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Optimizing exercise prescription during breast cancer rehabilitation in women: Analysis of the load–velocity relationship in the box squat exercise

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Abstract

The aims of this study were to assess (i) the load–velocity relationship during the box squat exercise in women survivors of breast cancer, (ii) which velocity variable (mean velocity [MV], mean propulsive velocity [MPV], or peak velocity [PV]) shows stronger relationship with the relative load (%1RM), and (iii) which regression model (linear [LA] or polynomic [PA]) provides a greater fit for predicting the velocities associated with each %1RM. Nineteen women survivors of breast cancer (age: 53.2 ± 6.9 years, weight: 70.9 ± 13.1 kg, and height: 163.5 ± 7.4 cm) completed an incremental load test up to one-repetition maximum in the box squat exercise. The MV, MPV, and the PV were measured during the concentric phase of each repetition with a linear velocity transducer. These measurements were analyzed by regression models using LA and PA. Strong correlations of MV with %1RM ($R^2 = 0.903/0.904$; the standard error of the estimate (SEE) = 0.05 m·s^{-1} by LA/PA) and MPV ($R^2 = 0.900$; SEE = 0.06 m·s^{-1} by LA and PA) were observed. In contrast, PV showed a weaker association with %1RM ($R^2 = 0.704$; SEE = 0.15 m·s^{-1} by LA and PA). The MV and MPV of 1RM was 0.22 ± 0.04 m·s^{-1}, whereas the PV at 1RM was 0.63 ± 0.18 m·s^{-1}. These findings suggest that the use of MV to prescribe relative loads during resistance training, as well as LA and PA regression models, accurately predicted velocities for each %1RM.

David M. Díez-Fernández and Alba Esteban-Simón have contributed equally to this work.

Assessing and prescribing resistance exercises during breast cancer rehabilitation can be facilitated through the monitoring of movement velocity.

KEYWORDS
exercise cancer prescription, load-velocity profile, lower-limb strength, resistance training, velocity-based training

Highlights

- Movement velocity allows to precisely determine the relative load during the box squat exercise without submitting the patient to excessive mechanical and metabolic stress.
- From a practical perspective, we suggest using the mean velocity and a linear adjustment.
- This approach could provide an advantage over traditional assessment methods, enabling the efficient evaluation and prescription of resistance training intensity in exercise rehabilitation programs for women survivors of breast cancer.

1 | INTRODUCTION

Survivors of breast cancer suffer substantial muscular strength loss during treatments (Blas et al., 2018; Mallard et al., 2023; Mallard et al., 2021). Upper and lower limbs have shown about a 12%–16% and 25% loss of muscular strength, respectively (Klassen et al., 2017). This decrease in strength negatively impacts on health-related quality of life (Mallard et al., 2021), daily functioning (Williams et al., 2017), long-term prognosis (Caan et al., 2018; Klassen et al., 2017), and leads to increased pain (Ballinger et al., 2022; Wang et al., 2018), fatigue (Ballinger et al., 2022; Mallard et al., 2021), and the risk of bone loss (Ballinger et al., 2022). Consequently, preserving and enhancing muscular strength is crucial during the rehabilitation of survivors of breast cancer.

Monitoring intensity is essential to properly control and prescribe RT to enhance muscular strength (Fry, 2004). Recent studies with survivors of breast cancer used traditional procedures to prescribe and monitor the relative load (%1RM, percentage of an individual's one-repetition maximum, used as a measure of RT intensity), including performing a one-repetition maximum (1RM, which is the maximum weight that an individual can lift for a single repetition in a specific exercise) (Garcia-Unciti et al., 2023; Guloglu et al., 2023) or performing repetitions to failure (XRM, the maximum number of repetitions that can be completed) (Calonego et al., 2023; Koevoets et al., 2023). However, these methods may cause significant muscle soreness and extended recovery times between sessions because of the high physical stress imposed (Shaw et al., 1995). In this line, emerging evidence questions the suitability of these methods for prescribing resistance intensity in cancer survivors (Schneider et al., 2022). Therefore, it seems important to establish training and testing procedures that maximize the benefits and minimize the risk of RT, optimizing exercise during breast cancer rehabilitation.

Compelling evidence demonstrates a strong relationship between the movement velocity and the %1RM in several exercises (Benavides-Ubric et al., 2020; Conceição et al., 2016; González-Badillo & Sánchez-Medina, 2010; Janicijevic et al., 2021; Muñoz-López et al., 2017; Pérez-Castilla et al., 2020; Sánchez-Moreno et al., 2017). However, these studies primarily included young and healthy individuals. Using movement velocity allows to precisely estimate the %1RM during training without the need to perform 1RM or XRM (González-Badillo et al., 2011), reducing mechanical and metabolic stress on the patient. Consequently, applying this approach into clinical conditions could offer a significant advantage, particularly in cancer patients who experience cancer-related fatigue, a major limiting factor to exercise (Stasi et al., 2003). Recent studies have started assessing the accuracy of movement velocity for estimating the relative load among individuals with clinical conditions, including survivors of breast cancer (Díez-Fernández et al., 2021; Franco-López et al., 2023), multiple sclerosis (Andreu-Caravaca et al., 2020), older women (Marcos-Pardo et al., 2019), and older adults without mobility limitations (Marques et al., 2023).

