A new portable method for load-velocity profiling: Double Pulley Rope System

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Load-velocity profile | Training equipment | Physical conditioning | Field testing | Resistance system | Performance

Headline

In the field of physical conditioning, several methods exist for establishing load-velocity profiles, varying according to data collection techniques and the way resistance is applied. Among the most studied loading techniques are: free weights or selectorized machines (1), classic methods, though they require a wide range of weights; iso-inertial flywheels (2), less heavy but expensive, and requiring a longer learning period; and isokinetic machines (3), with their cousins, pneumatic machines (4), bulky, expensive, and complex to maintain. Here, we focus on a profiling and training method particularly well-suited for field use: the **double-pulley rope system (DPRS)** with the Zercher squat exercise. This system offers a simple, innovative approach to applying adjustable resistance-like isokinetic machines, but with a key difference regarding velocity control. While those machines use a motor to regulate speed, the DPRS relies on the muscular action of a third party. Furthermore, certain two-point profiling methods, which estimate the full load-velocity curve using only two data points, have emerged to save time and minimize athlete fatigue (5). The profiling model using the points at each end of the relationship – no load, no velocity (NLNV) – is one of them.

Aim

Thus, this study aims to verify the reliability of the load-velocity profiling method using the DPRS and to examine the correlation between the curves of this newly proposed model and those of the NLNV.

Methods

Participants

A total of 14 participants (age: 24,43 ± 3,46 years old; body mass: 71,99 ± 6,56 kg; height: 176,00 ± 6,88 cm) who regularly performed squats (at least one squat session per week) and had an advanced level of resistance training experience (set at more than one year; 5,71 ± 3,91 years of training) were recruited following a call for participants. They were informed of the potential risks associated with the sessions before providing their written consent. Being in good health (free from injury or illness), be over 18 years old and possessing sufficient mobility to achieve 90° of knee flexion without lifting the heels were also mandatory inclusion criteria. This study complied with the standards of the Declaration of Helsinki.

Experimental approach

This study employed a test-retest and comparative design. Participants completed a total of four sessions, each separated by a 48-hour period of inactivity (See Figure 1):

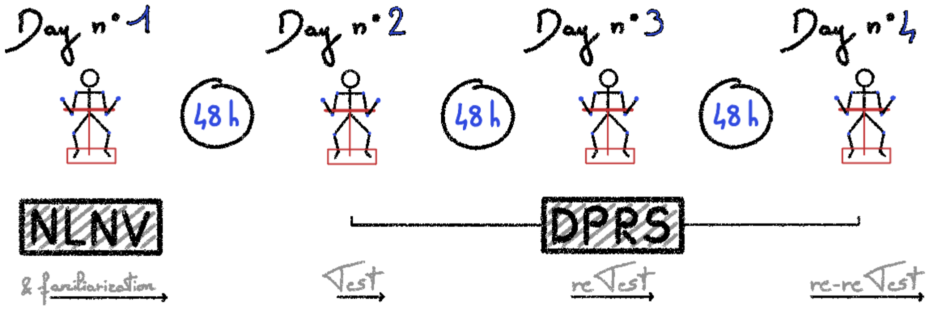

Fig. 1. Diagram of the study's experimental design.

The first session allowed participants to familiarize themselves with the experimental protocol, establish their load-velocity profiles at zero load and zero velocity, and record their anthropometric characteristics. The second, third, and fourth sessions were scheduled for experimental measurements using the double-pulley rope system. A 48-hour interval was selected to allow sufficient time for the motor tissues to fully recover from the session without affecting the subsequent one (6). Similarly, participants were asked to avoid any strenuous legs training throughout the duration of the experiment.

They were instructed to perform each movement within a trial at the highest possible intensity: "pushing upwards as hard and as fast as possible", and verbal encouragement was provided to ensure maximal effort.

The dynamic Zercher squat movements were all standardized: with the barbell held in the crooks of the elbows, positioned in front of the torso with the forearms parallel to it, participants performed a barefoot concentric squat without any countermovement. The starting position involved 90 degrees of knee flexion, and the final position involved full hip and knee extension. A signal to start and stop the movement was agreed upon in advance between the supervisor and the participant.

