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Research Article

AEROBIC ENERGY EXPENDITURE AND INTENSITY PREDICTION DURING A SPECIFIC CIRCUIT WEIGHT TRAINING: A PILOT STUDY

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ABSTRACT

During circuit weight training (CWT), workloads, index of intensity as well as estimation of energy expenditure (EE) have been under estimated. The aim of this study was to describe and evaluate physiological variables and gender related differences, including intensity prediction and EE, during CWT at different intensities. Twenty six subjects were assessed in a CWT, fourteen men and twelve women. The CWT program was performed at six different intensities, 40%, 50%, 60%, 70%, 80% and 85% of 15RM. Seven exercises made up the circuit: sitting bench press, leg press, lat pull down, shoulder press, hamstring curl, biceps curl, and triceps cable push downs. A polar heart rate monitor and a portable metabolic system were used to measure heart rate (HR), intensity measured relative to the HR reserve, cardiorespiratory variables, EE and EE relative to muscle mass (EEMM). Differences between genders were observed at the following variables: HR, intensity measured relative to the HR reserve (in percentage), VO_2, VCO_2, V_E, RER, aerobic EE and EEMM. The EE was significantly higher in men during the six intensities, but differences did not exist for EEMM from 70% to 85%. In addition HR, load and body weight were used to predict intensity and two gender specific equations were obtained for men and women [I (%) = 57.265 + 0.512HR - 0.696HR_{max} + 1.035 $Load_{avg}$ + 0.188 Body Weight (R^2=0.92; SEE=4.9%) for men; I (%) = 4.036 + 0.412HR% + 1.667 $Load_{avg}$ (R2=0.79; SEE=7.7%) for women]. Thus, we conclude that gender related differences are present during CWT for EE, even when expressed relative to muscle mass, in addition HR, work load and body weight can estimate the intensity during CWT.

Key words**:** resistance training, heart rate, energy cost, oxygen uptake, exercise intensity.

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INTRODUCTION

It has been estimated 42.8 million Americans trained with free weights in 1999, 60% more than the 26.7 million in 1990. In Europe, approximately 38.65 million people in 2006 trained in Fitness Centres. In addition, research relative to applied strength training (circuit weight training [CWT]) is very important, mainly for its application to special populations, for example overweight and obese people.

Measurement of training variables lends itself to many interesting questions, specifically in weight training, where loads have been traditionally the only index of intensity. Recently, there have been several papers that have reported energy expenditure (EE) calculations have been underestimated during weight training (Robergs et al., 2007). Unfortunately the aforementioned studies only evaluated two exercises at low intensities (between 31-57 % of 1RM) (Robergs et al., 2007) or two separate exercises (60 vs 80 % of 1RM) (Scott, 2006).

Additionally, the comparison of EE in exercise between men and women is quite frequent, (Byrne et al., 2006; Castellani et al., 2006; Hoyt et al., 2006; Kuo et al., 2005; Papazoglou et al., 2006; Venables et al., 2005) but few studies have examined CWT with progressive intensities (Scott, 2006; Hunter & Byrne, 2005; Hunter et al., 2000) and less still comparing the effects in both genders (Candow & Burke, 2007; Hunter et al., 2002; Smith et al., 2003).

Therefore, the aim of this study was to evaluate gender related differences in physiological variables, including EE, during CWT at a wide range of intensities. A secondary aim was to develop an equation to predict training intensity based on those variables.

MATERIAL AND METHODS

Participants

Twenty six subjects participated in this study, fourteen men aged 22-26 years and twelve women aged 20-24 years. All subjects fulfilled the following characteristics: healthy physically active students of Physical Education. Anthropometric data are shown in Table 1. This study was approved by the local ethic committee and an informed consent was obtained from each participant in accordance with the guidelines of the World Medical Association regarding human investigation as outlined in the Helsinki declaration.

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Table 1. Descriptive data for participants by gender

	All(26)	Men(14)	Women(12)
Age (yrs)	23.2±1.6	23.7±1.5	22.7±1.5
Weight (kg)	64±11	71.5±11	56.5±3[a]
Height (cm)	167.8±10.1	174.7±9.7	160.8±3.8[a]
HRrest (bpm)	72±11	80±6	63±8[a]
% Body fat	13±3.7	9.9± 1.4	16.1± 2.4[a]
MM (kg)	30.9±7.4	36.5±6.6	25.3±1.2[a]
$Load_{avg}$ (kg)	24.710.5	32.19.1	17.35.5[a]
$Load_{avg}$rel (%)	38.515.4	46.216	30.810[a]
$Load_{avg}$relMM (%)	78.925.7	89.726.3	68.320.3[a]

Values are mean±s. [a] Significantly different with men (P<0.01). HRrest: heart rate at rest. MM: muscular mass. $Load_{avg}$: mean weight lifted. $Load_{avg}$rel (%): weight lifted relative to body mass. $Load_{avg}$relMM (%): weight lifted relative to muscle mass.

