European Journal of Sport Science

ISSN: (Print) (Online) Journal homepage: https://www.tandfonline.com/loi/tejs20

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To cite this article: David M. Díez-Fernández, Andrés Baena-Raya, Celia Alcaraz-García, David Rodríguez-Rosell, Manuel A. Rodríguez-Pérez & Alberto Soriano-Maldonado (2021): Improving resistance training prescription through the load-velocity relationship in breast cancer survivors: the case of the leg-press exercise, European Journal of Sport Science, DOI: 10.1080/17461391.2021.1965220

To link to this article: https://doi.org/10.1080/17461391.2021.1965220

Accepted author version posted online: 06 Aug 2021.

Publisher: Taylor & Francis & European College of Sport Science

Journal: *European Journal of Sport Science*

DOI: 10.1080/17461391.2021.1965220

Improving resistance training prescription through the load-velocity relationship in breast cancer survivors: the case of the leg-press exercise

Type of article: ORIGINAL INVESTIGATION

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Running title: Leg-press load-velocity profile in breast cancer survivors

Word count for abstract: 242
Word count for main text: 4378
Number of Tables: 3
Number of Figures: 3
Number of references: 43

Abstract

The aims of this study were: i) to analyze the load-velocity relationship in the bilateral leg-press exercise in female breast cancer survivors, ii) to assess whether mean velocity (MV) or peak velocity (PV) show stronger relationship with the relative load, and iii) to examine whether linear (LA) or polynomic (PA) adjustment predict the velocities associated with each %1RM with greater precision. Twenty-two female breast cancer survivors (age: 50.2±10.8 years, weight: 69.6±15.2 kg, height: 160.51±5.25 cm) completed an incremental load test until 1RM in the bilateral leg-press exercise. The MV and the PV of the concentric phase were measured in each repetition using a linear velocity transducer, and were analyzed by regression models using LA and PA. A very close relationship of MV (R^2=0.924; $p<0.0001$; SEE=0.08m·s^{-1} by LA, and R^2=0.952; $p<0.0001$; SEE=0.063 m·s^{-1} by PA) and PV (R^2=0.928; $p<0.0001$; SEE=0.119 m·s^{-1} by LA and R^2=0.941; $p<0.0001$; SEE=0.108 m·s^{-1} by PA) with %1RM were observed. The MV of 1RM was 0.24±0.03 m·s^{-1}, whereas the PV at 1RM was 0.60±0.10 m·s^{-1}. A comprehensive analysis of the bilateral leg-press load-velocity relationship in breast cancer survivors is presented. The results suggest that MV is the most recommendable velocity variable to prescribe the relative load during resistance training, and that the PA presents better accuracy to predict velocities associated with each %1RM, although LA is sufficiently valid to use this model as an alternative to the quadratic model. The implications for resistance training in breast cancer are discussed.

Key words: resistance training, velocity-based training, lower-body exercise, exercise prescription, cancer.

Highlights

- The load-velocity relationship in the bilateral leg-press exercise was described in female breast cancer survivors.
- The mean velocity is the most recommendable velocity variable to prescribe the relative load during resistance training in this population.
- The polynomial adjustment presents a better accuracy to predict velocities associated with each %1RM, although the linear adjustment is sufficiently valid as an alternative.
- This study will likely contribute to improving exercise prescription and monitoring in breast cancer survivors.

Introduction

Breast cancer is the type of cancer with the highest incidence in women, with almost 2.1 million new patients diagnosed every year, and the leading cause of cancer death worldwide (Siegel, Miller, & Jemal, 2020). Although early detection significantly increases the survival rate (Eloranta, Smedby, Dickman, & Andersson, 2020), patients still have to deal with the consequences of the disease and its treatment during the following years (Campbell et al., 2012). A negative side effect of the treatment is the loss of muscle mass and muscular strength of the lower body (approximately 25% lower compared to healthy individuals) (Klassen et al., 2017). Since muscular strength is key to conduct daily tasks and preserve quality of life (Folland, Buckthorpe, & Hannah, 2014), assessing patient's strength levels is of major research and clinical importance.

Resistance training (RT) is a safe and effective method to increase muscular strength levels in breast cancer survivors, even in the presence of lymphedema (Strasser, Steindorf, Wiskemann, & Ulrich, 2013). In fact, previous studies report that patients who engage in RT programs show a lower mortality risk of up to 33% (Courneya et al., 2014; Hardee et al., 2014). Among the wide variety of lower-body RT exercises, the bilateral leg-press is one of the most commonly used exercise in fitness centres. Cešeiko et al., (2020) indicate that the feasibility and safety of the leg-press exercise during breast cancer treatment should be considered satisfactory. Therefore, this exercise might enable patients to improve strength and functionality during the follow up of adjuvant breast cancer therapy.