Material

The equipment used during these experiments was as follows (See Figure 2):

1. A 6-strand **double-pulley rope hoist** with a breaking strength of 907 kg, featuring two zinc-alloy steel hooks. Its mechanical advantage was set at 5:1.
2. A 90 cm long **grab bar** attached to the hoist's upper hook.
3. A **linear encoder** (QUELING® VBT01) with a 1000 Hz sampling frequency, connected to the center of the grab bar. It measured mean concentric velocity (7) and range of motion.
4. A **tension dynamometer** (homemade, consisting of a strain gauge, an NAU7802 ADC, and an ESP32-S3 XIAO microcontroller) with a breaking strength of 300 kg and a 333 Hz sampling frequency, placed between the upper hook and the bar. At the beginning of each session day, the dynamometer was calibrated using a 20 kg reference mass. It measured mean pulling force.
5. A 60 x 20 cm **wooden board** to which the hoist was connected at its center, via its lower hook, to a metal loop. The linear encoder was also attached to the center of the board using a magnetic mount. To be used correctly, this board had to be constantly placed on a hard, flat, and stable surface.
6. A **computer** running two software programs (FightTech® and a custom-designed application) captured Bluetooth signals from the linear encoder and the dynamometer. These signals were subsequently converted into usable data (force and average velocity over the full range of motion).
7. A **protractor** measuring from 0° to 180°.
8. A pair of **heat-resistant gloves** to protect the operator holding the rope from heat generated by friction.

→ Additional equipment was used to obtain the anthropometric and basic data: a scale (capacity of up to 180 kg and 100 g precision), and a measuring tape.

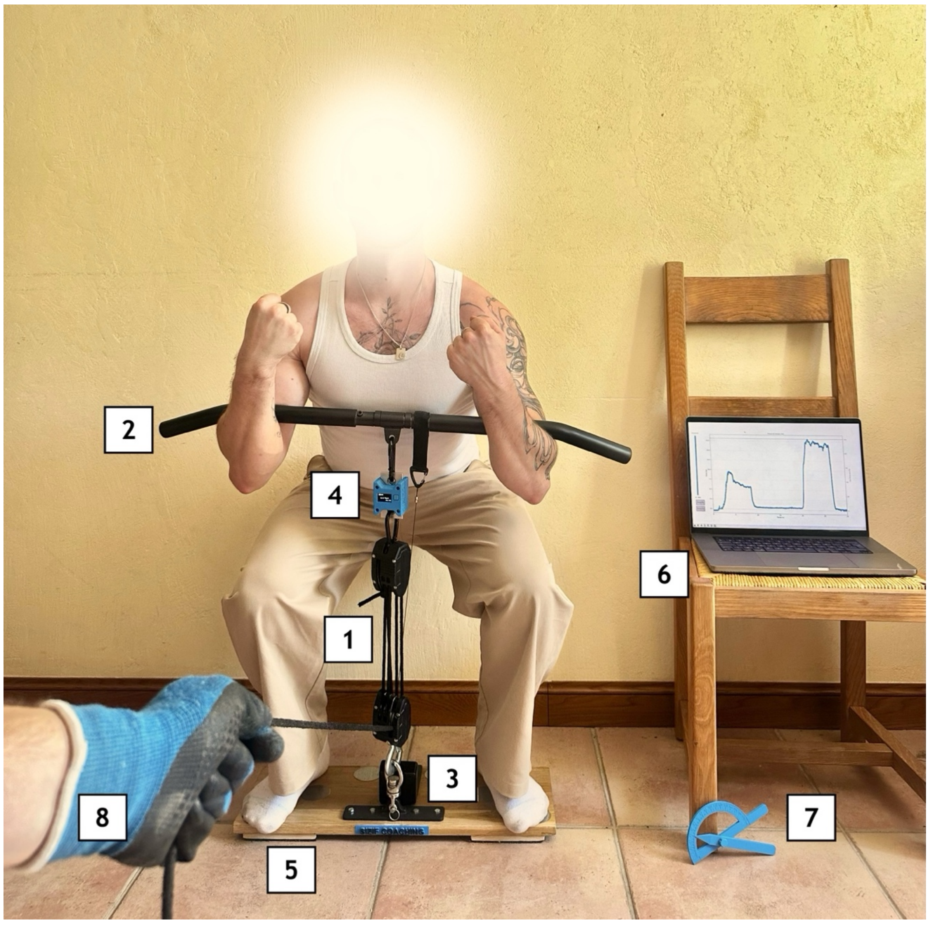

Fig. 2. Photo of a participant performing a Zercher squat with the DPRS.