Although the box squat is a commonly used exercise in training programs (Argus, Gill, Keogh, & Hopkins, 2011Argus et al., 2011; Mathieu et al., 2022), the load–velocity relationship in this exercise has not been investigated. Closed kinetic chain exercises are considered safer than open kinetic chain exercises because of the compressive joint load produced by bodyweight and the co-contraction of the quadriceps and hamstrings (Kvist & Gillquist, 2001). Specifically, the box squat exercise showed less medial tibial translation and less range of motion of the tibiofemoral joint in internal–external rotation and medial–lateral translation than other knee extension motions (Li et al., 2022). Regarding the differences between the squat and box squat, the shin maintained a less inclined position during box squat, resulting in lower peak joint moments at the spine and ankle (Swinton, Stewart, Lloyd, Keogh, & Agouris, 2012). Nevertheless, the peak force and power were similar, and minimal differences were observed for muscle activity (Mcbride, Szkinner, Schafer, Haines, & Kirby, 2010). Due to its safety features, the large musculature involved, and its potential to be prescribed in RT programs assessing the load–velocity relationship of the box squat exercise could be of wide practical and clinical interest.

Therefore, the aims of this study were to assess (i) the load–velocity relationship during the box squat exercise in women survivors of breast cancer, (ii) which velocity variable (mean velocity [MV], mean propulsive velocity [MPV], or peak velocity [PV]) shows stronger relationship with the relative load, and (iii) which regression model (linear [LA] or polynomic [PA]) provides a greater fit for predicting the velocities associated with each relative load (%1RM). We hypothesized that (i) a close relationship exists between movement velocity and relative load during the box squat exercise in women survivors of breast cancer as observed in a previous study in leg press exercise with the same population (Díez-Fernández et al., 2021), (ii) mean velocities (MV and MPV) show stronger relationship with the relative load (García-Ramos, Pestaña-Melero, et al., 2018), and (iii) both LA and PA demonstrate a good fit, which are consistent with previous research on different squat variations (Martínez-Cava et al., 2019; Pérez-Castilla et al., 2020).

2 | METHODS

2.1 | Participants

A group of 19 women volunteered to participate in this study. All participants had undergone surgery and had completed core breast cancer treatment (chemotherapy or radiotherapy) within the previous 10 years. The participants' characteristics are presented in Table 1. The exclusion criteria were as follows: (1) metastatic breast cancer; (2) to have undergone a breast reconstruction less than 3 months earlier; and (3) having any comorbidity that might contraindicate the performance of a maximum test. The present research was conducted in accordance with the Helsinki Declaration and was approved by the Ethics Committee of the University of Almeria, Spain (ref: UALBIO2022/008). After being informed of the purpose of the study and the experimental procedures, the participants signed a written informed consent form prior to participation.

2.2 | Experimental design

A descriptive cross-sectional study was conducted to assess the load–velocity relationship during the box squat exercise in women survivors of breast cancer. For this purpose, each participant underwent a single test performing an incremental load test up to 1RM for the individual determination of the full load–velocity relationship. The participants underwent a preliminary 10-week supervised resistance exercise program with 2 group-based (four to six participants) training sessions per week (a total of 20 sessions of 60 min). During these sessions, the participants were familiarized with the box squat exercise, while the exercise professional emphasized the technique and the intention to move the loads at maximum velocity during the concentric phase. The analyses were performed measuring different velocity variables: (1) MV: the average bar velocity ($m{\cdot}s^{-1}$) from the start of the concentric phase until the bar reaches the maximum height; (2) MPV: the average bar velocity values during the propulsive phase defined as the part of the concentric phase during which the measured acceleration is greater than the acceleration due to gravity ($\geq$-9.81 $m{\cdot}s^{-2}$) (Sanchez-Medina et al., 2010); and (3) PV: the highest velocity value recorded at a particular instant ($m{\cdot}s^{-1}$) during the concentric phase.

2.3 | Testing procedures

Participants attended a previous medical check-up to assess whether they had any contraindications for performing a maximum test. Additionally, height (digital-Seca 202 stadiometer; Seca Ltd, Hamburg, Germany), weight, and body composition were assessed (electrical bioimpedance-InBody 120; InBody Co Ltd, Seoul, South Korea). All the testing sessions were conducted in the same place (research sport laboratory, under similar environmental conditions (~21°C and ~60% humidity). Strong verbal stimulation was provided during testing to motivate the participants to exert maximum effort.

