Load-velocity relationship in variations of the half-squat exercise: Influence of execution technique

ABSTRACT

Previous studies have revealed that the velocity of the bar can be used to determine the intensity of different resistance training exercises. However, the load-velocity relationship seems to be exercise dependent. This study aimed to compare the load-velocity relationship obtained from two variations of the half-squat exercise (traditional *vs.* ballistic) using two execution techniques (standard *vs.* stop). Twenty men performed a submaximal progressive loading test in four half-squat exercises: standard half-squat (i.e. traditional half-squat using the standard technique), concentric half-squat (i.e. traditional half-squat using the stop technique), countermovement jump (i.e. ballistic half-squat using the standard technique), and squat jump (i.e. ballistic half-squat using the stop technique). Individual linear regressions were used to estimate the one-repetition maximum (1RM) for each half-squat exercise. Thereafter, another linear regression was applied to establish the relationship between relative load (%RM) and mean propulsive velocity (MPV). For all exercises, a strong relationship was observed between %RM and MPV: standard half-squat ($R^2 = 0.949$), concentric half-squat ($R^2 = 0.920$), countermovement jump ($R^2 = 0.957$), and squat jump ($R^2 = 0.879$). The velocity associated with each %RM was higher for the ballistic half-squat variation and the standard technique than for the traditional half-squat variation and stop technique. Differences in velocity among the half-squat exercises decreased with the increment in the relative load. These results demonstrate that the MPV can be used to predict exercise intensity in the four half-squat exercises. However, independent regressions are required for each half-squat exercise since the load-velocity relationship proved to be task specific.

Keywords: velocity-based training; traditional; ballistic; jump squat; standard technique; stop technique.

INTRODUCTION

Exercise intensity is generally recognised as the resistance training variable most important to induce changes in strength levels (12,20). The measurement of the one-repetition maximum (i.e. the maximum load that can be lifted only one time, 1RM) has been considered as the main reference to quantify and prescribe resistance exercise intensity (24,26). This approach inevitably requires 1RM determination for the main exercises that configure a given resistance training program (7,12,18). Traditionally, the 1RM strength has been obtained from a single maximal lift (direct method) or estimated from regression equations based on the maximum number of repetitions performed to failure with a submaximal load (indirect method) (3,7,12). However, due to the advancements in sport technology, a novel prediction method has been proposed to determine the 1RM strength from the velocity of the barbell recorded through linear transducers (2,7,12,22,24), accelerometers (6,29,32), video-systems (37) or smartphones app (1). Among those devices, linear transducers are considered the gold standard (1,12).

The main advantage of the velocity approach is that the relative load (%RM) can be estimated in real-time and with high accuracy, provided the bar is lifted with maximal intended velocity (7,12,22,24,28,35). This characteristic may allow the adjustment of the absolute load (kg) on a daily basis to match the desired %RM and to evaluate frequently changes in maximum strength that may occur during a resistance training program (7,12,22,24). The feasibility of using velocity output to monitor resistance training intensity is supported by numerous studies that have established a strong relationship between %RM and movement velocity for conventional resistance training exercises such as the bench press (12,22,28,35), bench pull (35), full squat (7,28), half-squat (7,24), leg press (7) and deadlift (15). However, it should be noted that the load-velocity relationship seems to be specific to the exercise and its execution mode (e.g., only-concentric *vs.* stretch-shortening cycle) (7,28,35). This fact emphasizes the need to determine the load-velocity relationship for the training exercises and their variations routinely incorporated in resistance training programs.

The half-squat is one of the most basic exercises employed to train the lower-body muscles (4). Typically, two variations of half-squat are commonly included in resistance training programs: 1) the traditional half-squat in which the feet are always in contact with the floor, and 2) the ballistic half-squat (or jump squat) in which the subjects are commonly instructed to jump as high as possible (30). The main difference between both variations is that while in the traditional half-squat the load is decelerated at the end of the concentric phase to avoid taking the feet off ground (especially under light loads) (10,23), in the ballistic half-squat the load is accelerated during the entire range of motion (10,23). Consequently, the ballistic half-squat allows the development of higher force, velocity, and power output compared to the traditional half-squat when performed with the same absolute load (10,21,25).

