentaje de la una repetición máxima [1RM]) o la carga que permite completar un número determinado de repeticiones antes de alcanzar el fallo muscular (XRM; por ejemplo, 7RM representa la carga con la que los sujetos pueden completar siete repeticiones, no más, antes de alcanzar el fallo muscular). Hoy en día, el uso de la tecnología deportiva nos permite proporcionar información para optimizar la prescripción de la intensidad en el entrenamiento de fuerza. Un método eficaz para predecir tanto el 1RM como el XRM consiste en **monitorizar la velocidad de la barra** a la que se levantan determinadas cargas submáximas.[3,4]

Este método surge a partir del "**entrenamiento de fuerza basado en la velocidad de ejecución**" y una de las aplicaciones más relevantes es que la carga se puede ajustar diariamente para regular la intensidad del entrenamiento, debido a la fuerte relación inversa que existe entre la velocidad y la carga levantada.[3] Varios estudios han determinado la relación general entre la velocidad de levantamiento y el %1RM en una variedad de ejercicios como el press de banca, remo tumbado, sentadilla o prensa de piernas. Otros estudios han estimado la 1RM a través de la relación carga-velocidad individualizada en ejercicios como el press de banca, remo tumbado,[3] jalón al pecho, remo Gironda, sentadilla o peso muerto. Hoy en día, existe un cierto consenso en que la relación carga-velocidad individualizada permite estimar la 1RM con mayor precisión que las relaciones carga-velocidad generalizadas,[5] principalmente porque la relación carga-velocidad es específica de cada persona y además puede modificarse después de un programa de entrenamiento de resistencia a corto plazo.

Hasta donde sabemos, sólo García-Ramos y col. [4] **han examinado la posibilidad de predecir diferentes XRM a partir de la monitorización de la velocidad de ejecución.** Al agrupar los datos de todos los sujetos, estos autores encontraron una fuerte relación entre la velocidad de ejecución y el XRM en el ejercicio de press de banca en máquina Smith (r^2 = 0,774). Sin embargo, el alto error estándar en la estimación (3,6 repeticiones) sugiere que las relaciones XRM-velocidad generalizadas no son métodos aceptables para estimar el XRM en entornos prácticos. De manera similar a la evidencia reportada para la predicción de la 1RM, se obtuvieron predicciones más precisas del XRM cuando se realizaron relaciones XRM-velocidad individualizadas (mediana r^2 = 0,984). En este sentido, es importante observar si estos resultados pueden verse extrapolados en otros ejercicios básicos de entrenamiento como el remo tumbado, especialmente considerando la disparidad de resultados al estimar el 1RM en diferentes ejercicios (los ejercicios de los miembros superiores suelen ser más precisos que los inferiores en la estimación) y la gran variabilidad entre sujetos (CV = 18.9-67.5%) para el XRM alcanzado ante un mismo porcentaje de pérdida de velocidad.[6] Otro aspecto relevante que observar y una limitación del estudio de García-Ramos y col. [4] es que la precisión de las ecuaciones XRM-velocidad individuales no fue evaluada en condiciones de fatiga, por lo que la precisión puede verse comprometida en la práctica diaria cuando se realiza ante múltiples series para un determinado ejercicio. Todos estos aspectos metodológicos permitirán en la práctica determinar cuál ha sido el **grado de esfuerzo** (número de repeticiones realizadas en relación con el máximo de repeticiones que eres capaz de completar durante una serie; por ejemplo, realizar 5 [10], significaría dejar 5 en reserva antes de llegar al fallo muscular) y realizar una prescripción objetiva de las cargas de entrenamiento.

Por otro lado, el **remo tumbado es un ejercicio comúnmente utilizado en determinadas disciplinas deportivas** como remo o natación, donde su rendimiento discrimina entre deportistas de élite o amateurs.[7] Concretamente, este ejercicio se puede realizar utilizando dos **modos de equipamiento:** barra libre (la barra puede desplazarse libremente en cualquier dirección) y en máquina Smith (el desplazamiento de la barra se restringe exclusivamente a la dirección vertical). Se ha comprobado que el equipamiento no influye en la estimación del 1RM, ya que la relación carga-velocidad no difirió entre el ejercicio de press de banca realizado en máquina Smith o con una barra libre, a pesar de que en este último la trayectoria de la barra no es completamente perpendicular.[8] No obstante, aún no se ha comprobado en la literatura científica si la bondad de ajuste de las relaciones XRM-velocidad generalizadas e individualizadas puede verse comprometida por el equipamiento usado en el ejercicio de remo tumbado.

Otro de los aspectos a tener en cuenta en el ejercicio de remo tumbado es el **modo de ejecución:** sólo concéntrico (previa a la fase concéntrica, se produce una pausa cuando la barra está en contacto con los frenos de la máquina durante la máxima extensión de brazos) y excéntrico-concéntrico (previa a la fase concéntrica, no se produce una pausa cuando la barra esté en contacto con los frenos durante la máxima extensión de brazos). La realización del modo de ejecución de sólo concéntrico puede ser utilizada para realizar la máxima aplicación de fuerza cuando los músculos están relajados, mientras que en el modo de ejecución excéntrico-concéntrico, se utiliza para generar una preactivación muscular previa a la fase concéntrica producida por la fase excéntrica anterior. Estudios previos han hallado que el modo de ejecución influye en la relación carga-velocidad en el ejercicio de press de banca, teniendo valores de velocidad mayores ante determinadas cargas cuando se realiza de manera excéntrica-concéntrica.[9] Esta consecuencia puede deberse a dos factores: (I) ciclo estiramiento-acortamiento y (II) preactivación previa de las fibras musculares como consecuencia de la inclusión de una fase previa excéntrica. Por lo tanto, se desconoce si en un ejercicio como el remo tumbado, que carece de ciclo de estiramiento- acortamiento, puede hacer que aumente o disminuya las velocidades asociadas ante cada XRM.