Box squat exercise was performed using a Smith machine (Multipower Fitness Line, Peroga, Murcia, Spain). The box squat comprised an eccentric phase followed by sitting on a box and then a concentric phase (Figure 1). First, subjects flexed their knees to 90° in a continuous and controlled manner and maintained this position for ~1 s sitting on a box. This ensured lack of glute bouncing on the box and avoided using elastic energy, obtaining more stable and reliable measurements (Pallarés et al., 2014). After the momentary pause, an audible signal was given by the evaluator and immediately afterward, the participant performed a purely concentric action at maximal intended velocity without lifting the toes off the ground. To be considered as a valid repetition, the participants' knees had to reach full extension. If the execution was not correct or the displacement range was not adequate (at the discretion of the evaluators), a new set was performed with the same absolute load after the corresponding resting period. Movement velocity during the concentric phase of all repetitions was recorded with a linear velocity transducer (T-Force System, Ergo-Tech, Murcia, Spain). During the test, one researcher helped the participants to remove and insert the barbell from the support at the beginning and end of the execution, while a second researcher provided information on correct execution and feedback on movement velocity after each repetition. These researchers also helped the participant to place the barbell in the starting position when the proposed load was not displaced. In these cases, after the relevant rest (~4 min), a new attempt was made with the same absolute load to verify that the participants were not actually able to displace that load.

The warm-up protocol consisted of 5-min walking at a self-selected velocity, 2 min of upper-body dynamic joint mobility exercises, a set of 10 repetitions performing box squat without additional weight, and a set of 6 repetitions in the Smith machine with 5 kg (mass of the barbell used in the testing procedure). During the warm-up, participants were instructed to squat flexing their knees until

TABLE 1 Descriptive characteristics (mean ± SD) of the study participants.

Subject's physical characteristics	
Age (years)	53.21 ± 6.93
Weight (kg)	70.87 ± 13.12
Height (cm)	163.52 ± 7.41
1RM box squat (kg)	50.11 ± 10.30
Medical information	
Time since diagnosis (years)	4.63 ± 3.25
Treatment *n* (%)	
Chemotherapy	13 (31.6)
Radiotherapy	17 (89.5)
Hormone therapy	14 (73.7)
Surgical procedure *n* (%)	
Tumorectomy	12 (63.2)
Mastectomy	7 (36.8)

Abbreviations: 1RM, one-repetition maximum; SD: standard deviation.

FIGURE 1 Box squat exercise, linear velocity transducer, and researcher during test.

reaching a position with 90° knee angle. This height was recorded for each subject. To ensure consistency and eliminate any potential impact of varying knee angles on the load–velocity relationship during the incremental test, all repetitions were performed at the same box height. This height was adjusted by manipulating the number of boxes and discs used as platforms. Participants were required to touch the box at 90° depth tailored to each subject. During the test, the initial load was set at 5 kg for all the subjects and was increased by 10 kg until reaching a MPV of ~0.60 $m \cdot s^{-1}$. Subsequently, there were 5 kg increments until reaching a MPV of ~0.40 $m \cdot s^{-1}$. Starting at this MPV, the load settings were increased by five or 1 kg, depending on the MPV, until reaching the 1RM. The last load that was correctly displaced completing the appropriate range of motion that was determined as the 1RM value. During the incremental test, the participants performed 3 repetitions at low loads (>0.60 $m \cdot s^{-1}$), 2 at medium loads (0.60–0.40 $m \cdot s^{-1}$), and only 1 at high loads (<0.40 $m \cdot s^{-1}$). The recovery time between sets ranged from 3 min (low loads) to 4 min (high loads). Only the best repetition (i.e., that with the highest value of each velocity variable) of each set was considered for further analysis.

2.4 | Statistical analysis

The descriptive data are presented as mean and standard deviation, calculated using standardized statistical methods. The normal distribution of the data was confirmed by the Shapiro–Wilk test ($p > 0.05$). For the correlation analysis between the relative load and the MV, MPV, and PV variables, linear and quadratic regression (second-degree polynomial) models were used. The goodness of fit was assessed by Pearson's multivariate coefficient of determination (R^2) and the standard error of the estimate (SEE). The between-subject coefficient of variation (CV) was calculated to determine the variability of the MV, MPV, and PV associated with each %1RM. A CV < 10% was determined as an acceptable reliability level. A Student's *t*-test for independent samples was used to explore the differences in regression models. Cohen's *d* effect sizes (ES) were used to assess the magnitude of the differences between regression models for each velocity variable, and the following scale was used for interpretation: trivial (<0.20), small (0.20 to < 0.60), moderate (0.60 to < 1.20), large (1.20 to < 2.00), and extremely large (>2.00) (Hopkins, 2000). The significance level was established at 5% ($P < 0.05$). All statistical analyses were performed using SPSS version 25.0 (SPSS, Chicago, IL).

3 | RESULTS

The 1RM mean value for the box squat exercise was 50.1 ± 10.3 kg. The number of loads used for the 1RM measurement was 11.0 ± 1.8. The MV and MPV of 1RM were 0.22 ± 0.04 m·s^{-1} (range: 0.15–0.30 m·s^{-1}), whereas the PV at 1RM was 0.63 ± 0.18 m·s^{-1} (range: 0.32–0.96 m·s^{-1}).