Both the traditional and ballistic half-squat variations can be performed using two execution techniques: 1) the standard technique which includes an eccentric muscle action previously to the concentric action (i.e. stretch-shortening cycle), and 2) the stop technique in which the subjects start the lift from a static flexed position and perform a purely concentric action (28). While the standard technique is commonly used to stimulate the natural stretch-shortening cycle, the stop technique is mainly used to improve muscle concentric capacities (26,28). Therefore, four half-squat exercises may be considered to design resistance training programs: standard half-squat (i.e. traditional half-squat using the standard technique), concentric half-squat (i.e. traditional half-squat using the stop technique), countermovement jump (i.e. ballistic half-squat using the standard technique), and squat jump (i.e. ballistic half-squat using the stop technique). Thus, it would be of interest to determine the load-velocity relationship of these half-squat exercises as well as to explore the differences that may exist among them.

In light of the aforementioned considerations, we designed a study to compare the load-velocity relationship among four basic half-squat exercises. Specifically, we compared the load-velocity relationship between 1) traditional *vs.* ballistic half-squats variations, and 2) standard *vs.* stop techniques. We hypothesized that the ballistic half-squat variation and the standard technique would provide higher velocity for each relative load (%RM) than the traditional half-squat variation and the stop technique, respectively. The results that we expected to find should provide an accurate estimation of the velocity associated with each relative intensity (%RM) in the four half-squat exercises frequently prescribed in resistance training programs.

METHODS

Experimental approach to the problem

A repeated-measures design was used to compare the load-velocity relationship among four half-squat exercises. To familiarize subjects with the testing procedures and to ensure a proper technique during the four half-squat exercises, subjects took part in eight familiarization sessions (twice a week, with 48 h of rest between sessions). Afterwards, subjects were tested on four separate occasions (one for each half-squat exercise) during two consecutive weeks in a counterbalanced order. During each testing session, the individual load-velocity relationship was determined by means of an incremental loading test. Testing sessions were separated by a minimum of 48 h. All evaluations were conducted at the same time of the day (±1 h) for each subject and under similar environmental conditions (~22ºC and ~60% humidity).

Subjects

Twenty healthy men (age 22.7 ± 2.3 years, body mass 74.0 ± 7.7 kg, height 176.8 ± 6.2 cm) volunteered to participate in this study. All subjects were physically active sport sciences students with 3.0 ± 1.6 years of resistance training experience, ranging from one to five years. Subjects did not report any physical limitations, health problems or musculoskeletal injures that could compromise testing. They were also instructed to avoid any strenuous exercise over the course of the study and all subjects were informed of the benefits and risks of the investigations prior to signing an institutionally approved informed consent document to participate in this study. The study protocol adhered to The Code of Ethics of the World Medical Association (Declaration of Helsinki) and was approved by the Institutional Review Board.

Testing procedures

Subjects arrived at the laboratory in a well-rested condition at the start of each testing session. Warm-up consisted of jogging, dynamic stretching and lower-body joint mobilization exercises, followed by one set of five repetitions with an absolute load of 20 kg in the corresponding exercise tested. Thereafter, subjects performed an incremental loading test using one of the following half-squat exercises:

- *Standard half-squat:* Subjects were instructed to perform a countermovement to 90º of knee flexion and ascend back to upright position without lifting the toes off the ground. Subjects were required to perform the eccentric and concentric phases at maximal voluntary velocity.

- *Concentric half-squat:* Subjects first flexed their knees to 90º in a continuous and controlled manner, they maintained this position for 1.5 s, and immediately afterwards performed a purely concentric action at maximal intended velocity without lifting the toes off the ground. The duration of the eccentric and isometric phases was paced by auditory signals.
- *Countermovement jump:* The execution technique was identical to the standard half-squat exercise, with the only difference being that subjects were instructed to jump as high as possible.
- *Squat jump:* The execution technique was identical to the concentric half-squat exercise, with the only difference being that subjects were instructed to jump as high as possible.