En el entrenamiento basado en la velocidad **hay dos metodologías bien asentadas para realizar la prescripción de la intensidad:** (I) método de múltiples puntos (normalmente entre 5 y 9 condiciones) y (II) método de los dos puntos (dos condiciones de carga equivalentes al 50%1RM y el 80%1RM). Dada la alta relación lineal entre velocidad de ejecución y la carga a vencer, García-Ramos y col. [5] propuso el método de los dos puntos como un procedimiento rápido y menos propenso a la fatiga, dónde sólo es necesario establecer dos puntos en la relación carga-velocidad. Este método ha demostrado una gran aplicabilidad para la prescripción de intensidades de manera diaria. No obstante, aún no se ha establecido si en las relaciones XRM-velocidad puede modelarse a partir del método de dos puntos. A efectos prácticos y considerando que hasta ahora solo se ha explorado el método de varios puntos para estimar el XRM (necesidad de realizar 4 cargas hasta el fallo muscular), es relevante explorar la viabilidad del “método de dos puntos” para el modelaje de las relaciones XRM-velocidad en el ejercicio de remo tumbado en distintos modos de ejecución (sólo concéntrico y excéntrico-concéntrico).

Por último, Pérez-Castilla y García-Ramos [10] han observado que se producen **cambios en el perfil carga-velocidad después de período de entrenamiento de 8 sesiones orientado al desarrollo de la fuerza máxima y la potencia muscular.** Por tanto, se recomienda una evaluación periódica del perfil carga-velocidad individual para realizar una prescripción más precisa de las intensidades de entrenamiento por medio del método de los dos puntos. No obstante, ningún estudio previo ha demostrado si estos cambios pueden producirse para las relaciones XRM-velocidad tras realizar un programa de entrenamiento de fuerza durante el ejercicio de remo tumbado.

2. OBJETIVOS ESPECÍFICOS

Proyecto 1

OE1. Comparar la bondad de ajuste entre las relaciones XRM-velocidad generales e individuales en el ejercicio de remo tumbado en máquina Smith.
OE2. Explorar la fiabilidad de las relaciones XRM-velocidad individuales en el ejercicio de remo tumbado en máquina Smith.

Proyecto 2

OE3. Comparar la relación XRM-velocidad entre el ejercicio de remo tumbado realizado con barra libre o con Máquina Smith.
OE4. Examinar el efecto de la fatiga muscular sobre la precisión de las ecuaciones XRM-velocidad generales e individuales en el ejercicio de remo tumbado en pórtico guiado realizado con barra libre o con pórtico guiado.

Proyecto 3
OE5. Comparar la relación XRM-velocidad entre los modos de ejecución sólo concéntrico y excéntrico-concéntrico del ejercicio de remo tumbado.
OE6. Explorar la viabilidad del "método de dos puntos" para el modelaje de las relaciones XRM-velocidad en el ejercicio de remo tumbado concéntrico y excéntrico-concéntrico.

Proyecto 4
OE7. Explorar la sensibilidad de las relaciones XRM-velocidad tras un programa de entrenamiento de fuerza orientado al desarrollo de la fuerza máxima o potencia muscular.

3. MATERIAL Y MÉTODOS

Descripción de la muestra

La muestra estará formada entre 30-40 estudiantes, físicamente activos entre 18 y 30 años residentes en Granada y reclutados de entre la **facultad de Ciencias de la Educación y/o Ciencias en Ciencias de la Actividad Física y del Deporte**. Los participantes deberán cumplir con los siguientes criterios de inclusión y exclusión específicos **(Tabla 1).** Suponiendo un potencia estadística del 95% (α = 0.05) y asumiendo una pérdida de participantes del 20% (n = 6), el tamaño de la muestra está justificado por estudios previos,[3,4,10] donde además utilizan el mismo instrumento con un bajo Error Estándar de Medida (EEM = 0.03 m/s [0.02-0.04]).

Tabla 1. Criterios de inclusión y exclusión.

Criterios de inclusión: - Edad: 18-35 años - Índice de masa corporal: 18,5-30 kg/m^2 - Capaz de comprender las ejecuciones técnicas y habituados al ejercicio de remo tumbado. - Experiencia mínima de 2 años en alguna disciplina deportiva.
Criterios de exclusión - Antecedentes de un evento cardiovascular adverso importante, insuficiencia renal, cirrosis, trastorno alimentario, síndrome de ovario poliquístico, intervención quirúrgica para el control de peso, diabetes mellitus tipo 2 o VIH / SIDA. - Cualquier patología crónica en la cual no sea recomendable realizar ejercicios de fuerza de alta intensidad. - Cualquier condición que, a juicio del investigador, perjudique la capacidad de participar en el estudio o represente un riesgo personal para el participante. - Uso de medicamentos que pueden afectar los resultados del estudio. - Peso corporal inestable durante 3 meses antes del comienzo del estudio (> 4 kg de pérdida o ganancia de peso) - Embarazo y lactancia. - Abuso activo de tabaco o uso ilícito de drogas o antecedentes de tratamiento por abuso de alcohol. - En una dieta especial o prescrita por otros motivos (por ejemplo, enfermedad celíaca). - No realizar entrenamiento de fuerza hasta fallo muscular dos días previos a las sesiones de evaluación.

Descripción del proyecto

Los participantes acudirán un total de 22 sesiones: proyecto 1 (4 sesiones), proyecto 2 (5 sesiones), proyecto 3 (3 sesiones) y proyecto 4 (10 sesiones). Dos veces por semana, con un descanso de 48 horas entre sesión y sesión. Todas las sesiones serán monitoreadas por un transductor de velocidad lineal (T-Force System; Ergotech, Murcia, España).

Proyecto 1: Dar respuesta a los objetivos OE1 y OE2. La primera sesión será estimación del 1RM y medidas antropométricas. Segunda y tercera sesión consistirán en realizar series al fallo muscular contra las cargas del 60-70-80-90%1RM con descansos de 10' entre series. La cuarta sesión consistirá en realizar 4 series al fallo muscular contra la carga del 75%1RM con 2' de descanso entre series.