Quantifying and monitoring the relative load during RT is essential because it directly determines the training effects and subsequent adaptations (Fry, 2004). The relative load has been traditionally prescribed through indirect measures, including the percentage of one-repetition maximum (1RM) or the maximum repetitions performed against a given absolute load (XRM), even in breast cancer patients (Cormie et al., 2013; de Paulo et al., 2018; Schmitz et al., 2010; Winters-Stone et al., 2013). However, these testing methods present a number of important drawbacks worth noting: 1) Attempting a 1RM with heavy weights tends to increase blood pressure and stress on the muscles, bones, and connective tissues and may increase the risk of muscular injury, especially in individuals not accustomed to resistance training (Brzycki, 1993), such as breast cancer patients; 2) Since lifting heavy loads (1RM) or perform repetitions to failure (XRM) tend to induce excessive mechanical and metabolic strain and a substantial fatigue (Sanchez-Medina & Gonzalez-Badillo, 2011), a core symptom of breast cancer (Stasi, Abriani, Beccaglia, Terzoli, & Amadori, 2003), these traditional methods might put the patient under unnecessary risks; 3) Additionally, the experience and level of practice of the participant may affect the accuracy of the results (Grgic, Lazinica, Schoenfeld, & Pedisic, 2020); 4) The 1RM value is rapidly increased during the first weeks of the intervention in untrained population (Garcia-Ramos & Jaric, 2018; Gonzalez-Badillo & Sanchez-Medina, 2010; Rodriguez-Rosell et al., 2021), and a number of XRM does not necessarily constitute the same %1RM for all participants (Gonzalez-Badillo, Yanez-Garcia, Mora-Custodio, & Rodriguez-Rosell, 2017; Rodriguez-Rosell, Yanez-Garcia, Sanchez-Medina, Mora-Custodio, & Gonzalez-Badillo, 2020). Therefore, alternative approaches to precisely estimate 1RM and the %1RM at a given load without excessive effort in breast cancer survivors are needed.

Monitoring movement velocity during the concentric phase allows: 1) to accurately prescribe the relative load of upper- and lower-body exercises in men and women (Gonzalez-Badillo & Sanchez-Medina, 2010; Pareja-Blanco, Walker, & Hakkinen, 2020); 2) increasing motivation by providing immediate feedback (Weakley et al., 2018); 3) adjusting the individual absolute load quickly and continuously (Gonzalez-Badillo, Marques, & Sanchez-Medina, 2011) making it easier to update the 1RM estimate or the %RM during the intervention when needed; 4) improving the effectiveness of RT compared to other training methods not performed at the maximum movement velocity (Pareja-Blanco, Rodriguez-Rosell, Sanchez-Medina, Gorostiaga, & Gonzalez-Badillo, 2014); and 5) controlling the level of fatigue incurred in the set (Rodriguez-Rosell et al., 2020; Sanchez-Medina & Gonzalez-Badillo, 2011). Numerous studies have shown a close relationship between movement velocity and the %1RM in several exercises such as the bench press (Gonzalez-Badillo & Sanchez-Medina, 2010; Loturco et al., 2017), prone bench pull (Garcia-Ramos et al., 2019; Sanchez-Medina, Gonzalez-Badillo, Perez, & Pallares, 2014), prone pull-up (Sanchez-Moreno, Rodriguez-Rosell, Pareja-Blanco, Mora-Custodio, & Gonzalez-Badillo, 2017), military-press (Balsalobre-Fernández, García-Ramos, & Jiménez-Reyes, 2018), dead-lift (Benavides-Ubric, Diez-Fernandez, Rodriguez-Perez, Ortega-Becerra, & Pareja-Blanco, 2020) and a number of variations of the squat exercise (Martinez-Cava, Moran-Navarro, Sanchez-Medina, Gonzalez-Badillo, & Pallares, 2019; Sánchez-Medina, Pallarés, Pérez, Morán-Navarro, & González-Badillo, 2017). Based on these results, the relative load is easily adjusted with great precision simply by executing the first repetition against a given load at the maximum intended velocity (Gonzalez-Badillo & Sanchez-Medina, 2010). Therefore, it represents an objective method to evaluate RT and to quantify and monitor the training dose.

Although the leg-press exercise is one of the most popular exercises, the load-velocity relationship in this exercise has hardly been studied (Conceicao, Fernandes, Lewis, Gonzalez-Badillo, & Jimenez-Reyes, 2015; Marcos-Pardo, Gonzalez-Hernandez, Garcia-Ramos, Lopez-Vivancos, & Jimenez-Reyes, 2019). Due to its safety features, the large musculature involved, and its potential to be prescribed as part of RT programs aiming to increase muscular strength in breast cancer patients, assessing the load-velocity relationship of the leg-press exercise in this population is of wide practical and clinical interest. Therefore, the aims of this study were i) to analyze the load-velocity relationship in the bilateral leg-press exercise in female breast cancer survivors, ii) to assess whether mean velocity (MV) or peak velocity (PV) show stronger relationship with the relative load, and iii) to examine whether linear (LA) or polynomic (PA) adjustment predict the velocities associated with each %1RM and the estimated 1RM with greater precision.

Methods

Participants

As part of the EFICAN study (Soriano-Maldonado et al., 2019), a subgroup of 30 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: 1) metastatic breast cancer 2) breast reconstruction performed less than 3 months before; 3) having any comorbidity that might contraindicate the performance of a maximum test (decompensated heart failure, unstable ischemic cardiomyopathy, untreated high blood pressure, severe valvulopathies, chronic obstructive pulmonary disease, chronic respiratory failure, etc.); 4) regularly performing more than 300 minutes of structured exercise per week; 5) not reaching a MV above 0.80 $m \cdot s^{-1}$ with the minimum load allowed by the leg-press machine used (i.e., 25kg) during the familiarization session (to ensure that the entire load-velocity relationship (including the low-load/high velocity area of the curve) could be assessed for all participants). This study was approved by the the Ethics Committee of the Torrecárdenas University Hospital, Almería, Spain. All the participants were informed of the study purpose and experimental procedures and signed written informed consent.