Experimental design

To carry out the study, a specific CWT program composed of the seven exercises was chosen. All exercise were performed on machines (Pannata, Italy), without free weight, and in the following order: sitting bench press, leg press, lat pull down, shoulder press, hamstring curl, biceps curl, and triceps cable push downs. The circuit was performed at six different intensities, 40%, 50%, 60%, 70%, 80% and 85% of 15 repetition maximum (15RM), in two separated days: 40, 50 and 60% first; 70, 80 and 85% the second day, and in random order. Thus, the complete training consisted of 3 laps (one lap for intensity) with 10 seconds of rest period between exercise and 5 minutes between circuit laps. The cadence was fixed at 1:2 (concentric-eccentric phase). This specific rhythm was established with music. Different sounds helped the subjects to follow the exact rhythm and to change into another exercise or rest interval.

Calculation of 15 repetition maximum

The 15 RM for each exercise was tested twice on different days and the week before performing the CWT. After a cardiovascular warm up of five minutes and using the same cadence (1:2), the subject starts lifting the weight corresponding to 70% of the estimated of 15 RM. Two minutes later, they performed 90% of the estimated 15 RM and after a new rest period of two minutes, maximal workload to perform 15 repetitions but not 16 was chosen. If the subject could or failed to lift this workload, then a maximum of two attempts were performed fitting the workload in ±2.5% (Kraemer, 2005).

Indirect calorimetry and calculations

Breath by breath measurements for oxygen uptake (VO_2), carbon dioxide production (VCO_2) and ventilation (V_E) were used in every test with a portable metabolic system Jaeger Oxycon Mobile® (Erich Jaeger, Viasys Healthcare, Germany) (Díaz et al., 2008; Perret & Mueller, 2006), and heart rate (HR) was registered with a Polar® heart rate monitor (Polar Electro, Kempele, Finland).

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Anthropometric variables
For the percentage body fat calculations, 6 skinfolds were measured (Carter & Heath, 1990): triceps, subscapular, suprailium, abdominal, calf and thigh and the following formula were applied for men and women respectively:

$$\% \text{ Body fat} = (((\sum 6\text{skinfolds}) \cdot 0.097) + 3.64) \cdot 100^{-1}$$

$$\% \text{ Body fat} = (((\sum 6\text{skinfolds}) \cdot 0.143) + 4.56) \cdot 100^{-1}$$

Body mass and height were also calculated following the procedures described by Carter and Heath (1990). Muscle mass (MM) was measured with the Martin equation (for men and women respectively) (Martin et al., 1990):

$$MM\ (g) = \text{Height}\ [0.0553 \cdot (\text{Thigh circumference} - \text{Thigh skinfold})^2 + 0.0987 \cdot (\text{Forearm circumference})^2 + 0.0331 \cdot (\text{Calf circumference} - \text{Calf skinfold})^2\ ] - 2445$$

$$MM\ (g) = 39.31 \cdot (\text{Forearm circumference} - \text{Forearm skinfold})^2 + 9.699 \cdot (\text{Calf circumference} - \text{Calf skinfold})^2 + 10.48 \cdot (\text{Upper arm circumference} - \text{biceps skinfold} + \text{triceps skinfold})^2 - 7993$$

Statistical analysis
All statistical analyses were performed using SPSS v.12.0 for Windows (SPSS Worldwide Headquarters, Chicago, IL). To find differences between genders, the Mann-Whitney U test was used. Probability level for statistical significance was set at $P<0.05$. Step by step regression analysis was used to predict load intensity in the test. Determination coefficient (R^2) and standard error of estimation (SEE) was used to show the accuracy of estimation. Residual plot was taken under consideration to analyze the normal distribution. A simple size of 12 subjects provided >80% statistical power at a α level of 0.05.

RESULTS

Mean values ± s for each physiological variable are presented in Tables 2 and 3 for males and females respectively. There were observed gender related differences for the following variables: HR, intensity measured relative to the heart rate reserve (I_{HRR}), VO_2, VCO_2, V_E, respiratory exchange ratio (RER), aerobic EE and EE relative to muscle mass (EEMM).

Table 2. Physiological response of the subject by gender.