3.1 | Relationship between relative load and movement velocity

The linear and quadratic fits analyzed individually for the MV resulted in R^2 values of 0.975 ± 0.028 (range: 0.941–0.992; CV = 1.4%) and 0.983 ± 0.025 (range: 0.953–0.992; CV = 1.0%), respectively. For the MPV variable, the individually analyzed linear and quadratic fits showed average R^2 values of 0.977 ± 0.028 (range: 0.911–0.992; CV = 1.9%) and 0.982 ± 0.027 (range: 0.942–0.993; CV = 1.2%), respectively. For the PV variable, the individually analyzed linear and quadratic fits showed average values of R^2 = 0.939 ± 0.060 (range: 0.812–0.990; CV = 4.2%) and 0.954 ± 0.055 (range: 0.818–0.994; CV = 4.1%), respectively.

Taking all the data as a whole, a strong relationship was observed between the MV and the %1RM using a linear fit (R^2 = 0.903; SEE = 0.05 m·s^{-1}; and Figure 2A) and a polynomial fit (R^2 = 0.904; $p < 0.0001$; SEE = 0.05 m·s^{-1}; and Figure 2B). Similarly, a strong relationship (R^2 = 0.900; SEE = 0.06 m·s^{-1}) was observed between the MPV and the %1RM using a linear fit (Figure 2C) and a polynomial fit (Figure 2D). For PV, a weaker relationship (R^2 = 0.704; SEE = 0.15 m·s^{-1}) was observed between the PV and the %1RM using a linear fit (Figure 2E) and a polynomial fit (Figure 2F).

Comparison of the regression models and velocity variables.

Tables 2–4 present the MV, MPV, and PV data analyzed using linear and polynomial fits in the individual load–velocity relationship, starting from approximately 10% 1RM and progressing in 5% increments. For all velocity variables, we found that the maximum difference between fits was only 0.02 m·s^{-1}. No significant differences and a trivial ES were observed between regression models. The three velocity variables showed a similar level of consistency for both fits. The between subject's variability in the incremental test was lower for MV and MPV compared to PV. On average, the MV and MPV variables using both fits showed an acceptable variability (CV~10%), while the PV showed greater dispersion (CV>10%) using both fits.

3.2 | Prediction of the relative load (%1RM) using the movement velocity

The prediction equations for estimating the relative load (%1RM) from the MV (in m·s-1) data were.

- Load (%1RM) = *-155.46 · MV + 135.57* [R^2 = 0.903; SEE = 9.03 %1RM] using the linear fit.
- Load (%1RM) = 5.93 · *MV*^{2}–161.44 · *MV + 136.89* [R^2 = 0.904; SEE = 9.05 %1RM] using the polynomial fit.

In cases where MPV (in m·s^{-1}) were used, the resulting equations were:

- Load (%1RM) = *-145.63 · MPV + 132.05* [R^2 = 0.900; SEE = 9.17 %1RM] from the linear fit
- Load (%1RM) = 36.35 · *MPV*^{2}– *183.76 · MPV + 140.72* [R^2 = 0.904; SEE = 9.09 %1RM] from the polynomial fit.

In cases where PV (in m·s^{-1}) were used, the resulting equations were:

- Load (%1RM) = *-89.34 · PV + 149.97* [R^2 = 0.704; SEE = 15.82 %1RM] from the linear fit
- Load (%1RM) = *-21.96 · PV*^{2}*–44.94 · PV + 129.14* [R^2 = 0.710; SEE = 15.70 %1RM] from the polynomial fit.

4 | DISCUSSION

This study analyzed the load–velocity relationship during the box squat exercise in women survivors of breast cancer. The main findings revealed (a) a strong relationship between the movement velocity and the %1RM in the box squat exercise; (b) that both the MV and MPV showed a slightly stronger relationship with the relative load and lower CV compared to PV; and (c) both the LA and PA regression models accurately predicted the velocities associated with each %1RM. Therefore, these results indicate that measuring the movement velocity of the concentric phase is a valid alternative for precisely quantifying and adjusting the RT intensity during the rehabilitation of survivors of breast cancer.

For the first time, we examine the load–velocity relationship during the box squat exercise in women survivors of breast cancer, observing a close relationship between movement velocity and relative load ($R^2 > 0.90$). Interestingly, these results concur with previous evidence indicating that using movement velocity for prescribing and monitoring the relative load in clinical populations