*** Please, insert Table 1 near to here ***

Study design

In this cross-sectional study, each participant performed an incremental loading test up to 1RM for the individual determination of the entire load-velocity relationship. The participants underwent a familiarization session comprising an incremental test of 2-4 absolute loads starting at 25kg and without exceeding a MV of 0.70 $m \cdot s^{-1}$ while the researchers emphasized the lifting technique and the intention to perform the concentric phase at maximum velocity. The following velocity variables were analyzed: 1) Mean Velocity (MV): the average bar velocity (ms) from the start of the concentric phase until the bar reaches the maximum height; and 2) Peak velocity (PV): the highest velocity value recorded at a particular instant (ms) during the concentric phase. The mean propulsive velocity (MPV) was not analyzed because the bilateral leg-press exercise did not present a braking phase so that the MPV and MV were equal.

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). The familiarization session and the testing session were conducted under the same environmental conditions (~21 °C and ~60 % humidity), in the same place and at the same time of the day (±1 hour) for each participant. Strong verbal encouragement was provided so that all the participants achieve maximum effort during testing.

A leg press (Platinum Series, Model PTT0116; dimensions 214 x 161 x 129 cm) was used for all tests. This machine has a 45º tilt for the lower body, a 30º tilt for the trunk, and a minimum load of 25kg. For the execution of the exercise, participants fully supported their back and head on the backrest. The soles of the feet were placed in parallel on the moving platform, spaced shoulder-width apart. Movement velocity during the impulsive phase of all repetitions was recorded with a linear velocity transducer (T-Force System, Ergo-Tech, Murcia, Spain). The reliability of this system has been studied previously (Courel-Ibanez et al., 2019). A platform with an adjustable tilt was used to position the transducer (**Figure 1**). Taking the horizontal plane into account, the platform was placed parallel to the hip axis. To be considered as a valid repetition, the knee flexion had to exceed ~90º in the eccentric phase and finish the movement with the knees extended in the concentric phase. This position was recorded for each subject and marked so that an audible signal was given by the evaluator when reaching that individual position. A momentary pause (~1 s) was imposed between the eccentric and the concentric phase to eliminate the use of elastic energy on the eccentric movement and to obtain more stable and reliable measurements (Pallares, Sanchez-Medina, Perez, De La Cruz-Sanchez, & Mora-Rodriguez, 2014). If the execution was not correct or the displacement range was not adequate (at the discretion of the evaluators), a new series was performed with the same absolute load after the corresponding rest period. During the test, two researchers helped breaking the load during the eccentric phase to facilitate weight reception by the participants, while a third researcher provided information on correct execution and feedback on movement velocity in each repetition. These researchers also helped the subject to place the platform in the starting position when the proposed load was not possible to displace. In these cases, after the relevant rest (~4 min), a new attempt was made with the same absolute load to verify that the subjects were not actually able to displace that load.

*** Please, insert Figure 1 near to here ***

The warm-up protocol consisted of 5 min walking at a self-selected easy pace, 2 minutes of dynamic joint mobility, 30 seconds performing squats without additional weight and a set of 6 repetitions with a 25kg load in the bilateral leg-press exercise. During the test, the initial load was set at 25kg for all the subjects and was increased by 20kg until reaching a MV of ~0.90 $m \cdot s^{-1}$. Subsequently, there were 10kg increments until reaching a MV of ~0.50 $m \cdot s^{-1}$. Starting at this MV, the load settings were increased by 5, 2.5 or 1kg, depending on the MV, until reaching the 1RM. The last load that was correctly displaced completing the set range was determined as the 1RM value. During the incremental test, subjects performed 3 repetitions at low loads (> 0.90 $m \cdot s^{-1}$), 2 at medium loads (0.90 – 0.60 $m \cdot s^{-1}$) and only 1 at high loads (< 0.60 $m \cdot s^{-1}$). The recovery time between sets ranged from 3 minutes (low loads) to 4 minutes (high loads). Only the best repetition of each series based on the higher MV criterion was considered for further analysis.

Statistical Analysis

The descriptive data are presented as the 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 (%1RM) and the MV and PV variables, the linear and quadratic regression (second-degree polynomial) models were used. The goodness of fit was assessed by the Pearson's multivariate coefficient of determination (R^2) and the (SEE). The between-subject coefficient of variation (CV) was calculated to determine the variability of the MV and PV associated with each %1RM. A CV < 10% was determined as an acceptable reliability level. The significance level was set at 5% ($P<0.05$). The SPSS version 22 statistical software package (SPSS, Chicago, IL) was used for the analysis.

Results

Of the 30 participants who volunteered to participate, 22 completed the test satisfactorily and are reported in this manuscript. Two women complained of low back pain and one of pressure on the breast prosthesis during testing, preferred not to continue, and were excluded from the study. Despite having participated in the familiarization session, five participants were also excluded because they were unable to reach a MV >0.80 $m \cdot s^{-1}$ with the minimum load allowed by the leg-press machine used.