Proyecto 2: Dar respuesta a los objetivos OE3 Y OE4. La primera sesión será estimación del 1RM y medidas antropométricas. La segunda y tercera sesión se realizará en una semana, mientras que la cuarta y quinta sesión se realizará en otra semana de manera contrabalanceada: I) Ejecución libre (series al fallo): 60-90-70-80%1RM con 5' descanso y en fatiga 2x65-2x85%1RM con 2' descanso y (II) Máquina Smith (series al fallo): 60-90-70- 80%1RM con 5' descanso y en fatiga 2x65-2x85%1RM con 2' descanso.

Proyecto 3: Dar respuestas a los objetivos OE5 Y OE6. La primera sesión será estimación del 1RM y medidas antropométricas. La segunda y tercera sesión se realizarán de manera contrabalanceada en las siguientes condiciones en máquina Smith: I) Sólo concéntrico (al fallo): 60-90-70-80%1RM (al fallo) con 5' descanso y II) Excéntrico-concéntrico (al fallo): 60- 90-70-80%1RM (al fallo) con 5' descanso.

Proyecto 4: Dar respuesta al objetivo OE7. La primera sesión será estimación del 1RM, medidas antropométricas y series al fallo al 90-60-70-80%1RM. Desde la segunda hasta la novena sesión se realizará un programa de entrenamiento orientado al desarrollo de la fuerza o potencia muscular. Programa fuerza máxima: S1 y S2 (4x8 70%1RM) + S3, S4 y S5 (5x4 85%1RM) + S6, S7 y S8 (6x2 90%1RM). Programa potencia: S1 y S2 (5x5 40%1RM) + S3 y S4 (6x5 40%1RM) + S5 y S6 (5x6 40%1RM) + S7 y S8 (4x6 40%1RM). Nuevamente, en la última sesión se realizarán series al fallo al 90-60-70-80%1RM.

Variables objeto de estudio

- Velocidad media de ejecución (m/s): La velocidad concéntrica media se define como la velocidad media tomada de todas las velocidades registradas (1000 Hz) durante toda la parte concéntrica de un ejercicio.
- Velocidad máxima de ejecución (m/s): El valor de velocidad registrado más alto tomado de la parte concéntrica del movimiento.
- Velocidad mínima de ejecución (m/s): La velocidad concéntrica media producida en la última repetición exitosa de una serie hasta el fallo realizada con el máximo esfuerzo de ejecución.
- Número de repeticiones (XRM): número de repeticiones hasta fallo muscular realizados en una serie durante el ejercicio.

Análisis estadístico

Los resultados de cada test se introducirán en el paquete SPSS v.25.0 (IBM Corporation, Pittsburgh, PA, EE. UU.). Histogramas, gráficos Q-Q y el test de Shapiro-Wilk se utilizarán para comprobar la normalidad de todas las variables. Los datos descriptivos también se presentarán como medias y desviaciones estándar. Asumiendo que las variables tengan una distribución normal:

- El coeficiente de determinación de Pearson (r^2) y el error estándar de la estimación.

- Análisis de las varianzas (ANOVA). Cuando se obtenga un valor F significativo, se llevará a cabo un análisis post-hoc (Bonferroni) para determinar las diferencias por pares.
- La fiabilidad entre sesiones se evaluará mediante el coeficiente de variación (intra- e inter- sujeto) y con el coeficiente de correlación intraclase (ICC; modelo 3,1) con sus respectivos intervalos de confianza al 95%.

El nivel de significación estadística se fijará en p <0,05. Por último, se calcularán adicionalmente los tamaños del efecto estandarizados utilizando los coeficientes d de Cohen. Los gráficos se realizarán con el programa GraphPad Prism v.8 (GraphPad Software, San Diego, CA, USA). Los análisis de fiabilidad se realizarán por medio de una hoja de cálculo Microsoft Excel 2019 personalizada (versión 16.32, Microsoft Corporations, Redmond, Washington, EE. UU.).[11]

Confidencialidad de los datos

En todo momento se respetará la confidencialidad de todos los datos de carácter personal sobre pacientes o participantes, sus familias y los profesionales a los que tenga acceso en el desarrollo del proyecto, los datos de las Historias Clínicas, documentos de la Unidad o cualesquiera otros datos de los pacientes o participantes que vayan a intervenir en este Proyecto manejándolos tal y como estipula la Ley Orgánica de Protección de Datos de Carácter Personal, Ley 15/99 de 13 de diciembre guardando su estricta confidencialidad y su no acceso a terceros no autorizados.

Asimismo, se actuará de acuerdo con las normas de buena práctica clínica en todo contacto con los sujetos del estudio o las personas relacionadas con el mismo, a respetar el derecho a la intimidad y la naturaleza confidencial de los datos de carácter personal de pacientes o participantes y personas vinculadas por razones familiares o de hecho, así como de los datos de los profesionales relacionados con los proyectos realizados, aún después de finalizados, conforme a lo dispuesto en la Ley 41/2002, de 14 de noviembre, básica reguladora de la autonomía del paciente y de derechos y obligaciones en materia de información y documentación clínica.

Por último, toda persona ajena a dichos trabajos que haya podido tener acceso justificado a dichos contenidos o a los datos utilizados, estará sujeta igualmente al deber de confidencialidad.

4. EXPERIENCIA DEL GRUPO DE INVESTIGACIÓN

La línea de investigación basada en el entrenamiento basado en la velocidad y su aplicación está muy bien consolidada en el grupo CTS- 362 y en el director **Dr. Francisco Javier Rojas Ruiz,** además de tener un gran auge en la literatura científica. Como se puede observar en las referencias aportadas en el proyecto de Tesis, varios miembros del equipo de investigación en el que se incorporaría **D. Sergio Miras Moreno** han publicado una gran cantidad de estudios en revistas indexadas en el Journal Citations Report relacionadas con el tema del presente proyecto de Tesis Doctoral.