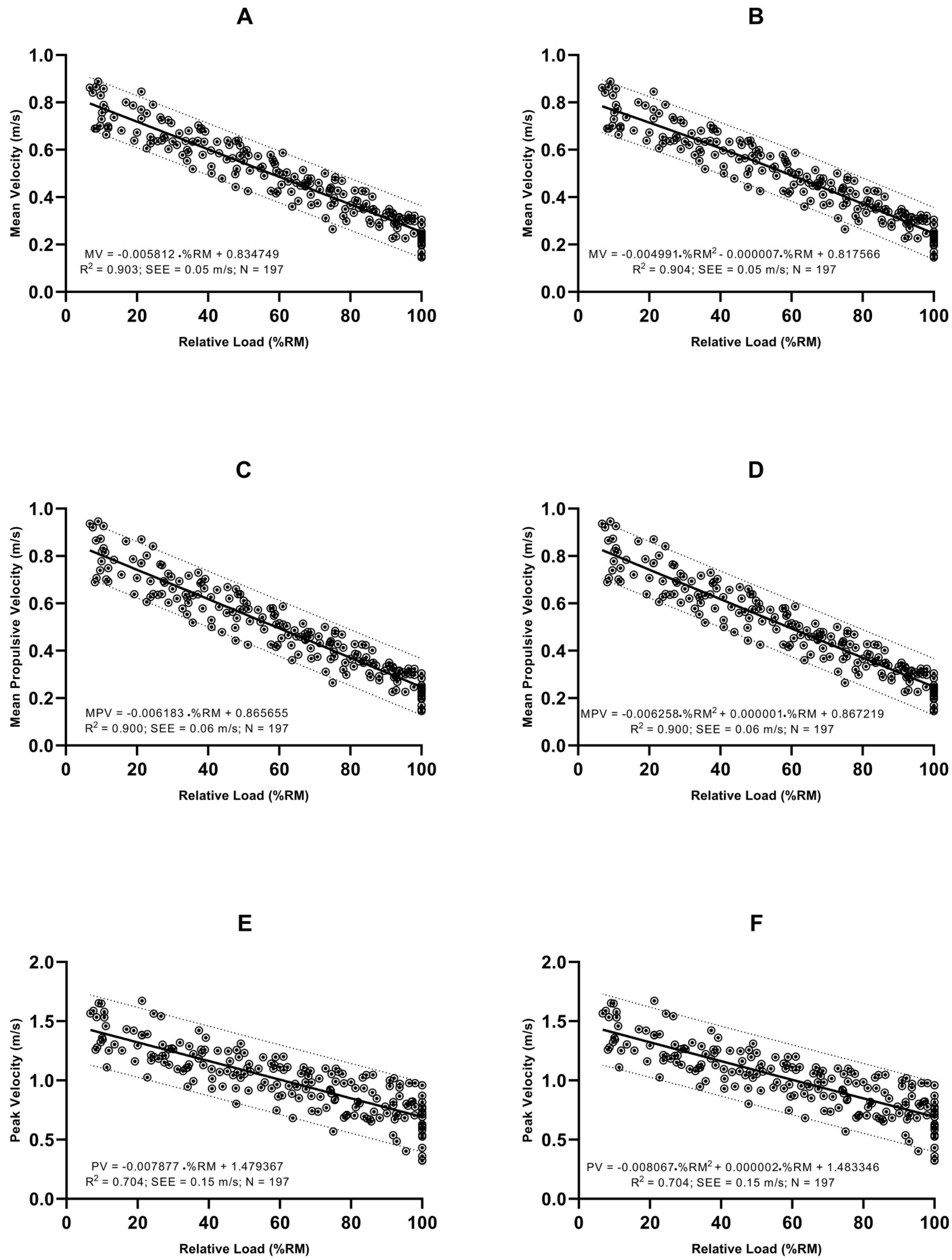

FIGURE 2 Relationship between the relative load (%1RM) and (A, B) the mean velocity, (C, D) the mean propulsive velocity, and the peak velocity (E, F) using a linear and polynomial fit. R^2, coefficient of determination; SEE, standard error of the estimate; N, number of observations; dotted lines indicate the 95% prediction bands.

during RT is feasible (Andreu-Caravaca et al., 2020; Díez-Fernández et al., 2023; Marcos-Pardo et al., 2019; Marques et al., 2023). In addition, our findings indicate that, for the box squat exercise, the utilization of individualized regression equations (R^2 = 0.94–0.98) yields more precise estimations of relative load compared to general equations (R^2 = 0.70–0.90). Significantly, this finding is in agreement with prior research, affirming that individual load–velocity relationships could provide more accurate predictions of relative load than general equations (Benavides-Ubric et al., 2020; García-Ramos, Haff, et al., 2018; Pestaña-Melero et al., 2018). However, the present results suggest that general equations using mean velocities variables (MV and MPV) show an acceptable relationship with the relative load (R^2 > 0.90 and SEE <0.06 ms-1) (Figure 2) and would avoid the need to perform a direct assessment of the load–velocity relationship,

TABLE 2 Mean velocity (m·s^{-1}) associated with each percentage of relative load obtained for the individual load–velocity relationship by linear and polynomial fit.