	HR (beats·min^{-1})	VO_2 (mL·min^{-1})	VO_2/kg (mL·kg^{-1}·min^{-1})	VO_2/kgMM (mL·kg·min^{-1})	VCO_2 (mL·min^{-1})	V_E (L·min^{-1})
All (26)	135±20	1074±270	16.84±3.78	35.15±7.11	1166±367	44±15
Men (14)	143±15	1314±139	18.93±4.20	37.31±8.86	1490±196	54±13
Women (12)	127±22	834±97	14.75±1.53	32.98±3.78	842±136	34±9
p-value	0.001	<0.001	<0.001	0.058	<0.001	<0.001

Values are mean±s. VO_2/kgMM: oxygen consumption relative to muscle mass.

Table 3. Energy cost and recovery response during the circuit.

	RER	EE ($Kcal \cdot min^{-1}$)	EEMM ($Kcal \cdot kg^{-1} \cdot min^{-1}$)	I_r (%)	$I_{(HRR)}$ (%)
All (24)	1.08±0.08	5.23±1.41	0.170±0.033	56.93±16.43	50±17
Men (14)	1.14±0.05	6.51±0.72	0.184±0.039	59.70±16.64	54±14
Women (12)	1.01±0.05	3.96±0.43	0.157±0.018	54.15±15.95	45±18
p-value	<0.001	<0.001	0.002	0.177	0.020

Values are mean±s. I_r: Recovery Index according Calderón (Calderon, Brita, Gonzalez, & Machota, 1997). $I_{(HRR)}$: Intensity respect the heart rate reserve (HRR).

Only in the recovery index variable did not present significant differences, despite the fact that it remained lower in women.

During the six different intensities the EE was significantly higher in men than in women, but it is in women where this variable seems to be more related with the intensity as it increased progressively (Table 4). Differences in EEMM did not exist between men and women from 70% to 85% of the intensity.

Table 4. Aerobic energy expenditure ($Kcal \cdot min^{-1}$) in men and women at progresive intensity.

	absolute EE			**EEMM**			**Load (Kg)**		
Intensity (% 15RM)	All	Men	Women	All	Men	Women	All	Men	Women
40%	4.9±1.4	6.2±0.7	3.6±0.3[a]	0.160±0.032	0.176±0.039	0.144±0.013[b]	15.4±5.4	20.0± 2.8	10.81±2.19[a]
50%	4.9±1.4	6.2±0.7	3.7±0.3[a]	0.160±0.032	0.176±0.038	0.145±0.013[b]	19.2±6.7	25.0± 3.5	13.51±2.74[a]
60%	4.9±1.4	6.2±0.7	3.7±0.3[a]	0.160±0.031	0.175±0.037	0.145±0.013[b]	23.1±8.0	30.0± 4.1	16.22±3.28[a]
70%	5.5±1.4	6.7±0.7	3.7±0.3[a]	0.179±0.032	0.190±0.042	0.168±0.015	27.0±9.4	35.0± 4.8	18.92±3.83[a]
80%	5.5±1.4	6.8±0.8	3.7±0.3[a]	0.181±0.034	0.193±0.044	0.169±0.015	30.8±10.7	40.0± 5.5	21.62±4.38[a]
85%	5.6±1.5	6.9±0.8	3.7±0.3[a]	0.182±0.034	0.194±0.045	0.169±0.014	32.7±11.4	42.5± 5.9	22.97±4.65[a]

Values are mean±s. [a] Significantly different with men ($P<0.01$). [b] Significantly different with men ($P<0.05$).

The linear relationship between the intensity and the average HR is clearer in men than in women (Figure 1). However, in the oxygen consumption, women showed better relationship with the intensity of the exercise (Figure 2).