The 1RM value for the bilateral leg-press exercise was 118.52 ± 23.3 kg (1.73 ± 0.32 normalized per kg of body mass). The number of loads used for the 1RM measurement was 10.3 ± 2.1. The MV of 1RM was 0.24 ± 0.03 $m \cdot s^{-1}$ (range: 0.15 - 0.29 $m \cdot s^{-1}$), whereas the PV at 1RM was 0.60 ± 0.10 $m \cdot s^{-1}$ (range: 0.40 - 0.85 $m \cdot s^{-1}$).

Relationship between relative load and velocity

The linear and quadratic fits analyzed individually for the MV gave R^2 values of 0.952 ± 0.025 (range: 0.990-0.886; CV = 2.6%) and 0.981 ± 0.012 (range: 0.998-0.953; CV = 1.3%), respectively. For the PV variable, the individually analyzed linear and quadratic fits showed average values of R^2 = 0.973 ± 0.020 (range: 0.993-0.905; CV = 2.0%) and R^2 = 0.999 ± 0.006 (range: 0.999-0.973; CV = 0.6%), respectively. For both variables, the individual polynomial fits showed significantly ($p < 0.001$) greater R^2 (0.981 ± 0.012 and 0.999 ± 0.006, for MV and PV respectively) compared to individual linear fits (0.952 ± 0.025 and 0.973 ± 0.020, for MV and PV respectively). **Figure 2** show the Load-velocity relationships for three representative participant whose R^2 for linear fit were < 0.90 (**Figure 2A**), between 0.90-0.95 (**Figure 2B**), and > 0.95 (**Figure 2C**). In these representative figures can be observe how the polynomial fit always showed a higher R^2 compared to the linear fit. In addition, the average MV and PV values achieved for each percentage of 1RM obtained for both individual fits, from 25% 1RM onwards, at increments of 5%, are presented in **Table 2** and **Table 3,** respectively.

*** Please, insert Table 2 near to here ***

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Taking all the data as a whole, a strong relationship was observed between the MV and the percentage of relative load (%1RM) using a linear fit ($R^2 = 0.924$ $p < 0.0001$; SEE = 0.080m·s^{-1}; **Figure 3A**) and a polynomial fit ($R^2 = 0.952$; $p < 0.0001$; SEE = 0.063 m·s^{-1}; **Figure 3B**). Similarly, a strong relationship was observed between the PV and the percentage of relative load (%1RM) using a linear fit ($R^2 = 0.928$; $p < 0.0001$; SEE = 0.119m·s^{-1}; **Figure 3C**) and a polynomial fit ($R^2 = 0.941$; $p < 0.0001$; SEE = 0.108m·s^{-1}; **Figure 3D**).

*** Please, insert Figure 3 near to here ***

Comparison of the regression models

The MV and PV data analyzed using the linear and polynomial fits in the individual load-velocity relationship are presented in **Table 2** and **Table 3.** For both variables analyzed, it is observed a minimum difference of 0.01 m·s^{-1} and a maximum difference of 0.07 m·s^{-1}. For MV variable (**Table 2**), there were statistically significant differences between polynomial and linear fits at low (25% 1RM; $p < 0.05$), medium (55-80% 1RM; all $p < 0.05$) and very heavy load (95-100% 1RM; all $p < 0.05$), whereas for PV variable (**Table 3**), there were only significant differences against light (25% 1RM; $p < 0.05$) and very heavy loads (100% 1RM; $p < 0.05$).

Prediction of the relative intensity (%1RM) using the movement velocity

The prediction equations for estimating the relative load (%1RM) from the MV (in $m \cdot s^{-1}$) data were:

- Load $(\%1RM) = -83.60 \cdot MV + 116.3$ [$R^2 = 0.924$; SEE = 6.97 %1RM] from the linear fit
- $Load\ (\%1RM) = 47.89 \cdot MV^2 – 152.7 \cdot MV + 136.1$ [$R^2 = 0.959$; SEE = 5.12 %1RM] from the quadratic fit.

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

- Load $(\%1RM) = -54.64 \cdot PV + 128.5$ [$R^2 = 0.928$; SEE = 6.76 %1RM] from the linear fit
- $Load\ (\%1RM) = 8.220 \cdot PV^2 – 75.35 \cdot PV + 139.7$ [$R^2 = 0.933$; SEE = 6.54 %1RM] from the polynomial fit.

Discussion

This study was designed to analyze the load-velocity relationship in the bilateral leg-press exercise in female breast cancer survivors. The main findings revealed (a) a strong relationship between the movement velocity (MV and PV) and the relative load (%1RM) in the leg-press exercise; (b) both the linear and polynomial regression models predicted the velocities associated with each %1RM and the estimated 1RM with acceptable accuracy, although the polynomial was slightly higher; and (c) the MV showed a slightly stronger relationship with the relative load and lower CV compared to PV. Therefore, the movement velocity of the concentric phase is a valid alternative for precisely quantifying and adjusting the training intensity from the first repetition performed in the bilateral leg-press exercise in female breast cancer survivors.