	Linear fit		Polynomial fit		Differences between fits		
Relative load (%1RM)	Mean ± SD (m·s^{-1})	CV (%)	Mean ± SD (m·s^{-1})	CV (%)	Mean ± SD (m·s^{-1})	*p*	ES (95% CI)
10%	0.77 ± 0.08	9.8	0.76 ± 0.07	8.6	0.01 ± 0.03	0.290	0.07 (−0.46; 0.82)
15%	0.74 ± 0.07	9.6	0.73 ± 0.06	8.7	0.01 ± 0.02	0.363	0.07 (−0.52; 0.75)
20%	0.71 ± 0.07	9.5	0.71 ± 0.06	8.8	0.00 ± 0.02	0.437	0.07 (−0.58; 0.69)
25%	0.69 ± 0.06	9.4	0.69 ± 0.06	9.0	0.00 ± 0.01	0.491	0.06 (−0.64; 0.63)
30%	0.66 ± 0.06	9.3	0.66 ± 0.06	9.3	0.00 ± 0.01	0.426	0.06 (−0.70; 0.58)
35%	0.63 ± 0.06	9.2	0.63 ± 0.06	9.6	−0.01 ± 0.01	0.371	0.06 (−0.74; 0.53)
40%	0.60 ± 0.05	9.1	0.61 ± 0.06	9.9	−0.01 ± 0.01	0.327	0.06 (−0.78; 0.49)
45%	0.57 ± 0.05	9.0	0.58 ± 0.06	10.2	−0.01 ± 0.01	0.292	0.06 (−0.82; 0.46)
50%	0.54 ± 0.05	9.0	0.55 ± 0.06	10.4	−0.01 ± 0.02	0.267	0.05 (−0.84; 0.44)
55%	0.51 ± 0.05	8.9	0.52 ± 0.06	10.6	−0.01 ± 0.02	0.252	0.05 (−0.86; 0.42)
60%	0.48 ± 0.04	8.9	0.49 ± 0.05	10.7	−0.01 ± 0.02	0.247	0.05 (−0.86; 0.42)
65%	0.46 ± 0.04	8.9	0.47 ± 0.05	10.8	−0.01 ± 0.02	0.252	0.05 (−0.86; 0.42)
70%	0.43 ± 0.04	9.0	0.44 ± 0.05	10.8	−0.01 ± 0.01	0.272	0.04 (−0.84; 0.44)
75%	0.40 ± 0.04	9.3	0.40 ± 0.04	10.7	−0.01 ± 0.01	0.310	0.04 (−0.80; 0.48)
80%	0.37 ± 0.04	9.6	0.37 ± 0.04	10.6	0.00 ± 0.01	0.376	0.04 (−0.74; 0.53)
85%	0.34 ± 0.03	10.1	0.34 ± 0.04	10.7	0.00 ± 0.01	0.476	0.04 (−0.66; 0.62)
90%	0.31 ± .03	10.9	0.31 ± 0.03	11.1	0.00 ± 0.00	0.390	0.03 (−0.55; 0.73)
95%	0.28 ± 0.03	12.0	0.28 ± 0.03	12.3	0.01 ± 0.01	0.250	0.03 (−0.42; 0.86)
100%	0.25 ± 0.03	13.5	0.24 ± 0.04	15.0	0.01 ± 0.02	0.142	0.04 (−0.29; 0.99)
Average	0.51 ± 0.05	9.7	0.51 ± 0.05	10.4	0.00 ± 0.01	0.328	0.05 (−0.68; 0.59)

Note: Differences between linear and polynomial fits.

Abbreviations: 1RM, one-repetition maximum; 95% CI, 95% confidence interval; CV, coefficient of variation; ES, effect size between linear and polynomial fits; *p*, *p*-value; SD, standard deviation.

which could be especially interesting when working with survivors of breast cancer.

Regarding the second hypothesis, our results showed differences in the magnitude of the relationship between the velocity variables. The MV and MPV show stronger relationship with the % 1RM for both fits (Figure 2). In addition, the PV variable displayed greater between-subject variability (CV>10%) across all relative loads (from 10% to 100% 1RM) (Table 4). This finding concurs with previous literature which suggested that PV could be more appropriate for examining ballistic movements (Sayers et al., 2018) or power cleans (Haff et al., 2020). In contrast, the MV showed a CV>10% only in heavy relative loads (>85% 1RM), with the worst value being observed at 100%1RM (Table 2). It has been argued that the ability to control movement is limited when heavy loads are being used, since changes in the movement pattern are produced by muscular tonic control (Gołaś et al., 2017). This could have led to greater variability in the execution technique in >85% 1RM load, especially in participants with a lower degree of experience with those loads as breast cancer survivors. Also, from a mathematical standpoint, given the absolute velocities attained against heavy relative loads are considerably low (<0.30 ms-1), a slight difference in the average velocity between attempts would represent a substantial change in relative terms. In addition, in survivors of cancer, the MV was identified as the most recommendable velocity variable for prescribing the relative load during the leg-press exercise (Díez-Fernández et al., 2021). Although our results showed no differences in the magnitude of the relationship between MV variables with the %1RM during the box squat exercise, the MV may be preferred due to its ease to be measured using commonly available linear transducers and other devices as suggested in prior literature (García-Ramos, Pestaña-Melero, et al., 2018).

Previous studies have analyzed the load–velocity relationship in young men during the half squat exercise (the range of motion during this exercise was the same as the box squat exercise in our study, i.e., 90° knee flexion) using LA (Conceição et al., 2016; Loturco et al., 2016; Pérez-Castilla et al., 2020) and PA (Martínez-Cava et al., 2019). Nevertheless, these previous studies did not provide

TABLE 3 Mean propulsive velocity (m·s^{-1}) associated with each percentage of relative load obtained for the individual load–velocity relationship by linear and polynomial fit.