Procedure

Warm-up → A warm-up was performed at the start of each session to ensure safe participation, thereby minimizing the risk of muscle and joint injuries. Participants began with a block focusing on full range of motion and isometrics: 20 full-range bodyweight squats, followed by a 20-second isometric hold involving leg adduction and abduction at the mid-squat position. They concluded with a specific progressive-load block using the DPRS: three movements performed at moderate intensity with decreasing speed, corresponding to an increasing load.

Familiarization → One familiarization session was conducted 48 h before the first multi-point measurement session, during which participants performed submaximal Zercher squat at different velocities, until they fully internalize the specific characteristics of the movement. The aim of this session was to familiarize participants with the postural constraints imposed by the system, using various loads, execution speeds and intensities. They performed a minimum of three repetitions at three different speeds (fast, moderate, and slow) at the discretion of the supervisor. If difficulties arose during the execution of the movement, additional sets could be performed until the participant demonstrated sufficient ease to carry out the exercise at maximum intensity.

PROFILING – No Load No Velocity (NLNV) → The first profiling method to be used, 5 to 10 minutes after the familiarization is the slope of the load-velocity relationship (S_{LV}) derived from 2 points: Zercher squat with no velocity and with no load, at 90, 60 and 30 degrees of knee flexion. The initial amplitude was verified using a protractor. At zero velocity, rope was blocked, and the tension had to be maintained 3 seconds as a Maximal Voluntary Isometric Contraction (MVIC). For each condition, 2 repetitions were performed with a 2-minute gap between sets. The highest of the peaks was selected, and the average force across all amplitudes was used to represent F0 over the entire range of the movement. At zero load, the bar was connected only to the linear encoder. Accounting for the mass of the bar and the encoder's slight resistance, a total of 1 kg was factored in. The participant was thus required to perform 3 bodyweight squats with maximal intended intensity and a 30-second gap between sets. The highest of the three mean velocities was recorded.

PROFILING – Double-Pulley Rope System (DPRS) → Performed during the second, third, and fourth sessions following a warm-up, this method utilizes a 3 points load-velocity relationship. Specifically, the force and mean velocity of 3 maximal-intensity repetitions are recorded: a fast repetition (mean force between 0% and 33% of MVIC), a moderate repetition (33% to 66%), and a slow repetition (66% to 99%). The supervisor controls the speed at which the rope moves based on each participant's performance. Assessment of these individual capabilities is fine-tuned during the specific warm-up phase. Except in the event of an error in the execution of the movement, the management of the setup, or data entry, only one repetition per condition was performed during this session. The range of motion of each trial was monitored. If it deviated by 10% from the unloaded reference recording of the two-point profile, the trial was invalidated and had to be repeated.

For each profile and method, the theoretical points F_0 (expressed in kg) and V_0 (expressed in m/s), either derived or directly entered, were collected. Similarly, the linear regression S_{LV} ($-F_0/V_0$; expressed in kg.s/m) and the maximal power P_{MAX} ($F_0 * V_0/4$; F_0 is normalized in Newtons to express the power in Watts) were calculated for each condition.

Statistical analysis

In this study, results are expressed as mean ± standard deviation (SD) or mean with confidence interval [CI = lower limit; upper limit]. Normality was assessed using the Shapiro-Wilk test and visual inspection of Q-Q plots. No severe deviations from normality were observed.

SAMPLE SIZE → The sample size was estimated a priori with G*Power® (version 3.1.9.6). All statistical power tests were performed with an alpha error α probability of 5% and a power of 80%. With a sample size of 14 participants, our study exceeds the required sample size for both the intra-group reproducibility analysis of DPRS and the inter-group comparison between DPRS and NLNV.

Statistical analysis of the results was performed using JAMOVI® software (version 2.7.37) and followed the recommendations of Batterham and Hopkins (8) for magnitude-based inferences. Consequently, all confidence intervals were set at 90%.