In the four half-squat exercises, subjects initiated the movement in a fully extended position, feet approximately shoulder-width apart and the barbell held across the top of the shoulders and upper back. The barbell was required to be in constant contact with subjects' shoulders and upper-back through the whole execution. The 90º knee angle was individually measured with a manual goniometer. To ensure the reproducibility of the 90º knee angle, a tripod adjustable with a telemetric photocell (Microgate, Bolzano, Italy) was placed on one side of the bar (Figure 1). The telemetric photocell emitted an acoustic signal when the bar crossed the depth linked to the 90º knee angle for each subject. The height of the tripod was same in the four testing sessions. When the telemetric photocell did not emit a sound (i.e. the subject did not reach the 90º depth) or the countermovement exceeded the criterion defined (10% below 90º depth), the trial was rejected and subsequently repeated after the corresponding period of rest. For each repetition, subjects received real-time velocity performance feedback to encourage them to give maximal effort. Trained spotters were presented and lifting belts were used to ensure safety.

--- Figure 1 near here ---

During each testing session, the initial load was set at 20 kg for all subjects and was progressively increased in 15 kg increments until the mean propulsive velocity attained (MPV) was lower than 0.60 $m\cdot s^{-1}$. Two attempts per load were executed with a recovery period of 1 min between loads. Rests between sets were set to 3 min for the lighter loads (MPV $\geq$ 1.00 $m\cdot s^{-1}$) and to 5 min for the medium loads (MPV < 1.00 $m\cdot s^{-1}$). Only the repetition with the highest MPV at each load was selected for further analysis (12,35). The average MPV for the heaviest load used in the incremental loading test was 0.50 ± 0.06 $m\cdot s^{-1}$ during the standard half-squat exercise (84.9 ± 4.7 %RM), 0.51 ± 0.04 $m\cdot s^{-1}$ during the concentric half-squat exercise (78.4 ± 4.2 %RM), 0.53 ± 0.07 $m\cdot s^{-1}$ during the countermovement jump exercise (88.3 ± 3.6 %RM), and 0.53 ± 0.04 $m\cdot s^{-1}$ during the squat jump exercise (83.6 ± 5.3 %RM). The average number of incremental loads tested were 8.1 ± 0.9 during the standard half-squat exercise, 6.5 ± 0.9 during the concentric half-squat exercise, 8.1 ± 0.9 during the countermovement jump exercise, and 7.2 ± 1.2 during the squat jump exercise.

Measurement equipment and data analysis

Height (Seca 202, Seca Ltd., Hamburg, Germany) and body mass (Tanita BC-418 MA, Tanita corporation, Tokyo, Japan) were measured at the start of each testing session. A Smith machine (Technogym, Barcelona, Spain) was used for all half-squat exercises. A linear velocity transducer (T-Force System; Ergotech, Murcia, Spain) with a sampling frequency of

1,000 Hz was used for mechanical measurements (34). The mean velocity within the propulsive phase (MPV) was analysed. The propulsive phase was defined as the portion of the concentric phase during which the barbell acceleration was greater than the acceleration due to gravity (36). The relationship between absolute load (kg) and MPV for each half-squat exercise was established by means of a linear regression. The absolute load linked to a MPV of 0.33 $m \cdot s^{-1}$ obtained from the individual load-velocity relationships was considered to be the 1RM strength (7,24). Once the 1RM strength was estimated, the absolute loads (kg) were expressed as relative loads (%RM) and another linear regression was conducted in order to establish the relationship between %RM and MPV (18).