El **grupo de investigación** solicitante dispone del material y experiencia necesarios para el desarrollo del proyecto de Tesis presentado por el solicitante. La experiencia acumulada del conjunto de los investigadores que colaborarán en el proyecto permite abordar con garantías las cuestiones relativas y los objetivos propuestos que actualmente carecen de respuesta y que tienen una enorme trascendencia práctica en el campo del deporte de alto rendimiento.

5. REFERENCIAS BIBLIOGRÁFICAS

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6. BENEFICIOS ESPERADOS

Los resultados que se obtengan nos permitirán establecer una base de conocimiento que mejore las estrategias de evaluación y aplicación de la estimación de las repeticiones hasta el fallo muscular ante una determinada carga. Durante la práctica y una vez ya establecida la relación XRM-velocidad de forma individualizada, los entrenadores solo tendrán que obtener la velocidad más rápida de la serie (normalmente en las primeras 1-3 repeticiones) y de esta forma predecir de manera objetiva cuál es el grado de esfuerzo máximo del individuo en tiempo real (máximo número de repeticiones que puede hacer, ese día, con ese peso y en esa serie). De esta manera, el entrenador podrá prescribir en tiempo real el grado del esfuerzo deseado (por ejemplo, realizar 5 repeticiones de las 10 máximas posibles).

7. POSIBLES EFECTOS INDESEABLES O SECUNDARIOS

La tesis doctoral implicará un total de **22 sesiones de duración** (48 horas de descanso entre sesión y sesión). El uso de sobrecargas durante las evaluaciones puede implicar el riesgo de lesión muscular/articular. No obstante, este riesgo es mínimo cuando las condiciones de entrenamiento son planificadas, individualizadas y supervisadas. Finalmente, serán arbitrados y desplegados todos los medios necesarios para evitar cualquier incidencia por medio de la evaluación de la información preliminar relacionada con el estado de salud de los participantes y por cualquier observación de síntomas durante el test o ejercicio.

¿Existe algún tipo de contraprestación y/ seguros para los participantes?:
NO

Consentimiento informado:
Ver adjunto 1

Hoja de información facilitada a los participantes:
Ver adjunto 2

Derecho explícito de la persona a retirarse del estudio. Garantías de confidencialidad:
SI. Ver cláusula en consentimiento informado.

Director

ROJAS RUIZ FRANCISCO JAVIER - 24254071L

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Francisco Javier Rojas Ruiz

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Sergio Miras Moreno

Anexo I: CONSENTIMIENTO INFORMADO

FÓRMULA DE CONSENTIMIENTO

D./Dña___________________________________con DNI_________________________acepta la participación al proyecto de tesis doctoral titulado ***"Velocidad de ejecución como un indicador de intensidad y grado de esfuerzo en el ejercicio de remo tumbado".***

....

INVESTIGADOR QUE INTERVIENE EN EL PROCESO DE INFORMACIÓN Y/O CONSENTIMIENTO

D. **Sergio Miras Moreno** con DNI **45322654G**, investigador predoctoral FPU en la Universidad de Granada (Facultad de Ciencias del Deporte), declara que se ha explicado la información relativa a la participación en el proyecto de tesis doctoral.

MIRAS MORENO SERGIO - 45322654G

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CONSENTIMIENTO:

Yo, D/Dña.______________________________ declaro bajo mi responsabilidad que **<u>he leído y comprendido la hoja de información</u>**, del que se me ha entregado un ejemplar.

He **<u>recibido suficiente información</u>** sobre mi participación en el proyecto, sobre la utilización de mis datos personales y/o tratamiento de datos derivados de las sesiones de entrenamiento de fuerza. He **<u>podido hacer preguntas</u>** sobre la información recibida y hablar con el profesional anteriormente indicado, quien me ha resuelto todas las dudas que le he planteado.

- Comprendo que mi participación es voluntaria.
- Comprendo que todos mis datos serán tratados confidencialmente, según Ley Orgánica 3/2018, de 5 de diciembre, de Protección de Datos Personales y garantía de los derechos.
- Comprendo que puedo retirarme del estudio:
  - Cuando quiera.
  - Sin tener que dar explicaciones.
  - Sin que esto repercuta en mis cuidados médicos.

FECHA (dd/mm/aaaa): ....

Fdo.
EL/LA PARTICIPANTE

Fdo.
EL/LA REPRESENTANTE LEGAL

REVOCACIÓN DEL CONSENTIMIENTO INFORMADO

D./Dª ……………………………………….………., con D.N.I. ………………………., declara que:

....

Sólo relativo a los familiares/tutores/representantes legales:

El paciente D./Dña. ………………………………………………, con D.N.I. ………………………, no tiene capacidad de decidir en este momento.

Por lo que D./Dña. ……………………………………….….., con D.N.I. …………………………. y en calidad de ……………………………. revoco el consentimiento anteriormente prestado por lo que queda sin efecto a partir de este momento.

....

1. He leído la Hoja de Información y Revocación del Consentimiento Informado que me ha sido entregada.
2. He hablado y aclarado las posibles dudas sobre mi revocación con el doctorando Sergio Miras Moreno.
3. Revoco el consentimiento anteriormente prestado por lo que queda sin efecto a partir de este momento.
4. Mi revocación es:

¤ TOTAL
¤ PARCIAL (indique cuál) ....

FECHA (dd/mm/aaaa): ....