To the best of our knowledge, this is the first study analyzing the relationship between the relative load and the movement velocity of the concentric phase in the bilateral leg-press exercise in female breast cancer survivors. Our results showed a strong association of the relative load with MV and PV (**Figure 2**), using both the linear and polynomial fit. These results concur with previous research (Benavides-Ubric, et al., 2020; Conceicao, et al., 2015; Garcia-Ramos, et al., 2019; Gonzalez-Badillo & Sanchez-Medina, 2010; Sánchez-Medina, et al., 2017; Sanchez-Moreno, et al., 2017) and extend current evidence to female breast cancer survivors, indicating that it is possible to accurately determine the %1RM that a given load represents during the concentric phase of the bilateral leg-press exercise, provided the movement is performed at maximal intended velocity.

Previous studies have analyzed the load-velocity relationship in the leg-press exercise in older women (Marcos-Pardo, et al., 2019) and in young athletes (Conceicao, et al., 2015) using different velocity variables. In both studies, these relationships were analyzed using the linear regression model (R^2 = 0.91; R^2 = 0.96 for MV and MVP, respectively), showing similar values than those shown in this study (R^2 = 0.924 and R^2 = 0.928 for MV and PV, respectively). However, these previous studies did not provide data on the quadratic fit. The present findings revealed that the second-order polynomial models presented better fit (higher R^2) than the linear models both when the data were analyzed individually (**Figure 2**) and in groups (**Figure 3**), and particularly in the case of velocities <30% 1RM **(Figure 2)**. The accuracy of the prediction equations for estimating the relative load (%1RM) from movement velocity was also higher for the quadratic fit than for the linear fit. Therefore, it might be hypothesized that the above-mentioned studies (Conceicao, et al., 2015; Marcos-Pardo, et al., 2019) selected the linear fit to simplify the regression equations as long as the results were reliable. In our study, we also observed a strong linear association [R^2= 0.924 (r = 0.961) for MV and R^2= 0.928 (r = 0.963) for PV], which support this model as an alternative to the quadratic model.

The present results suggest that the MV associated with submaximal loads in breast cancer survivors are different to those found in other populations for the bilateral leg-press exercise. For example, while the MV associated with a relative load of 60% 1RM was 0.44 $m \cdot s^{-1}$ in older women aged 68.2 ± 3.6 years (Marcos-Pardo, et al., 2019) and 0.89 $m \cdot s^{-1}$ in young athletes (Conceicao, et al., 2015), in female breast cancer survivors was 0.67 $m \cdot s^{-1}$ for the linear fit (to make results comparable). This variation was constant at all submaximal relative loads, supporting that the load (%1RM)-velocity relationship is dependent on the physical and physiological characteristics of each specific population. However, the MVs attained with the 1RM load were similar for the three population groups (0.21 ± 0.02 $m \cdot s^{-1}$ in older women; 0.21 ± 0.03 $m \cdot s^{-1}$ in young athletes; and 0.23 ± 0.03 $m \cdot s^{-1}$ in breast cancer survivors). These differences may be caused, in addition to the friction coefficients due to the machine features, by greater loss of applied force against medium and light loads (i.e., a greater deficit of force) than against heavy loads because of a lower level of practice in RT programs, shorter experience in velocity-based training and the possible side effects of breast cancer treatments (Klassen, et al., 2017). In particular, there were 8 participants who experienced complaints during testing or did not achieve a sufficient movement velocity with light loads to be included in the study. It could be hypothesized that the familiarization phase prior to strength testing in female breast cancer patients might need to be prolonged to 2-3 sessions or more, to ensure that all the participants get used to the testing methodology.

Regarding the stability of the relationship between the velocity variables (MV and PV) and the regression models (linear and quadratic), some differences in the individual load-velocity relationship were observed (**Table 2** and **Table 3**). The MV variable showed a similar level of reliability (CV<10%) for both fits while the PV turned out to be less reliable (CV>10%) at intensities greater than 80% 1RM for the linear fit and 60% 1RM for the quadratic fit. In addition, the between subject's variability in the incremental test (from 25 to 100% 1RM) was lower for MV compared to PV. This is in line with another study (Garcia-Ramos, Pestana-Melero, Perez-Castilla, Rojas, & Gregory Haff, 2018) suggesting that the MV could be the most appropriate variable for monitoring the relative load (%1RM) and one of the most used variable by researchers, trainers and new commercial devices to control the movement velocity during RT.

This study has several limitations that must be underlined. First, women included in the study had undergone breast cancer surgery and finished the core treatments up to 10 years before enrolment, which might result in a rather heterogeneous sample. Importantly, two issues could compromise the generalizability of the present results to all female breast cancer survivors: 1) the lack of information on the history of hormone therapy (because this factor can impact on muscle quality and strength); 2) the leg-press machine used in this study had a lower load limit of 25 kg, which represented >45% 1RM for 5 participants (17% of the initial sample), as they were not able to lift it with a velocity >0.80 $m \cdot s^{-1}$ during the familiarization session. This implied that the entire L-V relationship, particularly the low-load/high velocity area of the curve, was not assessable for these participants and, consequently, they were excluded and did not undertake further assessment. Therefore, we cannot ascertain that the present results will be generalizable to female breast cancer survivors with very low strength levels. However, previous studies (Gonzalez-Badillo & Sanchez-Medina, 2010; Sánchez-