	Linear fit		Polynomial fit		Differences between fits		
Relative load (%1RM)	Mean ± SD (m·s^{-1})	CV (%)	Mean ± SD (m·s^{-1})	CV (%)	Mean ± SD (m·s^{-1})	*p*	ES (95% CI)
10%	0.80 ± 0.09	10.9	0.80 ± 0.08	9.9	0.00 ± 0.03	0.477	0.08 (−0.62; 0.66)
15%	0.77 ± 0.08	10.7	0.77 ± 0.08	9.8	0.00 ± 0.03	0.498	0.08 (−0.64; 0.64)
20%	0.74 ± 0.08	10.6	0.74 ± 0.07	9.8	0.00 ± 0.02	0.481	0.08 (−0.65; 0.62)
25%	0.71 ± 0.07	10.5	0.71 ± 0.07	9.9	0.00 ± 0.01	0.462	0.07 (−0.67; 0.60)
30%	0.68 ± 0.07	10.3	0.68 ± 0.07	10.1	0.00 ± 0.01	0.445	0.07 (−0.68; 0.59)
35%	0.65 ± 0.07	10.2	0.65 ± 0.07	10.2	0.00 ± 0.01	0.430	0.07 (−0.69; 0.58)
40%	0.61 ± 0.06	10.0	0.62 ± 0.06	10.4	0.00 ± 0.01	0.417	0.06 (−0.70; 0.57)
45%	0.58 ± 0.06	9.9	0.59 ± 0.06	10.6	0.00 ± 0.01	0.407	0.06 (−0.71; 0.56)
50%	0.55 ± 0.05	9.8	0.56 ± 0.06	10.8	0.00 ± 0.01	0.400	0.06 (−0.72; 0.55)
55%	0.52 ± 0.05	9.7	0.53 ± 0.06	10.9	0.00 ± 0.01	0.396	0.05 (−0.72; 0.55)
60%	0.49 ± 0.05	9.6	0.50 ± 0.05	11.0	0.00 ± 0.01	0.397	0.05 (−0.72; 0.55)
65%	0.46 ± 0.04	9.5	0.47 ± 0.05	10.9	0.00 ± 0.01	0.402	0.05 (−0.72; 0.56)
70%	0.43 ± 0.04	9.6	0.43 ± 0.05	10.9	0.00 ± 0.01	0.412	0.04 (−0.71; 0.56)
75%	0.40 ± 0.04	9.7	0.40 ± 0.04	10.7	0.00 ± 0.01	0.431	0.04 (−0.69; 0.58)
80%	0.37 ± 0.04	9.9	0.37 ± 0.04	10.6	0.00 ± 0.01	0.459	0.04 (−0.67; 0.60)
85%	0.34 ± 0.04	10.4	0.34 ± 0.04	10.6	0.00 ± 0.00	0.499	0.04 (−0.64; 0.64)
90%	0.31 ± 0.03	11.1	0.31 ± 0.03	10.9	0.00 ± 0.00	0.449	0.03 (−0.59; 0.68)
95%	0.28 ± 0.03	12.2	0.28 ± 0.03	12.0	0.00 ± 0.01	0.389	0.03 (−0.55; 0.73)
100%	0.25 ± 0.03	13.8	0.24 ± 0.04	14.5	0.00 ± 0.02	0.333	0.03 (−0.50; 0.78)
Average	0.52 ± 0.05	10.4	0.53 ± 0.06	10.8	0.00 ± 0.01	0.431	0.05 (−0.66; 0.61)

Note: Differences between linear and polynomial fits.

Abbreviations: 1RM, one-repetition maximum; 95% CI, 95% confidence interval; CV, coefficient of variation; ES, effect size between linear and polynomial fits; *p*, *p*-value; SD, standard deviation.

data for both fits simultaneously (LA and PA). The present findings revealed a similar fit for both models (R2 and SEE) when the data were analyzed in groups (Figure 2). In addition, when the data were analyzed individually, there were no significant differences between both regression models for all velocity variables, and the differences showed a trivial ES (ranged from 0.03 to 0.17) (Table 2, Table 3, Table 4). Therefore, confirming our third hypothesis, both the LA and PA predicted the velocities associated with each %1RM in breast cancer survivors during box squat exercise with acceptable accuracy. From a practical perspective, it might be reasonable to use a linear fit to simplify the regression equations.

This study has limitations that must be underlined. Three issues could compromise the generalizability of the present results to all women survivors of breast cancer: the sample size was relatively small, we included women who had undergone different breast cancer types of surgery (tumorectomy or mastectomy) and the time since diagnosis was not the same for all the participants (4.63 ± 3.25 years). Finally, our study did not analyze the load–velocity relationship during the box squat exercise in healthy individuals. Further studies should analyze the load–velocity relationship across diverse populations to assess potential differences in movement velocity for each relative load during the box squat exercise.

5 | CONCLUSIONS

Our study shows that it is possible to accurately determine the load–velocity relationship during the box squat exercise in women survivors of breast cancer. This allows checking whether the proposed load (kg) for a given training session of an exercise rehabilitation program represents the intended effort (%1RM) in the box squat exercise. Furthermore, both regression models (LA and PA) offer similar accuracy, with mean velocities (MV and MPV) providing more reliable predictions of relative load. From a practical perspective, it might be reasonable to use MV and an LA to simplify the regression

TABLE 4 Peak velocity (m·s^{-1}) associated with each percentage of relative load obtained for the individual load–velocity relationship by linear and polynomial fit.

