Pooled Versus Individualized Load–Velocity Profiling in the Free-Weight Back Squat and Power Clean

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Original Investigation

Individualized vs. pooled load-velocity profiling in the back squat and power clean

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ABSTRACT

Purpose: This study compared pooled against individualized load-velocity profiles (LVPs) in the free-weight back squat and power clean. Methods: Ten competitive weightlifters completed baseline one repetition maximum (1RM) assessments in the back squat and power clean. Three incremental LVPs were completed and separated by 48–72 hours. Mean and peak velocity was measured via a linear-position transducer (Gymaware). Linear and non-linear (second-order polynomial) regression models were applied to all pooled and individualized LVP data. A combination of coefficient of variation (CV), intraclass-correlation coefficient (ICC) and limits of agreement (LOA) assessed between-subject variability and within-subject reliability. Acceptable reliability was defined a priori as ICC > 0.7 and CV < 10%. Results: Very high to practically perfect inverse relationships were evident in back squat (r = 0.83-0.96) and power clean (r = 0.83-0.89) for both regression models, however stronger correlations were observed in the individualized LVPs for both exercises (r = 0.85-0.99). Between-subject variability was moderate to large across all relative loads in the back squat (CV = 8.2%-27.8%), but smaller in the power clean (CV = 4.6%-8.5%). The power clean met our criteria of acceptable reliability across all relative loads, however, the back squat revealed large CVs in loads ≥ 90% 1RM (13.1%-20.5%). Conclusions: Evidently, load-velocity characteristics are highly individualized, with acceptable levels of reliability observed in the power clean, but not the back squat (≥ 90% 1RM). If practitioners want to adopt load-velocity profiling as part of their testing and monitoring procedures, an individualized LVP should be utilized over pooled LVPs.

Key Words: Velocity-based training, load-velocity relationship, maximal strength, resistance exercise, strength and conditioning

INTRODUCTION

Training intensity is typically derived from direct assessments (one repetition maximum (1RM)), followed by relative, submaximal load prescriptions (e.g. 85% 1RM).[1] Despite 1RMs showing good within-subject reliability,[1,2] it is hypothesized that this approach might struggle to account for acute changes in maximum strength or residual fatigue build-up.[2] Research has indicated that 1RM can significantly increase following acute bouts of resistance training (1 to 4 weeks).[3,4,5] Significant decreases in 1RM as a result of residual fatigue (24 hours to 1 week in duration) are also evident,[4,6] potentially affecting the accuracy of prescriptions on a week-to-week basis. Regular 1RM assessments are possible however practitioners are faced with time constraints and logistical impracticalities. Such drawbacks have prompted the development of additional aids and approaches to maximal strength testing, such as the load-velocity profile (LVP).

Strong inverse relationships have been observed between load and barbell velocity in free-weight[2,7,8,9] (r > 0.93) and Smith-machine exercises[10,11,12,13,14] (r > 0.90). However, the application of this method has often been dictated by the procedures employed. For example, the inclusion of fixed-path (Smith) machines, pauses between eccentric and concentric phases, single-session methodologies, and a failure to investigate the reliability of velocity across a full spectrum of loads questions the practical representation of many of these studies to an applied setting by which free-weight and full isotonic exercises are utilized. Furthermore, different modalities of training (e.g. Smith machine vs. free-weight or concentric-only vs. eccentric-concentric) produce different kinematic outputs and LVPs[12,15], highlighting the need for further research that investigates the reliability of velocity across a full spectrum of loads during multiple testing sessions in free-weight, full isotonic exercises.

A paucity of research, however, has begun to investigate more practically representative training methods such as free-weight exercises that utilize the stretch-shortening cycle. Banyard et al.[2,7] observed high intraclass correlation coefficients (ICC) (≥ 0.81), low coefficient of variation (CV) (≤ 9.1%) and small standard error of measurements (≤ 0.07 $m.s^{-1}$) between three separate LVP trials in loads ≤ 90% 1RM, and a strong relationship between load and velocity ($r \geq 0.93$) in the free-weight back squat. Similar values were found in the free-weight prone bench pull, bench press and deadlift.[8,10,9] Recent data, however, has highlighted that the reliability of LVPs is potentially load dependent;[16] that large between-subject variability at submaximal loads (CVs > 10%) is evident;[11,7] and poor reliability of velocity at 1RM (V_{1RM}) (ICC = 0.19 - 0.66; CV = 15.7 - 22.5%) can also be observed across a range of exercises.[2,8,10,9,7] Moreover, individualized LVPs seemingly provide stronger relationships between load and velocity.[10,11,7] With clear uncertainties about the most effective way to construct LVPs, further research in free-weight exercises investigating the individuality of load-velocity characteristics is needed.