Statistical analyses

Data are presented as means and standard deviations, while the correlation coefficients are presented through their median values and ranges. The relationship between relative load (%RM) and velocity was established by fitting first-order-polynomials to the data (7,22,24). The goodness of fit of the linear regressions was assessed by the coefficient of determination (R^2) and the standard error of the estimate (SEE). Two-way (half-squat variation [traditional *vs.* ballistic] × execution technique [stop *vs.* standard]) repeated measures ANOVAs were conducted to assess differences in the predicted 1RM strength as well as in the velocity at each relative load from 30 %RM to 100 %RM among the half-squat exercises. Bonferroni post-hoc tests were used to identify the source of any significant difference. The Wilcoxon test was conducted to determine the differences between the load-velocity relationship slopes. The magnitude of differences was expressed as standardized mean differences (Cohen´s d effect size, ES). Significance was accepted at $P < 0.05$. The individualized regression equations were plotted in an Excel spreadsheet (Excel Microsoft software Corporation, Seattle, WA, USA), while the remaining statistical analyses were performed using the software package SPSS (IBM SPSS version 21.0, Chicago, IL, USA).

RESULTS

Predicting relative load (%RM) from velocity data

After plotting MPV against relative load (%RM) and fitting first-order-polynomials to all data points, a strong relationship between these two variable was observed for the four half-squat exercises (Figure 2). Consequently, a prediction equation to estimate relative load (%RM) from MPV could be obtained for the different half-squat exercises: standard half-squat %RM = -86.835·MPV + 127.207 (R^2 = 0.949, SEE = 5.34%), concentric half-squat %RM = -117.266·MPV + 136.113 (R^2 = 0.920, SEE = 6.12%), countermovement jump %RM = -69.065·MPV + 121.342 (R^2 = 0.957, SEE = 5.09%), squat jump %RM = -91.902·MPV + 125.888 (R^2 = 0.879, SEE = 8.04%). It should be noted that the individual load-velocity relationships also proved to be very strong for the standard half-squat exercise (R^2 = 0.987 [0.958-0.996]), the concentric half-squat exercise (R^2 = 0.976 [0.911-0.996]), the countermovement jump exercise (R^2 = 0.990 [0.963-0.996]), and the squat jump exercise (R^2 = 0.972 [0.930-0.994]).

--- Figure 2 near here ---

Comparison of 1RM strength between the half-squat exercises

The two-way repeated measures ANOVA conducted on 1RM strength did not reveal a significant main effect for the factor ‘half-squat variation’ ($F = 0.24$, $P = 0.627$, $\eta^2 = 0.13$), but the main effects of the ‘execution technique’ ($F = 55.01$, $P < 0.001$, $\eta^2 = 0.743$) and their interaction ($F = 4.97$, $P = 0.038$, $\eta^2 = 0.21$) were significant. The standard technique was associated with higher 1RM strength. Specifically, the predicted 1RM strength was 150 ± 20 kg in the standard half-squat exercise (2.0 ± 0.3 $kg \cdot kg^{-1}$), 131 ± 19 kg in the concentric half-squat exercise (1.8 ± 0.3 $kg \cdot kg^{-1}$), 143 ± 14 kg in the countermovement jump exercise (1.9 ± 0.3 $kg \cdot kg^{-1}$), and 136 ± 22 kg in the squat jump exercise (1.8 ± 0.3 $kg \cdot kg^{-1}$).

Comparison of the VMP attained at each %RM among the half-squat exercises

The two-way repeated measures ANOVAs conducted on the velocity attained at each %RM revealed a significant main effect for the factor 'half-squat variation' and 'execution technique', while their interactions did not reach statistical significance (Table 1). The ballistic half-squat variation and the standard technique provided significantly higher values of MPV for each relative load (%RM) (except for 100 %RM) than the traditional half-squat variation and stop technique, respectively (Table 2). The relationship slopes were steeper in the ballistic half-squat variation than in the traditional half-squat variation both for the standard (-0.014 ± 0.001 *vs.* -0.011 ± 0.001, $P < 0.001$, ES = -2.72) and stop techniques (-0.009 ± 0.005 *vs.* -0.008 ± 0.001, $P = 0.01$, ES = -0.25). The relationship slopes were also steeper with the standard technique than with the stop technique in both the traditional (-0.011 ± 0.001 *vs.* -0.008 ± 0.001, $P < 0.001$, ES = -3.68) and ballistic half-squat variations (-0.014 ± 0.001 *vs.* -0.009 ± 0.005, $P < 0.001$, ES = -1.82).