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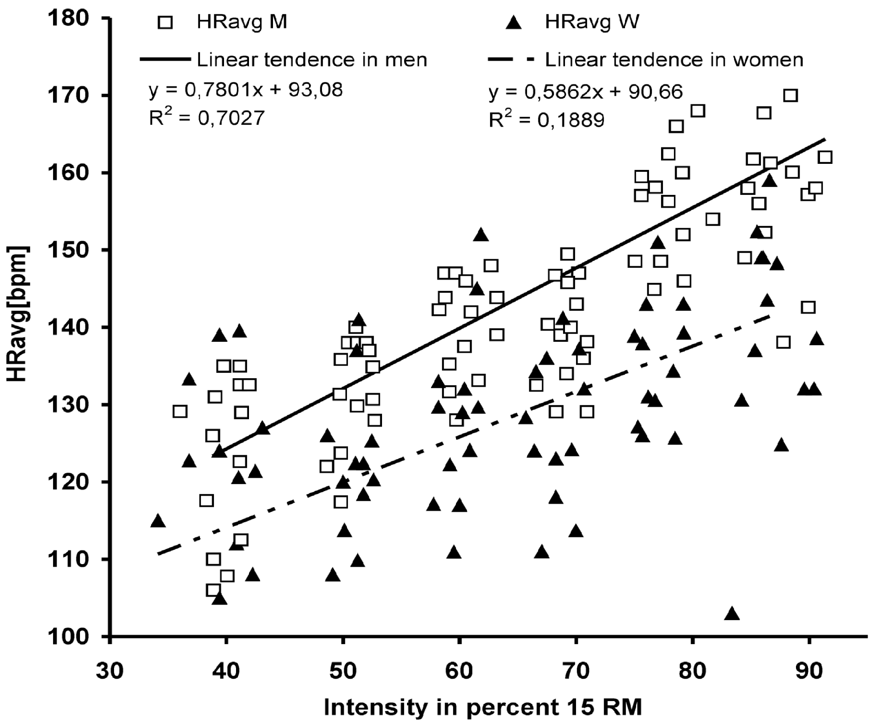

Figure 1. Relationship between the intensity and the average HR

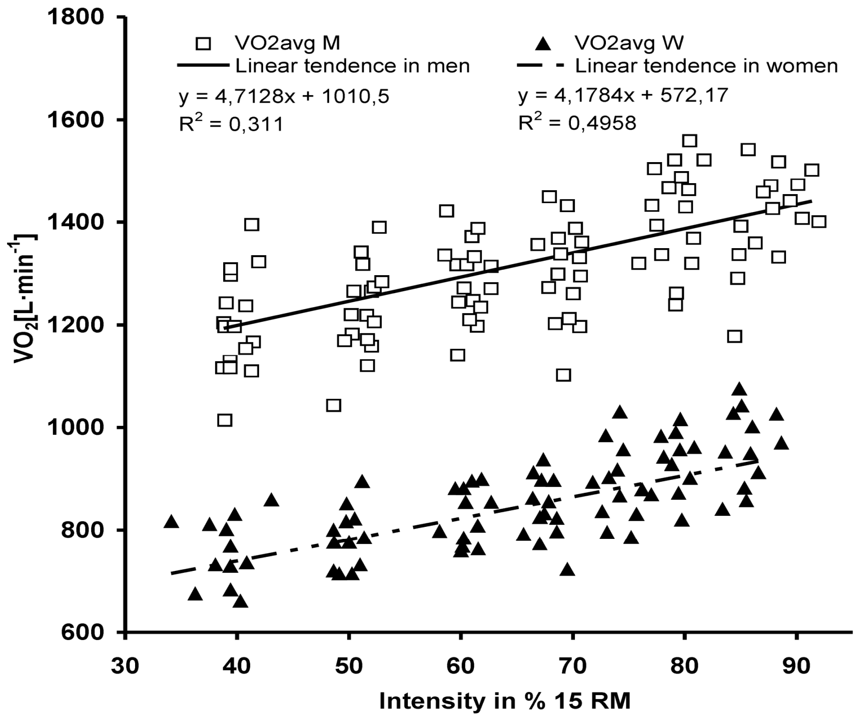

Figure 2. Relationship between the intensity and the oxygen consumption

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The most important finding, from a practical point of view, is obtained from the regression analysis. This analysis provided three prediction models in men and additionally, three different models for women (Table 5 and 6). All the following variables were used to predict the intensity of the circuit: HR relative to maximal HR (HR%), mean heart rate measured during the circuit (HR), maximal HR measured during the circuit (HR_{max}), HR after two minutes of recovery (HR2'), mean load moved during the circuit ($Load_{avg}$), intensity relative to the HRR ($I_{(HRR)}$) and body weight. Age and gender were introduced as predictor variables, but neither turned out to be significant. The variable of gender was used with the objective of making the equations more applicable and also to know the total variance explained by genders. Finally, the following equations were chosen to calculate the load intensity in men and women.

For men:
$I\,(\%) = 57.265 + 0.512HR - 0.696HR_{max} + 1.035\,Load_{avg} + 0.188\,Body\,Weight$
(R^2=0.92; SEE=4.9%)

For women:
$I\,(\%) = 4.036 + 0.412HR\% + 1.667\,Load_{avg}$
(R^2=0.79; SEE=7.7%)

Table 5. Estimated regression coefficients for predicting de intensity (%) in men (n=14) using three different models.