Fdo.
EL/LA PARTICIPANTE

Fdo.
EL/LA REPRESENTANTE LEGAL

(Debe entregarse una copia de este documento: al participante, otra para el investigador)

Anexo 2: HOJA DE INFORMACIÓN FACILITADA A PARTICIPANTES

HOJA DE INFORMACIÓN (HI) FACILITADA A PARTICIPANTES

TÍTULO DE ESTUDIO	Velocidad de ejecución como un indicador de intensidad y grado de esfuerzo en el ejercicio de remo tumbado
CÓDIGO DEL ESTUDIO	2022/PBP
INVESTIGADORES PRINCIPALES	**Francisco Javier Rojas Ruiz** **Sergio Miras Moreno**
CENTRO	**Universidad de Granada** **Facultad de Ciencias del Deporte**
CONTACTO	**smiras@ugr.es** **fjrojas@ugr.es**

1. Introducción y objetivos

El **entrenamiento de fuerza** está bien reconocido como un método eficaz para mejorar el rendimiento deportivo porque tiene el potencial de inducir adaptaciones favorables en la hipertrofia muscular, la fuerza y la potencia.[1] Sin embargo, las adaptaciones neuromusculares inducidas por los programas de entrenamiento de fuerza dependen en gran medida de la manipulación de ciertas variables, como el tipo y el orden del ejercicio, la magnitud de la carga, el volumen, los períodos de descanso entre series o la velocidad de ejecución de cada repetición.[1] En concreto, una de las principales preocupaciones de los entrenadores cuando están diseñando los programas de entrenamiento de fuerza es decidir cuánta carga y cuántas repeticiones deben levantar sus deportistas en un ejercicio determinado.[2] **Los dos métodos más utilizados comúnmente para prescribir la intensidad de los entrenamientos de fuerza** consiste en asignar una carga relativa basada en la capacidad de fuerza dinámica máxima del deportista (es decir, porcentaje de la una repetición máxima [1RM]) o la carga que permite completar un número determinado de repeticiones antes de alcanzar el fallo muscular (XRM; por ejemplo, 7RM representa la carga con la que los sujetos pueden completar siete repeticiones, no más, antes de alcanzar el fallo muscular). Hoy en día, el uso de la tecnología deportiva nos permite proporcionar información para optimizar la prescripción de la intensidad en el entrenamiento de fuerza. Un método eficaz para predecir tanto el 1RM como el XRM consiste en monitorizar la velocidad (m/s) a la que se levantan determinadas cargas submáximas (kg).[3,4] Hoy en día, existe un cierto consenso en que la relación carga-velocidad individualizada permite estimar la 1RM con mayor precisión que las relaciones carga-velocidad generalizadas, principalmente porque la relación carga-velocidad es específica de cada persona.[5]

Hasta donde sabemos, sólo García-Ramos y col.[4] han examinado **la posibilidad de predecir las repeticiones hasta fallo muscular a partir de la monitorización de la velocidad de ejecución.** Sin embargo, las limitaciones de este estudio es que sólo se realizó en press de banca y no evaluó el efecto de la fatiga muscular en estas predicciones de repeticiones hasta fallo muscular. Por otro lado, es necesario ver si estos resultados se pueden extrapolar a otros como el remo tumbado, siendo un ejercicio comúnmente utilizado en determinadas disciplinas deportivas como remo o natación, donde su rendimiento discrimina entre deportistas de élite o amateurs.[6] Concretamente, este ejercicio se puede realizar utilizando **dos modos de equipamiento**: barra libre (la barra puede desplazarse libremente en cualquier dirección) y en máquina Smith (el desplazamiento de la barra se restringe exclusivamente a la dirección vertical); **dos modos de ejecución:** sólo concéntrico (previa a la fase concéntrica, se produce una pausa cuando la barra está en contacto con los frenos de la máquina durante la máxima extensión de brazos) y excéntrico-concéntrico (previa a la fase concéntrica, no se produce una pausa cuando la barra esté en contacto con los frenos durante la máxima extensión de brazos) y **dos metodologías de estimación de repeticiones:** múltiple puntos (varias relaciones carga-velocidad) y dos puntos (dos relaciones carga-velocidad).[7]

Por último, otro de los aspectos que no se ha investigado hasta ahora en la literatura científica es, si este tipo de ecuaciones individuales de estimación de repeticiones **puede verse afectada por programas de entrenamiento de fuerza a largo plazo**.[8]

En este contexto, los objetivos específicos del proyecto es establecer criterios metodológicos que permitan establecer esta metodología de manera segura y precisa en:

O1. Ejercicio de remo tumbado
O2. Condiciones de fatiga muscular
O3. Diferentes modos de equipamiento
O4. Diferentes modos de ejecución
O5. Ante diferentes metodologías de estimación de repeticiones, permitiendo una mayor economía del tiempo (sólo dos puntos vs varios puntos).
O6. Programas de fuerza a largo plazo

2. Protocolo y contenido de la intervención

Los participantes acudirán un total de 22 sesiones: proyecto 1 (4 sesiones), proyecto 2 (5 sesiones), proyecto 3 (3 sesiones) y proyecto 4 (10 sesiones). Dos veces por semana, con un descanso de 48 horas entre sesión y sesión. Todas las sesiones serán monitoreadas por un transductor de velocidad lineal (T-Force System; Ergotech, Murcia, España).

Proyecto 1: Dar respuesta al objetivo O1 y O2. La primera sesión será estimación del 1RM y medidas antropométricas. Segunda y tercera sesión consistirán en realizar series al fallo muscular contra las cargas del 60-70-80-90%1RM con descansos de 10' entre series. La cuarta sesión consistirá en realizar 4 series al fallo muscular contra la carga del 75%1RM con 2' de descanso entre series.

Proyecto 2: Dar respuesta a los objetivos O3, O2 y O5. La primera sesión será estimación del 1RM y medidas antropométricas. La segunda y tercera sesión se realizará en una semana, mientras que la cuarta y quinta sesión se realizará en otra semana de manera contrabalanceada: **I**) Ejecución libre (series al fallo): 60-90-70-80%1RM con 5' descanso y en fatiga 2x65-2x85%1RM con 2' descanso y (**II**) Máquina Smith (series al fallo): 60-90-70- 80%1RM con 5' descanso y en fatiga 2x65-2x85%1RM con 2' descanso.