--- Table 1 near here ---

--- Table 2 near here ---

DISCUSSION

The present study was designed to compare the load-velocity relationship during traditional and ballistic half-squat variations using the standard and stop techniques. The main finding of the present study is that the load-velocity relationship is specific to the half-squat exercise performed. Our hypotheses were confirmed since the velocity attained at each %RM was higher for the ballistic half-squat variation and the standard technique than for the traditional half-squat variation and stop technique. The differences in velocity among the half-squat variations and the execution techniques decreased with the increment in the relative load (i.e., smaller differences at higher %RM). Regardless of the half-squat exercise, a strong relationship was observed between %RM and MPV. Taken together, these results highlight that 1) the MPV of the bar can be used to estimate relative load (%RM) in the four half-squat exercises, and 2) a same value of MPV represents different %RM for each half-squat exercise.

The very close relationship observed between relative load (%RM) and MPV confirms that movement velocity can be used to determine training intensity with high precision in the four half-squat exercises evaluated (Figure 2). These findings are in accordance with previous studies that have shown a strong relationship between %RM and MPV during the bench press (12,22,28,35), bench pull (35), full squat (7,28), leg press (7), and deadlift exercises (15). Specifically, the coefficients of determination of the load-velocity relationships obtained in the present study were similar to those previously reported in the traditional half-squat using the standard (R^2 = 0.97) (24) or stop technique (R^2 = 0.96) (7). Surprisingly, the MPV attained at each %RM in the present study is different to that reported in previous studies (7,24). The different training background of the subjects may be responsible for these results (15). Therefore, these results question the usefulness of providing general formulas to estimate the relative load (%RM) from movement velocity since the load-velocity relationship may be dependent on the population assessed.

Muscular power is one of the main determinants in the performance of high-velocity explosive-actions (10,13,33). These high-velocity actions (e.g., unloaded jumps, sprint, kicking, change of direction, etc.) are the determinants of success in many competitive sports (9,13). Therefore, due to the undeniable importance of possessing high levels of muscular power to optimize performance, great attention has been focused on identifying the best methods to enhance muscular power (10,38,39). Regarding exercise selection, power-oriented resistance training programs usually include ballistic exercises rather than traditional exercises since they are able to generate greater power output when training with the same absolute load (10,13). In this regard, the main novelty of the present study is that it is the first to provide a reference of the MPV associated with each %RM in the ballistic half-squat exercise using both the standard and stop techniques.

Due to the intrinsic mechanical differences between traditional and ballistic half-squat variations, we hypothesized that the MPV linked to each %RM would be higher for the ballistic half-squat variation. Our hypothesis was confirmed. However, it should be noted that these differences tended to decrease with the increment of the %RM. These results might be expected since the benefit of ballistic exercises in terms of higher velocity is known to be magnified under light loads (8,11). On the other hand, similar 1RM strength should be obtained in both traditional and ballistic half-squat variations since the sticking point (i.e., the point that determines if the repetition will be successfully completed) is present at the beginning of the movement (14,19). This assumption is supported by the absence of a significant main effect for the factor ‘half-squat variation’ for 1RM strength. Therefore, the braking phase characteristic of the traditional exercises at the end of the range of motion, which is especially prominent under light loads, may be the main factor responsible for the different load-velocity relationships observed between traditional and ballistic half-squat variations (21,28,35,36).