Medina, et al., 2017; Sanchez-Moreno, et al., 2017) have shown a high stability of the velocity attained at different exercises with each percentage of 1RM in participants with very diverse strength levels, especially in women (Torrejón, Balsalobre-Fernández, Haff, & García-Ramos, 2019). Therefore, it is very likely that the regression equations presented here would be applicable to most female breast cancer survivors. In addition, for safety reasons, three researchers participated in the testing sessions (one to provide feedback to the participants on the correct execution in each repetition and two to help breaking the load during the eccentric phase), which might limit the possibility to reproduce this test in some settings. However, once the load-velocity relationship has been described, only one researcher or coach is sufficient to use VBT as a method to evaluate and prescribe training programs because heavy loads are not required. In addition, the participant´s feet lost contact (2 to 4 cm) from the platform in some of the light load trials, which might have slightly affected the L-V relationship. Finally, the friction coefficients of different leg-press machines might differ, and this should be considered in the interpretation of future studies.

Practical Applications

The results of this study allow estimating the target training load in the bilateral leg-press exercise with a relatively low margin of error, in female breast cancer survivors. In particular, the proposed equations allow predicting any relative load from 25 to 100% of 1RM by evaluating the movement velocity during the concentric phase of the first repetition, provided it is carried out at the maximal intended velocity. The relevance of this contribution lies in the critical importance of optimizing RT prescription in breast cancer survivors, and accurately estimating the 1RM with little health-related risks for the participant and precisely determine the training loads. In cancer patients, who commonly suffer from cancer-related fatigue, this is particularly relevant as overloading might produce considerable damage. It must be taken into account that predicting the training load using regression equations that do not fit the target population can lead to important mistakes in the control and quantification of the training process. In practical terms, the main findings of this study allow: a) assessing lower body muscular strength in female breast cancer survivors without conducting a traditional 1RM or XRM test; (b) determining the degree of actual effort that the patient is exerting, with the ability to control the fatigue generated, which is especially relevant to the study population; c) prescribing and monitoring the relative load in the bilateral leg-press exercise according to the movement velocity of the concentric phase, thus allowing a better control and individualization of the training load. In conclusion, MV is the most recommendable velocity variable to prescribe the relative load during resistance training and the PA presents better accuracy to predict velocities associated with each %1RM, although LA is sufficiently valid to be used as an alternative to the quadratic model. This study contributes to improving exercise prescription and monitoring, which has been traditionally lacking in the breast cancer literature.

Acknowledgments

This work was funded by the Patronato Municipal de Deportes, Ayuntamiento de Almería, and by the UAL Transfiere Research Program of the University of Almería [reference number: TRFE-SI-2019/004]. David M. Díez-Fernández was funded by a scholarship from the UAL Transfiere Research Program of the University of Almería [reference number: TRFE-BT-2019/002] and is currently funded by the Ministry of Science, Innovation and Universities of the government of Spain (grant number:

FPU19/04608). Alberto Soriano-Maldonado is currently supported by the Spanish Ministry of Science, Innovation and Universities (ref. RTI2018–093302-A-I00).

Declaration of interest statement

The authors have no conflicts of interest to disclose between any outside institution, company, or manufacturer. The results of this study are presented clearly, honestly, and without fabrication, or inappropriate data manipulation.

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FIGURE LEGENDS

Figure 1. Leg-press machine, linear velocity transducer and platform used during test.

Figure 2. Load-velocity relationships for three representative participant whose R^2 for linear fit were < 0.90 (A), between 0.90-0.95 (B), and > 0.95 (C).

Figure 3. Relationship between the relative load (% 1RM) and (A and B) the MV and the PV (C and D) using a linear and polynomial fit.

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

Subject´s physical characteristics	Age (years)	50.2 ± 10.8
	Mass (kg)	69.6 ± 15.2
	Height (cm)	160.51 ± 5.29
	Body Mass Index (kg/m^2)	27.5 ± 6.8
	Body fat mass (kg)	26.4 ± 12.36
	Body mucle mass (kg)	23.7 ± 3.4
	1RM bilateral leg-press (kg)	118.52 ± 23.3
	1RM bilateral leg-press (normalized per kg of body mass)	1.73 ± 0.32
Treatment	Chemotherapy (sessions)	7.7 ± 3.9
	Radiotherapy (sessions)	26.4 ± 6.1
Medical information	Tumor type, HR+HER2- / HR+HER2+ / HR-HER2+ / HR-HER2-, (%)	65.1/18.3/3.3/13.3
	Surgical procedure, n (%) Tumorectomy / Mastectomy	15 (68.2) / 7 (31.8)
	Lymph node resection, n (%)	9 (40.9)
	Lymphedema, n (%)	2 (9.1)
	Endocrine therapy, n (%)	19 (86.4)

SD: standard deviation; 1RM: one maximum repetition; HR: hormone receptor; HER2: human epidermal growth factor receptor 2