Proyecto 3: Dar respuestas a los objetivos O4 y O5. La primera sesión será estimación del 1RM y medidas antropométricas. La segunda y tercera sesión se realizarán de manera contrabalanceada en las siguientes condiciones en máquina Smith: **I**) Sólo concéntrico (al fallo): 60-90-70-80%1RM (al fallo) con 5' descanso y **II**) Excéntrico-concéntrico (al fallo): 60-90-70-80%1RM (al fallo) con 5' descanso.

Proyecto 4: Dar respuesta al objetivo O6. La primera sesión será estimación del 1RM, medidas antropométricas y series al fallo al 90-60-70-80%1RM. Desde la segunda hasta la novena sesión se realizará un programa de entrenamiento orientado al desarrollo de la fuerza o potencia muscular. Programa fuerza máxima: Sesión(S)1 y S2 (4x8 70%1RM) + S3, S4 y S5 (5x4 85%1RM) + S6, S7 y S8 (6x2 90%1RM). Programa potencia: S1 y S2 (5x5 40%1RM) + S3 y S4 (6x5 40%1RM) + S5 y S6 (5x6 40%1RM) + S7 y S8 (4x6 40%1RM). Nuevamente, en la última sesión se realizarán series al fallo al 90-60-70-80%1RM.

3. Compromiso entre investigador y participante

El **investigador del presente proyecto se compromete** a:

- **Se respetará la confidencialidad** según la normativa vigente del punto 4 de todos los datos de carácter personal sobre pacientes o participantes, sus familias y los profesionales a los que tenga acceso en el desarrollo del proyecto, los datos de las Historias Clínicas, documentos de la Unidad o cualesquiera otros datos de los pacientes o participantes que vayan a intervenir en este Proyecto.
- Asimismo, se actuará de acuerdo con las **normas de buena práctica** clínica en todo contacto con los sujetos del estudio o las personas relacionadas con el mismo, a respetar el derecho a la intimidad y la naturaleza confidencial de los datos de carácter personal de pacientes o participantes y personas vinculadas por razones familiares o de hecho, así como de los datos de los profesionales relacionados con los proyectos realizados, aún después de finalizados.

- **Toda persona ajena a dichos trabajos** que haya podido tener acceso justificado a dichos contenidos o a los datos utilizados, estará sujeta igualmente al deber de confidencialidad.
- Explicar detalladamente el contenido del estudio, objetivos, beneficios y efectos secundarios, así como cualquier información relativa a la comprensión y seguimiento del presente estudio.
- **No tomar muestras biológicas** (sangre, saliva, etc.) o de tejido del sujeto debido al carácter del estudio no invasivo.
- Los datos obtenidos por los investigadores será los reportados por el transductor lineal de velocidad y serán utilizados **de manera exclusiva para el desarrollo del presente proyecto.**
- Reportar a los participantes los resultados del estudio una vez publicado el estudio.

El **participante deberá de atender de manera honesta a los siguientes criterios** de inclusión y exclusión siendo consciente que su participación es voluntaria y puede cambiar de opinión y retirar su fórmula de consentimiento en cualquier momento o circunstancia:

Criterios de inclusión del estudio
- Edad: 18-35 años
- Índice de masa corporal: 18,5-30 kg/m2
- Capaz de comprender las ejecuciones técnicas y habituados al ejercicio de remo tumbado.
- Experiencia mínima de 2 años en alguna disciplina deportiva.

Criterios de exclusión del estudio
- Antecedentes de un evento cardiovascular adverso importante, insuficiencia renal, cirrosis, trastorno alimentario, síndrome de ovario poliquístico, intervención quirúrgica para el control de peso, diabetes mellitus tipo 2 o VIH / SIDA.
- Cualquier patología crónica en la cual no sea recomendable realizar ejercicios de fuerza de alta intensidad.
- Cualquier condición que, a juicio del investigador, perjudique la capacidad de participar en el estudio o represente un riesgo personal para el participante.
- Uso de medicamentos que pueden afectar los resultados del estudio.
- Peso corporal inestable durante 3 meses antes del comienzo del estudio (> 4 kg de pérdida o ganancia de peso)
- Embarazo y lactancia.
- Abuso activo de tabaco o uso ilícito de drogas o antecedentes de tratamiento por abuso de alcohol.
- En una dieta especial o prescrita por otros motivos (por ejemplo, enfermedad celíaca).
- No realizar entrenamiento de fuerza hasta fallo muscular dos días previos a las sesiones de evaluación.

¿Existe algún tipo de contraprestación y/ seguros para los participantes?: NO

4. Normativa de confidencialidad de datos

El investigador seguirá la **siguiente normativa aplicable** a la confidencialidad de datos:
- Ley 14/2007, de 3 de julio, de Investigación biomédica.
- Ley 41/2002, de 14 de noviembre, básica reguladora de la autonomía del paciente y de derechos y obligaciones en materia de información y documentación clínica.
- REGLAMENTO (UE) 2016/679 DEL PARLAMENTO EUROPEO Y DEL CONSEJO de 27 de abril de 2016 relativo a la protección de las personas físicas en lo que respecta al tratamiento de datos personales y a la libre circulación de estos datos y por el que se deroga la Directiva 95/46/CE (Reglamento general de protección de datos)
- Ley Orgánica 3/2018, de 5 de diciembre, de Protección de Datos Personales y garantía de los derechos digitales.

5. Beneficios esperados

Los resultados que se obtengan **nos permitirán establecer una base de conocimiento que mejore las estrategias de evaluación y aplicación de la estimación de las repeticiones** hasta el fallo muscular ante una determinada carga. Durante la práctica y una vez ya establecida la relación XRM-velocidad de forma individualizada, los entrenadores solo tendrán que obtener la velocidad más rápida de la serie (normalmente en las primeras 1-3 repeticiones) y de esta forma predecir de manera objetiva cuál es el grado de esfuerzo máximo del individuo en tiempo real (máximo número de repeticiones que puede hacer, ese día, con ese peso y en esa serie). De esta manera, el entrenador podrá **prescribir en tiempo real el grado del esfuerzo deseado** (por ejemplo, realizar 5 repeticiones de las 10 máximas posibles).