LVPs are traditionally fitted with either linear regression[7] or non-linear equivalents such as second-order polynomials.[13,14] A small number of studies have compared the two statistical models,[2,8,10] however these have often been limited to smith-machine or upper body exercises. Nevertheless, Banyard et al.[2] did investigate this comparison during the free-weight back squat and found no statistical differences, however, the small number of loads (6) used to construct the LVP may account for this. Therefore, further clarification is required to assess the most appropriate statistical model to apply when constructing a full LVP (> 6 loads and < 20% increments). Further investigation is also needed into the strength of the load-velocity relationship when utilizing more practically representative methods such as free-weight, isotonic exercises, constructing the profile individually and when employing more explosive movements such as weightlifting derivatives.

Weightlifting derivatives such as the power clean are common in strength and conditioning (S&C) interventions as they train important movement patterns such as the triple extension[17] and are strongly linked to physical characteristics such as sprinting and jumping.[18] Weightlifting stimulates high levels of force generation, rate of force development (RFD) and impulse,[17,19] requiring greater acceleration of heavier loads in comparison to biomechanically similar exercises such as loaded squat jumps.[20] High levels of inter- and intra-session reliability in experienced, novice and youth lifters (ICC > 0.98; TE = 2.9 kg and smallest detectable differences (SDD) = 3.76 kg)[19,21,22] have also been reported when performing this exercise incrementally to 1RM. The explosive nature of the power clean and the technical competency required to perform this lift might impact load-velocity characteristics. The margin for error to successfully execute this exercise therefore may be smaller than the back squat, and it is proposed that heavier relative loads are likely to be performed at faster velocities and in smaller increments. Importantly, limited research is available that fully assesses LVPs in the power clean. Naclerio et al.[23] investigated the LVP in this exercise, but only measured peak velocity and did not assess reliability or evaluate the most appropriate method to construct the profile. Moreover, our study is the first to evaluate these important considerations when wanting to implement LVP in weightlifting exercises.

Therefore, the primary aim of this study was to investigate the load-velocity relationship of the free-weight back squat and power clean exercises, comparing pooled vs. individualized LVPs and linear vs. non-linear regression models. Secondary aims were to determine between-subject variability and within-subject reliability at each relative load for both exercises.

METHODS

Design

A repeated-measures, within-subject design investigated the reliability of pooled (all subject data combined) and individualized (one profile for one subject) LVPs in the free-weight back squat and power clean. 1RM assessments were conducted in each exercise, followed by three incremental LVPs utilizing loads of: 30%, (back squat only), 40-80% (in 10% increments) and 85% to 100% (in 5% increments), with mean and peak velocity recorded for each repetition.

Subjects

Ten (8 male, 2 female) healthy competitive Weightlifters (age: 25.0 ± 5.6 y; body mass: 73.6 ± 13.9 kg; stature: 169.6 ± 6.6 cm), who had competed at a minimum of regional level within the previous 12 months and possessed appropriate relative strength levels (squat > 1.5 x body mass and power clean > 1.15 x body mass) were recruited. Subjects' relative (absolute) strength values were: 2.1 ± 0.3 (157.0 ± 35.8 kg) and 1.4 ± 0.2 (104.4 ± 22.8 kg) for the back squat and power clean, respectively. Informed consent was provided prior to data collection with ethical approval granted by the local institutional ethics committee in accordance with 7th revision (2013) of the declaration of Helsinki.