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

Relative load (%1RM)	**Linear fit**		**Polynomial fit**		
	Mean ± SD	CV (%)	Mean ± SD	CV (%)	Differences
25%	1.05 ± 0.09	8.3	1.12 ± 0.09	8.5	-0.06 ± 0.03*
30%	1.00 ± 0.08	8.1	1.03 ± 0.08	8.2	-0.03 ± 0.02
35%	0.94 ± 0.08	8.0	0.95 ± 0.08	7.9	-0.01 ± 0.01
40%	0.89 ± 0.07	7.8	0.88 ± 0.07	7.8	0.01 ± 0.02
45%	0.83 ± 0.06	7.7	0.80 ± 0.06	7.8	0.03 ± 0.02
50%	0.78 ± 0.06	7.5	0.74 ± 0.06	7.8	0.04 ± 0.02*
55%	0.72 ± 0.05	7.3	0.67 ± 0.05	7.9	0.05 ± 0.03**
60%	0.67 ± 0.05	7.2	0.61 ± 0.05	8.2	0.05 ± 0.03**
65%	0.61 ± 0.04	7.0	0.56 ± 0.05	8.4	0.05 ± 0.03***
70%	0.56 ± 0.04	6.9	0.51 ± 0.04	8.4	0.05 ± 0.02***
75%	0.50 ± 0.03	6.9	0.46 ± 0.04	8.4	0.04 ± 0.02***
80%	0.45 ± 0.03	7.1	0.42 ± 0.03	8.4	0.03 ± 0.02*
85%	0.39 ± 0.03	7.5	0.38 ± 0.03	8.4	0.01 ± 0.01
90%	0.34 ± 0.03	8.5	0.34 ± 0.03	9.0	-0.01 ± 0.01
95%	0.28 ± 0.03	10.4	0.31 ± 0.03	10.6	-0.03 ± 0.01*
100%	0.23 ± 0.03	13.7	0.28 ± 0.04	13.8	-0.06 ± 0.03***

1R[illegible] differences between linear and polynomial fits. $p < 0.05$; $p < 0.01$; $p < 0.001$.

Table 3. Peak velocity ($m \cdot s^{-1}$) associated with each percentage of relative load obtained for the individual load-velocity relationship by linear and polynomial fit.

Relative load (%1RM)	Linear fit		Polynomial fit		
	Mean ± SD	CV (%)	Mean ± SD	CV (%)	Differences
25%	1.84 ± 0.11	5.8	1.91 ± 0.10	5.2	-0.07 ± 0.03*
30%	1.76 ± 0.10	5.9	1.80 ± 0.10	5.6	-0.04 ± 0.02
35%	1.68 ± 0.10	6.1	1.68 ± 0.10	6.2	-0.01 ± 0.02
40%	1.59 ± 0.10	6.3	1.58 ± 0.11	6.9	0.01 ± 0.02
45%	1.51 ± 0.10	6.5	1.47 ± 0.11	7.7	0.03 ± 0.03
50%	1.42 ± 0.10	6.8	1.38 ± 0.12	8.5	0.05 ± 0.04
55%	1.34 ± 0.10	7.2	1.28 ± 0.12	9.3	0.05 ± 0.04
60%	1.25 ± 0.10	7.6	1.19 ± 0.12	10.1	0.06 ± 0.04
65%	1.17 ± 0.09	8.1	1.11 ± 0.12	10.9	0.06 ± 0.04
70%	1.08 ± 0.09	8.8	1.03 ± 0.12	11.6	0.06 ± 0.04
75%	1.00 ± 0.10	9.5	0.95 ± 0.12	12.1	0.05 ± 0.03
80%	0.91 ± 0.10	10.5	0.88 ± 0.11	12.6	0.03 ± 0.02
85%	0.83 ± 0.10	11.7	0.81 ± 0.11	13.0	0.02 ± 0.01
90%	0.74 ± 0.10	13.2	0.75 ± 0.10	13.4	-0.01 ± 0.01
95%	0.66 ± 0.10	15.1	0.69 ± 0.10	13.9	-0.03 ± 0.02
100%	0.57 ± 0.10	17.7	0.64 ± 0.09	14.7	-0.06 ± 0.04*