6. Riesgos o efectos secundarios de la intervención

La tesis doctoral implicará un total de 22 sesiones de duración (48 horas de descanso entre sesión y sesión). **<u>El uso de sobrecargas durante las evaluaciones puede implicar el riesgo de lesión muscular/articular</u>**. No obstante, este riesgo es mínimo cuando las condiciones de entrenamiento son planificadas, individualizadas y supervisadas. Finalmente, serán arbitrados y desplegados todos los medios necesarios para evitar cualquier incidencia por medio de la evaluación de la información preliminar relacionada con el estado de salud de los participantes y por cualquier observación de síntomas durante el test o ejercicio.

7. Referencias bibliográficas

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6. Bartolomei S, Gatta G, Cortesi M. A Comparison between Elite Swimmers and Kayakers on Upper Body Push and Pull Strength and Power Performance. International journal of environmental research and public health. 2020 Nov 2;17(22):1–8.
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8. Pérez-Castilla A, García-Ramos A. Changes in the Load–Velocity Profile Following Power- and Strength-Oriented Resistance-Training Programs. International Journal of Sports Physiology and Performance. 2020 Nov 1;15(10):1460–6.

Investigador predoctoral FPU

MIRAS MORENO SERGIO - 45322654G

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Fdo. Sergio Miras Moreno

ANNEX 2:

Doctoral student Curriculum Vitae.

Fecha del CVA	18/06/2024

Parte A. DATOS PERSONALES

Nombre	Sergio		
Apellidos	Miras Moreno		
Sexo	Hombre	Fecha de Nacimiento	20/11/1995
DNI/NIE/Pasaporte	45322654G		
URL Web	https://www.researchgate.net/profile/Sergio-Miras-Moreno		
Dirección Email	smiras@ugr.es		
Open Researcher and Contributor ID (ORCID)	0000-0002-0235-2099		

A.1. Situación profesional actual

Puesto	Contratado predoctoral FPU		
Fecha inicio	2021		
Organismo / Institución	Universidad de Granada		
Departamento / Centro	Departamento de Educación Física y Deportiva / Facultad de Ciencias del Deporte		
País		Teléfono	
Palabras clave	Educación física y deporte		

A.3. Formación académica

Grado/Master/Tesis	Universidad / País	Año
Máster Universitario en Investigación en Actividad Física y Deporte	Universidad de Granada	2021
Máster Universitario en Profesorado de Educación Secundaria Obligatoria y Bachillerato, Formación Profesional y Enseñanza de Idiomas. Especialidad en Educación Física.	Universidad de Granada	2020
Graduado en Educación Primaria (Esp. Educación Física)	Universidad de Granada	2019
Graduado en Ciencias de la Actividad Física y del Deporte	Universidad de Granada	2019

Parte C. LISTADO DE APORTACIONES MÁS RELEVANTES

C.1. Publicaciones más importantes en libros y revistas con "peer review" y conferencias

AC: Autor de correspondencia; (nº x / nº y): posición firma solicitante / total autores. Si aplica, indique el número de citaciones

1 **Artículo científico**. (1/4) Miras-Moreno, Sergio; Garcia-Ramos, Amador; Fernandes, John F. T.; Perez-Castilla, Alejandro. 2023. Lifting More Than Two Loads Compromises the Magnitude of the Load-Velocity Relationship Variables: Evidence in Two Variants of the Prone Bench Pull Exercise. Applied Sciences-BASEL. MDPI. 13-3, pp.1944. https://doi.org/10.3390/app13031944

2 **Artículo científico**. (1/4) Miras-Moreno, Sergio (AC); Pérez-Castilla, Alejandro; Rojas-Ruiz, Francisco Javier; García-Ramos, Amador. 2023. Lifting velocity predicts the maximum number of repetitions to failure with comparable accuracy during the Smith machine and free-weight prone bench pull exercises. Heliyon. Cell Press. 9-9. ISSN 24058440. https://doi.org/10.1016/j.heliyon.2023.e19628

3 **Artículo científico**. (1/4) Miras-Moreno, Sergio (AC); Garcia-Ramos, Amador; Jukic, Ivan; Perez-Castilla, Alejandro. 2023. Two-point Method Applied in Field Conditions: A Feasible Approach to Assess the Load-Velocity Relationship Variables During the Bench Pull Exercise. Journal of Strength and Conditioning Research. Wolters Kluwer. 37-7, pp.1367-1374. ISSN 1064-8011. https://doi.org/10.1519/JSC.0000000000004405

4 **Artículo científico**. (1/3) Miras-Moreno, Sergio; Perez-Castilla, Alejandro; Garcia-Ramos, Amador. 2022. Lifting Velocity as a Predictor of the Maximum Number of Repetitions That Can Be Performed to Failure During the Prone Bench Pull Exercise. International Journal of Sports Physiology and Performance. Human Kinetics. 17-8, pp.1213-1221. ISSN 1555-0265. https://doi.org/10.1123/ijspp.2021-0534

5 **Artículo científico**. (1/7) Miras-Moreno, Sergio; Perez-Castilla, Alejandro; Rojas, F. Javier; Janicijevic, Danica; De la Cruz, Juan Carlos; Cepero, Mar; Garcia-Ramos, Amador. 2021. Inter-limb differences in unilateral countermovement jump height are not associated with the inter-limb differences in bilateral countermovement jump force production. Sports Biomechanics. Taylor & Francis. ISSN 1476-3141. https://doi.org/10.1080/14763141.2021.1980091

6 **Artículo científico**. Alejandro Pérez-Castilla; Santiago A. Ruiz-Alias; Rodrigo Ramírez-Campillo; (4/6) Sergio Miras-Moreno; Felipe García-Pinillos; Aitor Marcos-Blanco. 2024. Acute Effect of Velocity-Based Resistance Training on Subse- quent Endurance Running Performance: Volume and Intensity Relevance. Applied Sciences - BASEL. MDPI. 14-7, pp.2736. https://doi.org/10.3390/app14072736

7 **Artículo científico**. Danica Janićijević; (2/4) Sergio Miras-Moreno; María Dolores Morenas-Aguilar; Amador García-Ramos. 2024. Does the length of inter-set rest periods impact the volume of bench pull repetitions completed before surpassing various cut-off velocities?. Journal of Human Kinetics. Human Kinetics. Recently Accepted.