INTRA-GROUP (DPRS) → The reproducibility of the three measurements from the DPRS experimental protocol was analyzed using the ICC3,1, the standard error of measurement (SEM), and the coefficient of variation (CV). The practical ICC deductions applied are interpreted according to these thresholds: ICC $<$ 0,50 = poor reliability; 0,50 $<$ ICC $<$ 0,75 = moderate reliability; 0,75 $<$ ICC $<$ 0,90 = good reliability; ICC $>$ 0,90 = excellent reliability (9). SEM and CV were considered acceptable if it was less than 10%. Furthermore, for each three-point S_{LV} relationship, the Pearson correlation coefficient r was determined and interpreted as follows: (for both positive and negative values): r $<$ 0,60 = weak correlation; 0,60 $<$ r $<$ 0,80 = moderate correlation; 0,80 $<$ r $<$ 0,95 = strong correlation; r $>$ 0,95 = very strong correlation.

INTER-GROUP (DPRS VS NLNV) → Between-group comparisons were conducted using a Bland-Altman plot (10), with 90% limits of agreement (LoA). The interpretation of the mean bias (MB) depending on the NLNV mean value was established as an overestimation or underestimation: high ($>$ ±15%); moderate (±15% to 10%); slight (±10% to 5%); or a good estimate (-5% to +5%).

Results

Among our trained participants, it is interesting to observe significant heterogeneity in performance. We note an F_0 NLNV value ranging from 96,65 to 166,81 kg and a V0 ranging from 0,85 to 1,52 m/s. All values obtained during this study are detailed in Table 1, and all mean slopes of the load-velocity relationship are shown in Figure 3:

Table 1. Data for all values by group (mean ± SD).

	F_0	V_0	S_{LV}	P_{MAX}
DPRS 1	122,17 ± 24,06 kg	1,19 ± 0,20 m/s	-103,82 ± 21,36 kg·s/m	362,24 ± 108,88 W
DPRS 2	117,99 ± 21,16 kg	1,20 ± 0,20 m/s	-99,24 ± 17,27 kg·s/m	351,47 ± 103,64 W
DPRS 3	119,18 ± 22,71 kg	1,20 ± 0,19 m/s	-100,60 ± 19,99 kg·s/m	354,95 ± 102,41 W
DPRS (all)	119,78 ± 22,18 kg	1,20 ± 0,19 m/s	-101,42 ± 19,21 kg·s/m	356,22 ± 102,52 W
NLNV	126,54 ± 24,09 kg	1,25 ± 0,19 m/s	-102,65 ± 20,27 kg·s/m	391,99 ± 115,79 W

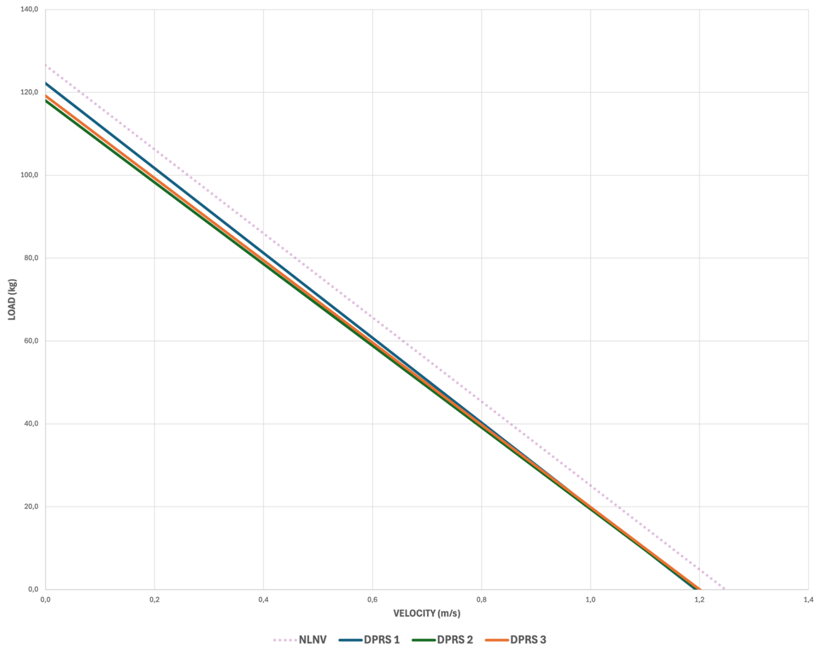

Fig. 3. Plot of all average relationships for the entire set of measurements.