Methodology

Subjects attended four separate sessions, each separated by 48-72 hours. Each session occurred at the same time of day with participants asked to perform no additional exercise during data collection. Body mass (kg) (InBody 720, Biospace, Korea), stature (cm) (Harpenden, Holtain Ltd, Wales) and rack height (cm) were all recorded during the initial visit. Subjects undertook a standardized, individualized warm-up that included 5 minutes on a cycle ergometer (Ergomedic 874E, Monark, Sweden) at 100W followed by a combination of body weight movements, mobility exercises and light barbell lifts. Baseline 1RM assessments were then conducted in the power clean (AM) followed by the back squat (PM). A calibrated

International Weightlifting Federation's (IWF) approved 20kg Olympic barbell and bumper plates (Werksan, Turkey), and portable squat rack (Mirafit, UK) were used throughout the study. The 1RM protocols started at an estimated 50% 1RM and increased incrementally until 1RM was reached. Multiple repetitions were performed at warm-up loads (5 reps @ 50% 1RM; 3 reps @ 70% & 80% 1RM) with single repetitions for all remaining loads (85%, 90%, 95% and 100% 1RM). Up to five attempts were allowed to determine a true 1RM, with loads being increased by 0.5 to 5 kg. Rest periods were 3-5 minutes between all sets. Subjects were habituated to performing lighter loads with maximal intent and velocity during this visit.

The three subsequent LVP sessions were identical in procedure and consisted of incremental protocols for the power clean, followed by the back squat with loads being determined from baseline 1RM. Three repetitions were performed for lighter loads (30% to 60% 1RM), two repetitions for moderate loads (70% & 80% 1RM) and one repetition for heavy loads (85% to 100% 1RM). Up to five attempts were permitted to achieve the 100% 1RM load. Rest periods were 3-5 minutes between all sets.

Power clean and back squat repetitions were required to meet the IWF, International Powerlifting Federation's (IPF) regulations guidelines, as well as previous research.[2,17,21,24,25] A power clean was deemed successful if upon catch, the greater trochanter of the hip was superior to the lateral epicondyle of the knee and the subject was able to fully extend the lower limbs.[17,21] The back squat required subjects to descend, ensuring the greater trochanter was inferior to the lateral epicondyle of the knee at full descent and the subject could fully extend the lower limbs on ascent.[2,24] Technical competency of both exercises was evaluated via a simple 2d video assessment (iPhone 7, Apple, USA) and an experienced S&C coach. Subjects were instructed to perform the ascents of both lifts as '*quickly*' and '*explosively*' as possible for all loads, and the descent at a natural speed.

The Gymaware was used to measure mean and peak velocities during each repetition and has previously been shown to be reliable and valid when measuring barbell velocity.[26] Mean velocity refers to the velocity recorded across the full concentric phase of the lift (propulsive and braking phases), with peak referring to the instantaneous maximum velocity recorded during the concentric phase. The tether of the device was attached to the right-hand collar of the barbell, 100 mm from the end of the bar. The unit was placed directly under the bar for each repetition, with a tether angle of 0 ± 5°.

Statistical Analysis

Normal distribution and relevant assumptions were assessed prior to analysis. Linear and non-linear (second-order polynomial) regression models were fitted to the pooled and individualized data to assess the relationship between load and mean or peak velocities. Fisher's *r* to *z*-transformations were used to determine significant differences between linear vs. non-linear regression model correlation coefficients.[2]

Pearson product-moment correlations (*r*) and standard error of the estimate (SEE) assessed the relationship between load and velocity. The strength of the correlations was determined using the following criteria: trivial (< 0.1), small (0.1 to 0.3), moderate (0.3 to 0.5), high (0.5 to 0.7), very high (0.7 to 0.9) or practically perfect (> 0.9).[27] Between-subject variability at each relative load was analyzed using CV (CV (%) = $\frac{Between-subject\ SD}{subject\ mean\ score}$ x 100). Within-subject reliability at each relative load was assessed using ICC (model 3.1), CV (CV (%) = $\frac{Within-subject\ SD}{subject\ mean\ score}$ x 100), typical error of measurement (TE) and Bland-Altman’s limits of agreement (LOA) (95% confidence). Within-subject reliability refers to the reliability between sessions. The reliability of the 1RM data were assessed via one-way repeated measures analysis of variance (ANOVA), partial eta squared effect sizes (η_p^2), ICC, CV and TE. All three trials were used for all reliability analyses except for LOA. For LOA, trials one and three were utilized in order to allow for the largest impact of habituation and residual fatigue on the data. Statistical significance was set at $p < 0.05$ for all relevant statistical tests. Magnitudes of the CVs were determined as: large (> 10%), moderate (5% to 10%) and small (< 5%).[7] Acceptable reliability was defined *a priori* as: a very high correlation (> 0.70) and a small to moderate CV (< 10%).[2]

Smallest worthwhile change (SWC) was calculated for each relative load of both exercises.