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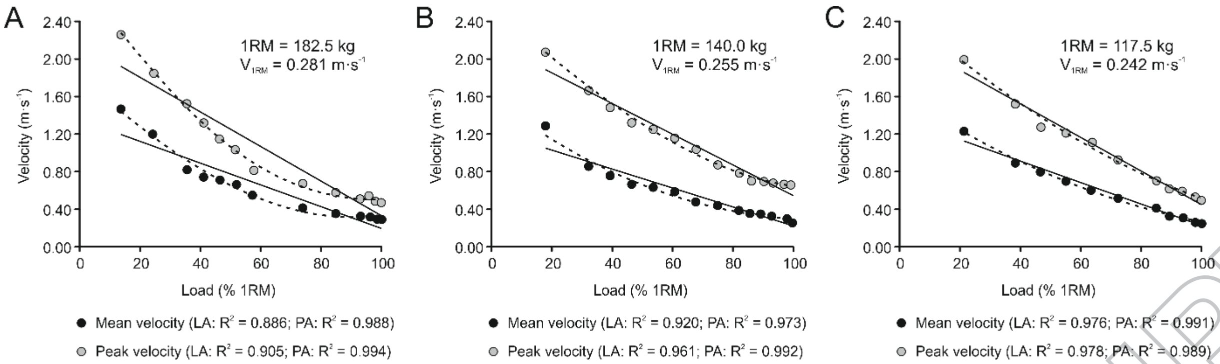
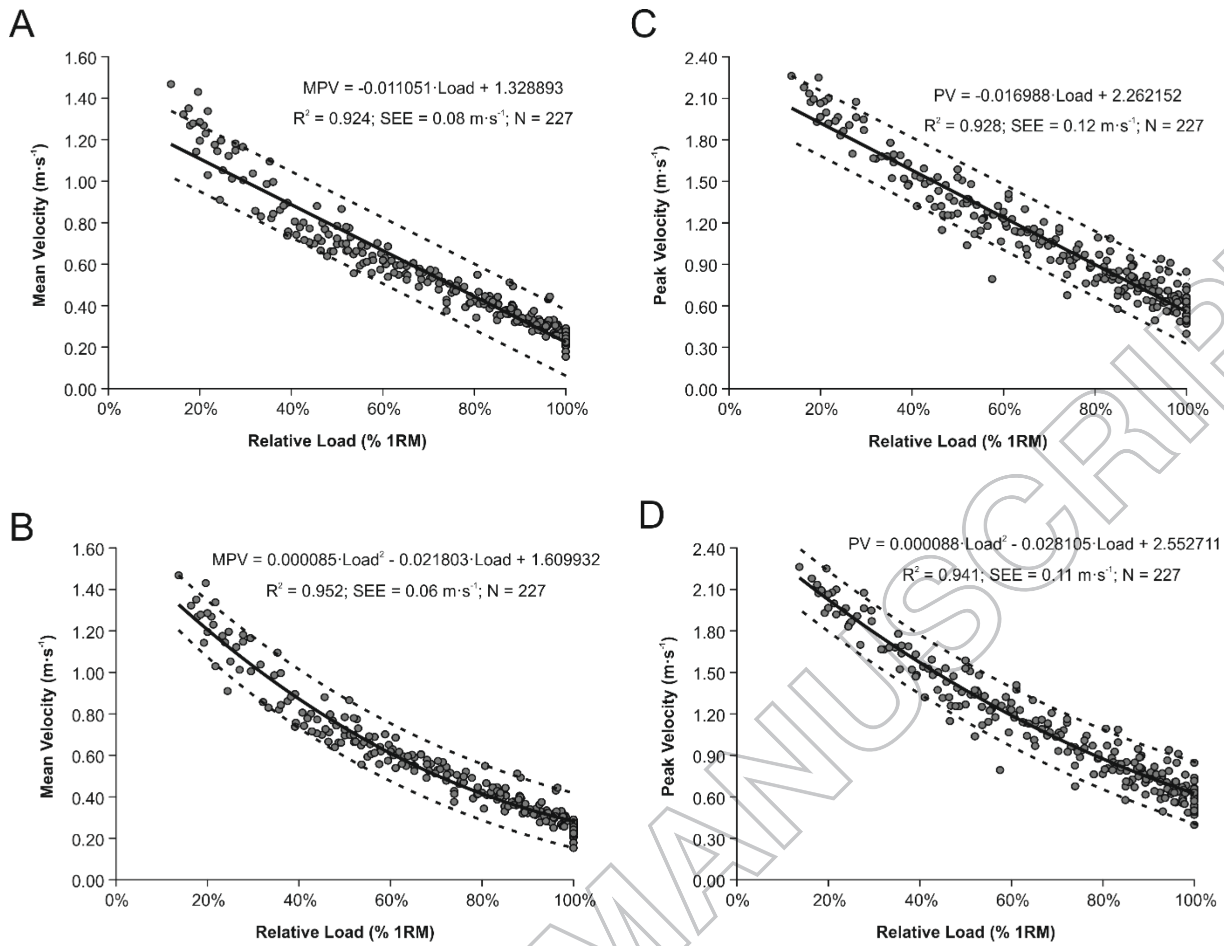

A
1RM = 182.5 kg
V1RM = 0.281 m·s-1
Velocity (m·s-1)
Load (% 1RM)
Mean velocity (LA: R2 = 0.886; PA: R2 = 0.988)
Peak velocity (LA: R2 = 0.905; PA: R2 = 0.994)
B
1RM = 140.0 kg
V1RM = 0.255 m·s-1
Velocity (m·s-1)
Load (% 1RM)
Mean velocity (LA: R2 = 0.920; PA: R2 = 0.973)
Peak velocity (LA: R2 = 0.961; PA: R2 = 0.992)
C
1RM = 117.5 kg
V1RM = 0.242 m·s-1
Velocity (m·s-1)
Load (% 1RM)
Mean velocity (LA: R2 = 0.976; PA: R2 = 0.991)
Peak velocity (LA: R2 = 0.978; PA: R2 = 0.989)


A
MPV = -0.011051·Load + 1.328893
R² = 0.924; SEE = 0.08 m·s⁻¹; N = 227
Mean Velocity (m·s⁻¹)
Relative Load (% 1RM)
B
MPV = 0.000085·Load² - 0.021803·Load + 1.609932
R² = 0.952; SEE = 0.06 m·s⁻¹; N = 227
Mean Velocity (m·s⁻¹)
Relative Load (% 1RM)
C
PV = -0.016988·Load + 2.262152
R² = 0.928; SEE = 0.12 m·s⁻¹; N = 227
Peak Velocity (m·s⁻¹)
Relative Load (% 1RM)
D
PV = 0.000088·Load² - 0.028105·Load + 2.552711
R² = 0.941; SEE = 0.11 m·s⁻¹; N = 227
Peak Velocity (m·s⁻¹)
Relative Load (% 1RM)