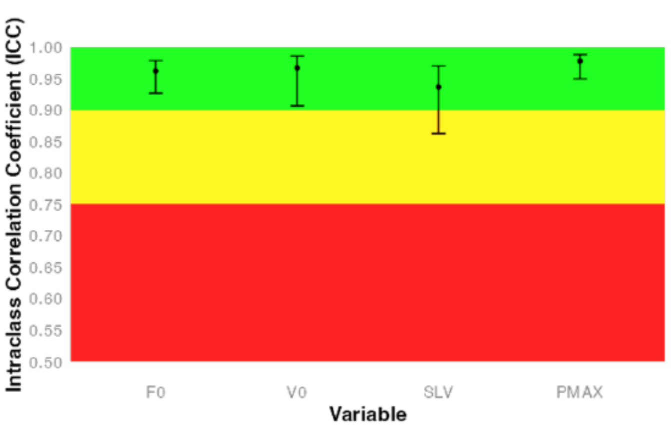

Fig. 4. Reliability of DPRS measurement repeatability (values are presented as means with a 90% CI bars).

INTRA-GROUP(See Figure 4) → For the $\mathbf{F_0}$ value, the ICC was 0,96 [CI = 0,93; 0,98], with an SEM of 4,48 kg [CI = 3,42; 6,66 kg] and a CV of 3,18% [CI = 2,37; 3,96%], both of which were acceptable. This represents excellent reliability.

For the $\mathbf{V_0}$ value, the ICC was 0,97 [CI = 0,91; 0,99], with an SEM of 0,04 m/s [CI = 0,03; 0,05 m/s] and a CV of 2,58% [CI = 1,97; 3,26%], both of which were acceptable. This represents excellent reliability.

For the $\mathbf{S_{LV}}$ value, the ICC was 0,94 [CI = 0,86; 0,97], with an SEM of 5,01 kg·s/m [CI = 3,82; 7,44 kg·s/m] and a CV of 4,17% [CI = 3,17; 5,24%], both of which were acceptable. This represents excellent reliability.

For the $\mathbf{P_{MAX}}$ value, the ICC was 0,98 [CI = 0,95; 0,99], with an SEM of 15,85 W [CI = 12,09; 23,55 W] and a CV of 3,90% [CI = 2,86; 5,01%], both of which were acceptable. This represents excellent reliability.

A very strong correlation was measured for the S_{LV} relationship regarding DPRS 1 (r = -0,99 ± 0,02), DPRS 2 (r = -0,99 ± 0,02), and DPRS 3 (r = -0,99 ± 0,02) measurements, as well as for the mean (r = -0,99 ± 0,02).

INTER-GROUP (See Figure 5) → The NLNV two-point method provides a good estimate for $\mathbf{V_0}$, with a MB of 4,01% [CI = 0,80; 7,21%] and for $\mathbf{S_{LV}}$, with a MB of 1,17% [CI = -2,47; 4,81%]. It slightly overestimates $\mathbf{F_0}$, with a MB of 5,34% [CI = 3,37; 7,33%], and $\mathbf{P_{MAX}}$, with a MB of 9,11% [CI = 6,16; 12,07%].

→ All the data is available via open access at this link: `https://doi.org/10.13140/RG.2.2.27190.46403`