RESULTS

Data were normally distributed and met the assumptions for regression. A very high to practically perfect inverse relationship was found between velocity and load for both exercises (figure 1, table 1). The group's maximum load (kg) during each LVP session demonstrated an acceptable level of reliability in the back squat ($p = 0.17$; $\eta_p^2 = 0.18$; ICC = 0.99; CV = 1.8%; TE = 2.69 kg) and power clean ($p = 0.99$; $\eta_p^2 = 0.001$; ICC = 0.99; CV = 2.0%; TE = 1.84 kg), indicating true 1RMs were observed each session and confounding variables such as residual fatigue were controlled for.

Insert Figure 1

Insert table 1

Linear regression and second order polynomials were fitted to the pooled LVPs of the sample and indicated very strong to practically perfect relationships between load and velocity for the back squat and power clean (table 1). Individualized LVPs were then analyzed using the same approaches. Individualized LVPs were stronger for all data sets, but substantially stronger for peak velocity in both lifts (table 1). All correlations were statistically significant ($p = 0.001$). Fisher's *r* to *z*-transformations revealed no significant differences (back squat: $p = 0.45$; power clean: $p = 0.50$) between the linear and non-linear regression models (table 1). Large CVs for between-subject variability were present in the back squat (> 10%) for a number of relative intensities for mean (70-100% 1RM) and peak velocity (40-100% 1RM) (figures 2). The power clean presented CVs < 10% for all relative loads (figure 3).

Insert Figures 2 and 3

The systematic bias and LOAs (95%) between trials 1 and 3 were: 0.009 ± 0.06 $m.s^{-1}$ (mean velocity) and -0.002 ± 0.14 $m.s^{-1}$ (peak velocity) for the back squat and 0.001 ± 0.05 $m.s^{-1}$ (mean velocity) and 0.004 ± 0.07 $m.s^{-1}$ (peak velocity) for the power clean (figure 4). Within-subject reliability can be seen in figures 5 and 6. Mean and peak velocity presented ICCs of

0.82 to 0.98, CVs of 2.1 to 4.9% and TEs of 0.03 to 0.07 m.s^{-1} for all relative intensities in the power clean, meeting the criteria for acceptable reliability. The back squat, however, did not meet the criteria for acceptable reliability at relative intensities of ≥ 95% (ICC = 0.75 to 0.86; CV = 13.1 to 20.6%; TE = 0.03 to 0.06 m.s^{-1}) and ≥ 90% (ICC = 0.87 to 0.91; CV = 11.8 to 15.6%; TE = 0.10 to 0.14 m.s^{-1}) for mean and peak velocity, respectively. Mean and peak velocity SWC for each relative load for both exercises can be seen in table 3.

Insert Figures 4, 5 and 6

Insert table 3

DISCUSSION

The primary aim of this study was to investigate the load-velocity relationship of the free-weight back squat and power clean exercises, comparing pooled vs. individualized LVPs and linear vs. non-linear regression models. The primary findings of this investigation were: 1) the back squat and power clean demonstrated strong, inverse relationships between load and velocity, with stronger relationships observed from individualized LVPs and no statistical differences observed between the two regression models; 2) the back squat demonstrated moderate-to-large between-subject variability whereas the power clean displayed much lower variability.