We also aimed to explore the effect of the execution technique on the load-velocity relationship. Our second hypothesis was also confirmed since the MPV attained at each %RM was higher in the standard technique than in the stop technique (see Table 1). The performance of a rapid muscle stretch (eccentric action) prior to the concentric action is known to enhance the velocity during the subsequent concentric action in comparison with the concentric only exercises (5,17,27,28). This enhancement in velocity is especially prominent at the beginning of the movement, which is essential to overcome the "sticking point" (27). In fact, the standard technique promoted higher values of 1RM than the stop technique. However, our results are in line with previous studies indicating that the potentiation effect of pre-stretching is magnified under lighter loads (27,28). Therefore, although 1RM strength was higher using the standard technique, the higher potentiation of the stretch-shortening cycle under lighter loads promoted steeper load-velocity slopes for the standard technique. These results are in line with Pallarés et al. (28) who previously compared the load-velocity relationship for the bench press and full squat exercises using both execution techniques. These authors found significantly higher MPV values for each relative load (%RM) using the standard technique respect rather than stop technique, especially at light and medium loading conditions. Similarly, Jiménez-Reyes et al. (17) also revealed that the force-velocity relationship parameters obtained for the vertical jumps exercises were meaningful higher in the countermovement jump (i.e. standard technique) compared to the squat jump (i.e. stop technique).

The main limitation of the current study was the indirect determination of 1RM strength. Lifting a maximal weight might induce muscle pain or risk of muscular injury with novice subjects (3,7,12). In addition, the direct method might not be accurate enough to determine the half-squat 1RM strength in populations with limited experience in resistance training (31). Therefore, we decided to use the model proposed by Jidovtseff to estimate the 1RM strength from barbell velocity (16).

To summarize, the close relationship between MPV and %RM observed in the four half-squat exercises emphasizes the use of movement velocity as a feasible method to monitor exercise intensity during resistance training programs. However, strength and conditioning coaches must take into account that the load-velocity relationship is influenced significantly by the half-squat exercise performed. Namely, the same value of MPV might represent very different relative loads depending on the exercise (e.g., a MPV of 0.90 $m \cdot s^{-1}$ is equivalent to ≈ 30 %RM in the concentric half-squat and ≈ 60 %RM in the countermovement jump). Further research should investigate whether these findings are present during other types of resistance training exercise (e.g., bench press).

PRACTICAL APPLICATIONS

The MPV can be used to estimate relative load (%RM) with a high degree of precision in the main half-squat exercises commonly prescribed in resistance training programs. These findings support the practical use of the velocity-based approach in the prescription and control of the resistance training and the assessment of maximal strength levels without the need to perform an actual 1RM test. However, it should be noted that the load-velocity relationship proved to be task specific (i.e., the same value of MPV represents different %RM for each half-squat exercise). Therefore, individual load-velocity profiles are required for each half-squat exercise to successfully monitor exercise intensity based on movement velocity.

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FIGURE LEGEND

Figure 1. Experimental setup including a tripod adjustable with a telemetric photocell to control the depth linked to the 90º knee angle. Subjects executed the half-squat exercises in a Smith machine that allows only vertical displacement of the barbell along a fixed pathway.

Figure 2. Comparisons of the relationships between relative load (%RM) and mean propulsive velocity in function of (a) the half-squat variation and (b) the execution technique. R^2, coefficient of determination; SEE, standard error of the estimate.

Table 1. Two-way repeated measures ANOVA conducted for each relative load (%RM) in function of the half-squat variation and the execution technique (n = 20).

Load (%RM)	**Half-squat variation**			**Execution technique**			**Interaction**		
	F	*P*	η^2	F	*P*	η^2	F	*P*	η^2
30	149.85	< 0.001	0.89	445.19	< 0.001	0.96	4.08	0.058	0.18
35	149.87	< 0.001	0.89	446.42	< 0.001	0.96	4.04	0.059	0.18
40	149.84	< 0.001	0.89	447.74	< 0.001	0.96	3.99	0.060	0.17
45	149.73	< 0.001	0.89	449.15	< 0.001	0.96	3.93	0.062	0.17
50	149.49	< 0.001	0.89	450.62	< 0.001	0.96	3.86	0.064	0.17
55	149.04	< 0.001	0.89	452.06	< 0.001	0.96	3.78	0.067	0.17
60	149.24	< 0.001	0.89	453.32	< 0.001	0.96	3.67	0.071	0.16
65	146.85	< 0.001	0.89	454.00	< 0.001	0.96	3.53	0.076	0.16
70	144.41	< 0.001	0.88	453.23	< 0.001	0.96	3.35	0.083	0.15
75	140.04	< 0.001	0.88	448.87	< 0.001	0.96	3.10	0.094	0.14
80	131.92	< 0.001	0.87	435.38	< 0.001	0.96	2.74	0.114	0.13
85	116.27	< 0.001	0.96	397.29	< 0.001	0.95	2.19	0.155	0.10
90	86.26	< 0.001	0.82	293.87	< 0.001	0.94	1.32	0.264	0.07
95	38.19	< 0.001	0.67	91.39	< 0.001	0.83	0.19	0.665	0.01
100	1.32	0.265	0.07	4.75	0.042	0.20	0.89	0.357	0.05