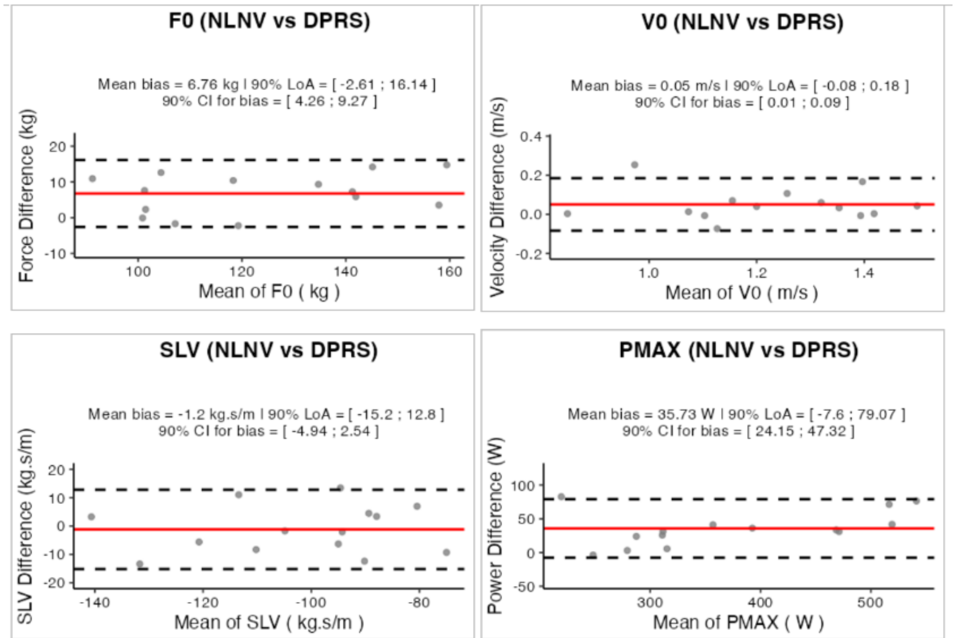

Fig. 5. Bland-Altman plots for the agreement between NLNV and DPRS for all values (the red line represents MB, and the dotted lines represent LoA).

Discussion

This study investigated the validity of a new load-velocity profiling method: the three-point double pulley rope system (DPRS). Its agreement with a simple method based on the two extreme points of the relationship (NLNV) was also examined.

This study thus demonstrates that the DPRS is highly reliable for establishing a profile. Overall, data collection techniques used during profiling are highly reliable, whether using simple video, linear encoders, or optical sensors to measure velocity (11,12), and load counting, force plates, or tension dynamometers to measure force. However, load management has been less extensively explored, even though every new machine entering the physical conditioning world appears relevant for profiling purposes. To cite a few examples regarding the reliability of movement velocity during knee and hip extension: free weights (13), selectorized (1), isokinetic (3) and pneumatic machines (4) have all demonstrated high validity. In contrast, flywheel devices exhibit moderate reliability, which heavily depends on the inertial load used (14). In addition, measurement systems using a tension dynamometer and a linear encoder have already been studied in conjunction with lightweight resistance systems, such as flywheels (14). Thus, the DPRS method joins the ranks of these profiling techniques.

We adopted here a field-based perspective: the most relevant F_0 value is the one actually produced isometrically across the full range of motion, just as V_0 represents a ballistic bodyweight movement. Here, the F_0 and P_{MAX} values appear to be slightly underestimated by our multi-point curve. Indeed, with a mean bias of 6,76 kg and 35,73 W, our results appear to align with those of other studies (15, 16), although we believe that the multi-angle approach narrows the gap between theory and reality. In the same way, the most significant slope is the one most applicable to training settings. Regarding prediction, the DPRS demonstrates excellent capabilities in a dynamic context (ICC $>$ 0,94). Furthermore, the transfer of load-velocity data points from concentric to isometric contractions appears to be individual-specific, with a relationship that likely exhibits curvilinear characteristics (17) as well as physiological limits. Although the reliability of the NLNV curve was not specifically examined here, its close proximity to our new relationship suggests it could be a valuable tool for performance assessment and, given time constraints, for training applications. Consequently, combining these two methods, shaped by a more flexible modeling approach, would be beneficial for establishing a comprehensive and more pragmatic relationship.

One of the main limitations of this study lies in the resistance setting, which is extremely subjective and requires a learning period. A braking system could be implemented for the sake of standardization. To go further, it would be worthwhile to explore the DPRS by performing movements with a greater range of motion. The profiles are indeed quite sensitive to this type of parameter (18), highlighting the importance of proper standardization. It is also worth noting that this device can facilitate eccentric overload conditions, provided the appropriate ratio is used and the supervisor employs a well-honed technique. Consequently, a non-linear load-velocity profile could also be generated by exploring points beyond F_0 (19). It could thus be added to the list of training tools that are easy to implement and monitor.

Practical applications

- We recommend that strength and conditioning specialists and other sports professionals facing constraints regarding time, space, or resources use the double-pulley rope system in conjunction with three-point profiling for dynamic assessment.
- Using MVIC and unloaded ballistic movement as profiling points appears to slightly overestimate theoretical F0 and, consequently, P_{MAX}. Thus, this approach is particularly relevant when the goal is to complete the dynamic range at the extremes of the relationship.

- It is worth noting that this system imposes clear limitations on the choice of exercises; therefore, one must ensure the reliability of the selected exercises for profiling purposes.

Disclosure statement

The author has declared no conflicts of interest.

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