Very high to practically perfect, inverse relationships (r = 0.81 to 0.96) were observed between load and velocity for both exercises (figure 1 and table 1), reflecting existing data in the free weight back squat (r and R^2 = 0.93 to 0.99).[2,7] The impact of cross-bridge cycling on force production is thought to underpin this association. As the shortening of a muscle quickens, actin and myosin have less time for cross-bridges to form, inhibiting force production.[28] Comparable studies for the power clean are scarce, however, it is evident that the LVP of the power clean is unique (figure 1), indicating load-velocity relationships are exercise specific. Naclerio et al.[23] suggested only 46% of variance could be explained when using peak velocity to predict relative load (% 1RM). This suggests a much lower correlation compared to our data, potentially due to technical competency of the elite sample recruited for the present study. Similarly, comparisons to mean velocity with Naclerio's data are not possible, limiting the interpretation of their research. Furthermore, the application of the LVP when applied to the power clean may differ depending on the velocity characteristic of interest. Peak velocity is most likely to occur during the second pull phase,[17] providing greater insight into an individual's explosive strength whereas mean velocity may be a more stable metric to monitor and will largely be determined from the first pull and transition phases.

We observed large between-subject variability across relative loads in the back-squat exercise, with CVs of up to 24.2% and 27.8% for mean and peak velocity, respectively (figure

2). This finding reflects Balsalobre-Fernandez et al.[11] who observed CVs of up to 24.6% when performing a seated military press in a smith-machine, and Banyard et al.[2] who, reported large absolute differences between subjects across all loads (0.33 to 0.68 $m.s^{-1}$) in the free-weight back squat. This variability could be a contributing factor to the poor application of pre-determine generalized predictive equations such as those developed by Gonzalez-Badillo et al.[13] Garcia-Ramos et al.[29] investigated the use of these predictive equations to estimate 1RM and observed large discrepancies from the measured maximal loads (2.8 kg to 11.4 kg) when using mean velocity. Furthermore, greater results were obtained when employing an individualized LVP (0.6 kg to 2.6 kg). Research has shown that individuals with similar 1RM values can produce different force-velocity profiles depending on their neuromuscular properties, such as fiber typing, recruitment patterns and synergistic coordination,[1,28,30,31] highlighting the need to profile athletes individually. This can facilitate the development of individualized training programs as well as optimizing the efficiency and effectiveness of a training intervention to elicit desired training effects.

Between-subject variability within the power clean was lower than that of the back squat (CVs of < 10%) (figure 3). Similarly, stronger correlations were found for an individualized LVP in comparison to the pooled profiles (table 1). Further, within-subject variability (CVs - figure 6) was lower than between-subject variability (CVs - figure 3) across all relative loads, indicating that individualized LVPs are favorable. This relationship has previously been reported for the bench press and prone bench pull,[8,10,32] reflecting our data, and indicating that individualized LVPs are a more accurate and reliable measurement when training and testing athletes.

Both exercises in this study exhibited strong, inverse relationships (figure 1). The use of non-linear regression models (second-order polynomials) have been proposed as a method of strengthening the predictive model.[2,10] Our data supports that of previous research showing no statistical differences are evident between the two regression models in either exercises ($p > 0.05$) (table 1).[2,10] Therefore, either approach could be implemented dependent on the preference of the practitioner and the number of loads included in the profile.

The secondary aim of this study was to determine the within-subject reliability of the LVPs and velocity measures at each relative load. To our knowledge, this is the first study to examine the between-session reliability of load-velocity profiling in the power clean. Importantly, we observed high repeatability in the 1RM data (kg) across the three sessions in both exercises, indicating that 1RM testing is a reliable method for assessing maximal strength as well as demonstrating the robustness of our methodology. Despite this, previous research has indicated that 1RM can significantly change with respect to strength developments and fatigue build up over a short-time period,[3,4,5,6] and therefore frequent 1RM assessments to monitor changes in strength are not always desirable, particular during in-season competition.

When evaluating LVPs as a whole, we observed minimal systematic bias between trials in both exercises (-0.002 to 0.009 $m.s^{-1}$), with 95% confidence intervals of 0.05 to 0.06 $m.s^{-1}$ and 0.07 to 0.14 $m.s^{-1}$ for mean and peak velocity, respectively (figure 4). Given the scale of the unit of measure, the 95% confidence intervals could indicate important methodological considerations. For example, accurate manipulation of load could be compromised if the associated measurement error is not taken into account by practitioners. The SWC (table 2) provides practitioners with practical values in order for confidence to be assumed that meaningful changes are occurring throughout training interventions. The smaller SWCs observed for mean velocity in the present study compared to peak velocity suggests that mean velocity is perhaps the better metric to use in order to evaluate the effectiveness of training interventions.