8 **Artículo científico**. (1/4) Sergio Miras-Moreno (AC); Amador García-Ramos; FJ Rojas-Ruiz; Alejandro Pérez-Castilla. 2024. Impact of Lifting Straps on the Relationship Between Maximum Repetitions to Failure and Lifting Velocity During the Prone Bench Pull Exercise. Sports Health: A Multidisciplinary Approach.Sage. Published Ahead. https://doi.org/10.1177/19417381241235163

9 **Artículo científico**. Danica Janicijevic; (2/6) Sergio Miras-Moreno; María Dolores Morenas-Aguilar; Sara Chacón-Ventura; Jonathon Weakley; Amador García-Ramos. 2024. Impact of squat set configuration on mechanical performance in paired sets of upper-body exercises. BMC Sports Science, Medicine and Rehabilitation. BMC. Springer Nature. 16-119. https://doi.org/10.1186/s13102-024-00912-7

10 **Artículo científico**. Danica Janicijevic; (2/6) Sergio Miras-Moreno; María Dolores Morenas-Aguilar; Andrés Baena-Raya; Jonathon Weakley; Amador García-Ramos. 2024. Maximal and submaximal intended velocity squat sets: Do they selectively impact mechanical performance in paired multijoint upper-body exercise sets?. European Journal of Sport Science. Wiley. 24, pp.200-209. https://doi.org/10.1002/ejsc.12078

11 **Artículo científico**. Danica Janićijević; (2/6) Sergio Miras-Moreno; María Dolores Morenas-Aguilar; Enzo Moraga-Maureira; Jonathon Weakley; Amador García-Ramos. 2024. Optimizing mechanical performance in the bench press: The combined influence of inter-set rest periods and proximity to failure. Journal of Sports Sciences. Taylor & Francis. 24-41, pp.2193-2200. https://doi.org/10.1080/02640414.2024.2317644

12 **Artículo científico**. Danica Janicijevic; (2/6) Sergio Miras-Moreno; María Dolores Morenas-Aguilar; Pablo Jiménez-Martínez; Carlos Alix-Fages; Amador García-Ramos. 2024. Relationship between perceptual and mechanical markers of fatigue during bench press and bench pull exercises: impact of inter-set rest period length. Peer J. Life & Environment. Peer J. 12. https://doi.org/10.7717/peerj.16754

13 **Artículo científico**. (1/2) Sergio Miras-Moreno (AC); Amador García-Ramos. 2024. The effect of lifting straps on the prediction of the maximal neuromuscular capabilities and one-repetition maximum during the prone bench pull exercise. Journal of Strength and Conditioning Research. Wolters Kluwer. Recently Accepted.

14 **Artículo científico**. (1/5) Sergio Miras-Moreno; Óscar López-Belmonte; Amador García-Ramos; Raúl Arellano; Jesús J. Ruiz-Navarro. 2024. Which strength manifestation is more related to regional swimmers' performance and in-water performance? Maximal neuromuscular capacities vs. maximal mechanical maintenance capacity.International Journal of Sports Physiology and Performance. Human Kinetics. Published Ahead. https://doi.org/10.1123/ijspp.2023-0475

15 **Artículo científico**. Osuna-Prieto, Francisco J.; Milla-Martin, Dario; (3/9) Miras-Moreno, Sergio; et al; Amaro-Gahete, Francisco J.2023. A single dose of dihydrocapsiate does not improve neuromuscular performance in resistance-trained young adults: A randomised, triple-blinded, placebo-controlled, crossover trial. European Journal of Sport Science. Wiley. 23-12, pp.2299-2310. ISSN 1746-1391. https://doi.org/10.1080/17461391.2023.2229854

16 **Artículo científico**. Robles-Gonzalez, Lidia; Ramirez Maldonado, Mauricio; Alcala-Escamilla, Juan Carlos; et al; Amaro-Gahete, Francisco J.; (5/9) Miras-Moreno, Sergio. 2023. Caffeine ingestion attenuates diurnal variation of lower-body ballistic performance in resistance-trained women. European Journal of Sport Science. Wiley. 23-3, pp.381-392. ISSN 1746-1391. https://doi.org/10.1080/17461391.2022.2038274

17 **Artículo científico**. Antonio Piepoli; (2/5) Sergio Miras-Moreno; Danica Janicijevic; Antonio Martínez-Amat; Amador García-Ramos. 2023. Differences in Various Strength Manifestations Between the Flat and Retracted Bench Press Variants: Are They Affected by Subjects' Experience or Strength Levels?. Journal of Strength and Conditioning Research. Wolters Kluwer. 37-12, pp.2339-2345. https://doi.org/10.1519/JSC.0000000000004561

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C.3. Proyectos o líneas de investigación

1 **Proyecto**. Factores determinadas de la potencia crítica y del rendimiento en pruebas de carrera de 3.000 y 10.000 lisos. Alejandro Pérez Castilla. (Universidad de Granada). 01/01/2023-31/12/2023. 1.500 €.

2 **Proyecto**. Asimetrías y Composición Corporal en la Edad Escolar: Repercusión sobre el Aprendizaje Deportivo y la Salud. María del Mar Cepero González. (Universidad de Granada). 01/05/2021-31/05/2023. 58.080 €.

3 **Proyecto**. iBOW-Training Project: Entrenamiento de fuerza en pacientes con enfermedad inflamatoria intestinal (EII): efectos en biomarcadores inflamatorios e inmunitarios.. Sergio Miras-Moreno. (Universidad de Granada). Desde 2024. 1.000 €.

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