F, Snedecor's F; P, P-value; η^2, partial eta squared.

Table 2. Comparison of the mean propulsive velocity ($m \cdot s^{-1}$) attained against each relative load (%RM) among half-squat exercises (n =20).

Load (%RM)	Standard half-squat	Concentric half-squat	Countermovement jump	Squat jump
30	1.11 ± 0.06 [b, c, d]	0.90 ± 0.05 [a, c, d]	1.31 ± 0.08 [a, b, d]	1.02 ± 0.09 [a, b, c]
35	1.06 ± 0.06 [b, c, d]	0.86 ± 0.05 [a, c, d]	1.24 ± 0.07 [a, b, d]	0.97 ± 0.08 [a, b, c]
40	1.00 ± 0.05 [b, c, d]	0.82 ± 0.04 [a, c, d]	1.17 ± 0.07 [a, b, d]	0.92 ± 0.08 [a, b, c]
45	0.95 ± 0.05 [b, c, d]	0.78 ± 0.04 [a, c, d]	1.10 ± 0.06 [a, b, d]	0.87 ± 0.07 [a, b, c]
50	0.89 ± 0.05 [b, c, d]	0.74 ± 0.04 [a, c, d]	1.03 ± 0.05 [a, b, d]	0.83 ± 0.07 [a, b, c]
55	0.84 ± 0.04 [b, c, d]	0.70 ± 0.03 [a, c, d]	0.96 ± 0.05 [a, b, d]	0.78 ± 0.06 [a, b, c]
60	0.78 ± 0.04 [b, c, d]	0.66 ± 0.03 [a, c, d]	0.89 ± 0.04 [a, b, d]	0.73 ± 0.05 [a, b, c]
65	0.73 ± 0.03 [b, c, d]	0.62 ± 0.03 [a, c, d]	0.82 ± 0.04 [a, b, d]	0.68 ± 0.05 [a, b, c]
70	0.67 ± 0.03 [b, c, d]	0.58 ± 0.02 [a, c, d]	0.75 ± 0.03 [a, b, d]	0.63 ± 0.04 [a, b, c]
75	0.62 ± 0.02 [b, c, d]	0.54 ± 0.02 [a, c, d]	0.69 ± 0.03 [a, b, d]	0.59 ± 0.03 [a, b, c]
80	0.56 ± 0.02 [b, c, d]	0.50 ± 0.02 [a, c, d]	0.62 ± 0.02 [a, b, d]	0.54 ± 0.03 [a, b, c]
85	0.51 ± 0.01 [b, c, d]	0.46 ± 0.01 [a, c, d]	0.55 ± 0.02 [a, b, d]	0.49 ± 0.02 [a, b, c]
90	0.45 ± 0.01 [b, c]	0.42 ± 0.01 [a, c, d]	0.48 ± 0.01[a, b, d]	0.44 ± 0.02 [b, c]
95	0.39 ± 0.01 [b, c]	0.38 ± 0.01 [a, c, d]	0.41 ± 0.01[a, b, d]	0.39 ± 0.01 [b, c]
100	0.34 ± 0.01	0.34 ± 0.01	0.34 ± 0.01	0.35 ± 0.01

1RM, one-repetition maximum; [a], significant differences with respect to standard half-squat exercise; [b], significant differences with respect to concentric half-squat exercise; [c], significant differences with respect to countermovement jump exercise; [d], significant differences with respect to squat jump exercise. Significance was accepted at the $P < 0.05$.