Analyzing LVPs as a whole could limit its practical use given prescriptions typically occur from specific relative loads (e.g. 85% 1RM). The power clean produced acceptable levels of reliability across all relative loads in mean and peak velocity (figure 6), suggesting it could be utilized as an appropriate tool for practitioners to test and monitor the progress of their athletes. Conversely, the back squat did not meet the reliability criteria for loads ≥ 95% for mean velocity and ≥ 90% for peak velocity (CVs = 13.1% to 20.6%) (figure 5). This is in agreement with previous research that observed moderate ICCs (0.55 to 0.63) and large CVs (15.7% to

19.4%) at heavier loads (> 90%) when measuring mean velocity in the free-weight back squat and deadlift.[2,9,7] However, practitioners could look to utilize LVPs of 30% to 90% 1RM using mean velocity given the low to moderate CVs and TEs (3.0% to 6.1% and 0.03 $m.s^{-1}$ to 0.05 $m.s^{-1}$, respectively) (figure 5).

Small horizontal movements and the influence of the stretch-shortening cycle have previously been attributed to the poorer within-subject reliability at heavy loads.[2,9,7] Furthermore, biomechanical deviations could affect the path of the barbell, altering kinematic variables such as barbell velocity. For example, significant inter- and intra-individual variability in barbell velocity, and hip, knee and ankle angular velocity at 90% 1RM back squat have previously been reported.[33] Better within-subject reliability in the power clean observed in our study further reinforces this argument. The power clean is technically more complex, with a requirement to produce faster velocities to successfully complete a lift (figure 1). This smaller margin for error requires greater consistency in the biomechanical positioning achieved from repetition to repetition. For example, differences of ≥ 8cm in forward barbell displacement, ≤ 0.19 $m.s^{-1}$ in barbell velocity and ≤ 33° resultant acceleration angle in the second-pull phase can dictate the success of a repetition.[17] Therefore, movement variability could contribute to the poorer reliability evident at heavier loads in the back squat.

Despite favorable reliability data for the LVP, a full-individualized profile, if performed in a similar way to the present study, may still be time consuming and logistically difficult. Furthermore, if adopting such a method, it is advised that practitioners should aim to do so alongside more traditional 1RM testing given the acceptable reliability of the 1RM data observed in this study when free from confounding variables. This combination will ensure S&C coaches are able to accurately and reliably measure the maximum strength capabilities of their athletes (1RM) and optimally manipulate load session-to-session (LVP). Practitioners, however, must be cognizant of the limitations that surround the construction, application and utilization of LVPs if opting to employ them with their practices.

PRACTICAL APPLICATIONS

S&C practitioners wanting to profile an athlete’s load-velocity characteristics should ensure an individualized approach is utilized. Practitioners should evaluate the need for profiling their athletes, the time and equipment available, and factor in the SWC associated with each relative load. S&C coaches should not replace traditional methods such as the 1RM with LVPs, but instead, consider the addition of LVPs to assist in testing and monitoring. For example, warm up sets of an incremental protocol utilized during a 1RM assessment could be used to form the light to moderate loads of an LVP. Despite this, practitioners should be cognizant to the logistical and time-related issues surrounding individualized LVPs and should adopt a method that will fit in to the scope of their practices. Finally, if undertaking LVPs in the free-weight back squat, practitioners should be mindful of the associated error when performing this method multiple times and adjust the approach accordingly.

CONCLUSIONS

Load and velocity demonstrate a very strong to practically perfect inverse relationship in the free-weight back squat and power clean. However, large between-subject variability, or a smaller within-subject to between-subject variability ratio, indicates that load-velocity characteristics are highly individualized. The back squat highlighted poor within-subject reliability in mean and peak velocity during the heavier loads (≥ 90% 1RM), perhaps due to greater movement variability, however, mean and peak velocity demonstrated high within-subject reliability across all relative loads in the power clean.

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TABLES

Table 1. Linear regression and second-order polynomials correlation coefficients (*r*) with standard error of the estimates (SEE) for the back squat and power clean. Pooled vs. individualized data.