	Linear fit		Polynomial fit		Differences between fits		
Relative load (%1RM)	Mean ± SD (m·s^{-1})	CV (%)	Mean ± SD (m·s^{-1})	CV (%)	Mean ± SD (m·s^{-1})	*p*	ES (95%CI)
10%	1.40 ± 0.14	10.2	1.39 ± 0.15	11.2	0.01 ± 0.07	0.415	0.15 (−0.57; 0.71)
15%	1.36 ± 0.14	10.3	1.35 ± 0.15	10.8	0.01 ± 0.05	0.453	0.14 (−0.60; 0.67)
20%	1.32 ± 0.14	10.5	1.32 ± 0.14	10.6	0.00 ± 0.03	0.489	0.14 (−0.63; 0.65)
25%	1.28 ± 0.14	10.7	1.28 ± 0.13	10.5	0.00 ± 0.02	0.478	0.14 (−0.65; 0.62)
30%	1.24 ± 0.13	10.9	1.24 ± 0.13	10.5	−0.01 ± 0.02	0.449	0.13 (−0.68; 0.59)
35%	1.20 ± 0.13	11.2	1.21 ± 0.13	10.6	−0.01 ± 0.02	0.426	0.13 (−0.70; 0.58)
40%	1.16 ± 0.13	11.5	1.17 ± 0.13	10.9	−0.01 ± 0.02	0.408	0.13 (−0.71; 0.56)
45%	1.12 ± 0.13	11.9	1.13 ± 0.13	11.1	−0.01 ± 0.03	0.396	0.13 (−0.72; 0.55)
50%	1.08 ± 0.13	12.3	1.09 ± 0.13	11.5	−0.01 ± 0.03	0.390	0.13 (−0.73; 0.55)
55%	1.04 ± 0.13	12.8	1.05 ± 0.13	11.9	−0.01 ± 0.03	0.390	0.13 (−0.73; 0.55)
60%	1.00 ± 0.13	13.4	1.01 ± 0.13	12.5	−0.01 ± 0.03	0.396	0.13 (−0.72; 0.55)
65%	0.96 ± 0.14	14.1	0.97 ± 0.13	13.1	−0.01 ± 0.03	0.407	0.13 (−0.71; 0.56)
70%	0.92 ± 0.14	14.9	0.93 ± 0.13	13.9	−0.01 ± 0.03	0.424	0.13 (−0.70; 0.57)
75%	0.88 ± 0.14	15.8	0.89 ± 0.13	15.0	−0.01 ± 0.02	0.447	0.14 (−0.68; 0.59)
80%	0.84 ± 0.14	16.8	0.85 ± 0.14	16.3	0.00 ± 0.01	0.474	0.14 (−0.66; 0.62)
85%	0.80 ± 0.14	18.0	0.80 ± 0.15	18.1	0.00 ± 0.01	0.495	0.14 (−0.63; 0.64)
90%	0.77 ± 0.15	19.3	0.76 ± 0.15	20.3	0.00 ± 0.01	0.461	0.15 (−0.60; 0.67)
95%	0.73 ± 0.15	20.8	0.72 ± 0.17	23.2	0.01 ± 0.02	0.426	0.16 (−0.58; 0.70)
100%	0.69 ± 0.15	22.5	0.67 ± 0.18	26.9	0.02 ± 0.04	0.392	0.17 (−0.55; 0.73)
Average	1.04 ± 0.14	14.1	1.04 ± 0.14	14.2	0.00 ± 0.03	0.432	0.14 (−0.66; 0.61)

Note: Differences between linear and polynomial fits.

Abbreviations: 1RM, one-repetition maximum; 95% CI, 95% confidence interval; CV, coefficient of variation; ES, effect size between linear and polynomial fits; *p*, *p*-value; SD, standard deviation.

equations in survivors of breast cancer. Therefore, this method is helpful for clinicians, researchers, and coaches to prescribe and monitor the relative load in the box squat exercise according to the movement velocity of the concentric phase.

AUTHOR CONTRIBUTIONS

David M. Díez-Fernández participated in the design of the study, contributed to data collection and statistical analysis, wrote original draft; Alba Esteban-Simón participated in the design of the study, contributed to data collection, wrote original draft; Andrés Baena-Raya participated in the design of the study, contributed to data collection, wrote original draft; David Rodríguez-Rosell participated in the design of the study, contributed to statistical analysis; Filipe Conceição contributed to statistical analysis; Manuel A. Rodríguez-Pérez participated in the design of the study, contributed to data collection, provided resources and carried out project administration.; Alberto Soriano-Maldonado participated in the design of the study, obtained funding, provided resources and carried out project administration. All the authors contributed to the manuscript writing. All the authors have read and approved the final version of the manuscript and agree with the order of presentation of the authors.

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CONFLICT OF INTEREST STATEMENT

No potential conflict of interest was reported by the authors. This manuscript is original and not previously published, nor is it being considered elsewhere until a decision is made as to its acceptability by the EJSS Editorial Review Board.

DATA AVAILABILITY STATEMENT

The data that support the findings of this study are available from the corresponding author upon reasonable request.

PERMISSION TO REPRODUCE MATERIAL FROM OTHER SOURCES

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