Table 2. Recommendations for the smallest worthwhile change (SWC) of mean and peak velocity for each relative load performed across both exercises.

Table 1

		Linear Regression				Second-order Polynomial			
		Pooled		Individualized		Pooled		Individualized	
		r	SEE (m.s^{-1})	*r*	SEE (m.s^{-1})	*r*	SEE (m.s^{-1})	*r*	SEE (m.s^{-1})
Back Squat	MV	0.96	0.09	0.98-0.99	0.02-0.06	0.96	0.09	0.98-0.99	0.02-0.05
	PV	0.83	0.22	0.96-0.99	0.03-0.11	0.83	0.22	0.98-0.99	0.01-0.05
Power Clean	MV	0.89	0.08	0.87-0.99	0.02-0.06	0.90	0.08	0.92-0.99	0.01-0.04
	PV	0.83	0.16	0.85-0.99	0.02-0.10	0.83	0.16	0.85-0.99	0.01-0.09

Table 2

	Back Squat		Power Clean	
Load (% 1RM)	Mean Velocity (m.s^{-1})	Peak Velocity (m.s^{-1})	Mean Velocity (m.s^{-1})	Peak Velocity (m.s^{-1})
30	0.02	0.04		
40	0.02	0.04	0.03	0.04
50	0.02	0.04	0.02	0.04
60	0.02	0.04	0.02	0.04
70	0.02	0.04	0.02	0.04
80	0.02	0.05	0.01	0.03
85	0.02	0.05	0.01	0.03
90	0.02	0.05	0.01	0.03
95	0.02	0.05	0.01	0.03
100	0.02	0.05	0.01	0.03

FIGURES

Figure 1. Group mean (SD) values from three load-velocity profiles for mean velocity (m.s^{-1}) (▲) and peak velocity (m.s^{-1}) (◆) for a) back squat and b) power clean. Linear regression (---) and second-order polynomial (····) are presented with respective equations (located in box). *1RM* = one repetition maximum.

Figure 2. Between-subject variability for mean velocity (m.s^{-1}) (A) and peak velocity (m.s^{-1}) (B) for the back squat. Means (SD) are represented by the horizontal bar (error bars). Coefficients of Variation (CV) are displayed above each relative load in parentheses. *1RM* = one repetition maximum.

Figure 3. Between-subject variability for mean velocity (m.s^{-1}) (A) and peak velocity (m.s^{-1}) (B) for the power clean. Means (SD) are represented by the horizontal bar (error bars). Coefficients of Variation (CV) displayed above each relative load in parentheses. *1RM* = one repetition maximum.

Figure 4. Bland-Altman plots exhibiting variations in mean velocity (m.s^{-1}) (A and C) and peak velocity (m.s^{-1}) (B and D) between trials 1 and 3 measured in 10% increments (30 to 80% 1RM) and 5% increments (85 to 100% 1RM) for the back squat (A and B) (n = 100) and 10% increments (40 to 80% 1RM) and 5% increments (85 to 100% 1RM) for the power clean (n = 90) (C and D). — represents mean systematic bias and --- represents Limits of Agreement (95% confidence intervals).

Figure 5. Within-subject reliability of mean velocity (m.s^{-1}) (▲) and peak velocity (m.s^{-1}) (◆) in the back squat at all submaximal relative loads. Forest plots displaying Intraclass Correlations (ICC) (A), Coefficient of Variation (CV) (B) and Technical Error of Measurement (TE) (C) with error bars indicating 95% confidence intervals. Right y axis details group mean and 95% confidence values. Grey shaded areas indicate the criteria for acceptable reliability defined a priori. *1RM* = one repetition maximum.

Figure 6. Within-subject reliability of mean velocity (m.s^{-1}) (▲) and peak velocity (m.s^{-1}) (◆) in the power clean at all submaximal relative loads. Forest plots displaying Intraclass Correlations (ICC) (A), Coefficient of Variation (CV) (B) and Technical Error of Measurement (TE) (C) with error bars indicating 95% confidence intervals. Right y axis details group mean and 95% confidence values. Grey shaded areas indicate the criteria for acceptable reliability defined a priori. *1RM* = one repetition maximum.