MEN					
MODEL	Variables	β^a	$SE(\beta)^b$	p-value	R^2
	K^c				
	HR%	29.958		0.329	
1	HR	0.287	0.326	0.043	
	HR_{max}	0.701	0.667	<0.001	
		-0.542	-0.241	0.032	0.83
	K^c	75.376		0.001	
2	HR	0.539	0.513	<0.001	0.90
	HR_{max}	-0.734	-0.327	<0.001	
	$Load_{avg}$	0.963	0.543	<0.001	
	K^c	57.265		0.009	
	HR	0.512	0.487	<0.001	0.92
	HR_{max}	-0.696	-0.310	<0.001	
3	$Load_{avg}$				
	Weight	1.035	0.584	<0.001	
		0.188	0.127	0.022	

[a] Estimate regresión coefficient. [b] Asymptotic Standard error of the coefficient. [c] Constant. HR_{max}: maximal HR measured during the circuit. $Load_{avg}$: mean load dring the circuit.

Table 6. Estimated regression coefficients for predicting de intensity (%) in women (n=12) using three different models.

WOMEN					
MODEL	Variables	β^a	$SE(\beta)^b$	p-value	R^2
1	K^c	19.113		0.082	
	HR2'	-0.414	-0.491	0.018	
	HR	0.328	0.447	0.062	
	HR%	0.594	0.658	<0.001	0.62
2	K^c	-671.923		0.020	
	HR2'	-0.444	-0.527	0.007	
	HR	10.030	13.659	0.014	
	HR%				
	$I_{(HRR)}$	0.579	0.642	<0.001	
		-12.026	-13.175	0.016	0.68
3	K^c	4.036		0.497	
	HR%	0.412	0.456	<0.001	
	$Load_{avg}$	1.667	0.568	<0.001	0.79

[a] Estimate regression coefficient. [b] Asymptotic Standard error of the coefficient. [c] Constant. HR_{max}: maximal HR measured during the circuit. $Load_{avg}$: mean load during the circuit. HR2': HR after 2 minutes of recovery. $I_{(HRR)}$: intensity relative to the heart rate reserve.

DISCUSSION AND CONCLUSIONS

Our study shows that when the results are corrected for MM and total body weight, significant differences exist in the aerobic EE in a circuit resistance training program at various intensities. The differences between sex could be explained by anthropometric differences (Castellani et al., 2006), as well as the external load (Beckham & Earnest, 2000). MM could explain differences in EE and in the load used during the circuit, but when EE is expressed in relative terms, we observe that one more factor influence, so significant differences still exist, which is in agreement with previous study carried out in a similar CWT (Ortego et al., 2009). In this work, Ortego et al. (2009) suggest that gender differences could be related with load to muscle mass ratio, sex hormone levels and stroke volume. In addition, intramuscular coordination factor or fibrilar composition (genetic factor) have been presented as possible arguments to explain those differences (Glenmark, 1994; O'Hagan et al., 1995), since training does not produce significant changes in the composition of those fibers (O'Hagan et al., 1995). Differences in the energy expended are not an exclusive question of strength training. Knechtle et al. found that significant differences existed between genders during continuous peddling on a cycle ergometer, but in this study the data are not expressed relative to body composition (Knechtle et al., 2004). Other work that relates EE, body weight and gender, reached the conclusion that these variables are the most important to explain the variations in EE (Hiilloskorpi et al., 2003).

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Intervention studies with 29 weeks of training program have suggested that MM gain due to gender is similar, but absolute values in men were higher than in women. The authors suggested differential levels of that fiber recruitment as the rationale for the difference (O'Hagan et al., 1995). Strength training has been shown to produce significant improvements in MM and progressive decreases in fat mass percentage (Ronnestad et al., 2007), two important factors in total energetic daily balance (Hunter et al., 2000) and weight loss (Donnelly et al., 2004).

The difficulty of estimating the proportion of work load in CWT, and strength training in general, has confounded and continues to trouble trainers, scientists and participants of these disciplines. For this reason our regression equations present, for the first time, the possibility of estimating work load through HR with a relatively small error. The variables introduced in the pattern are of simple calculation and the result gives the possibility of quantifying consistently training loads through this technique, without the risks of applying more theoretically dangerous (1RM) protocols. Additionally, using HR in EE estimation is not new in exercise (Hiilloskorpi et al., 2003; Collins et al., 1991), although few studies have applied these techniques in CWT (Collins et al., 1991) and none have made proposed estimation equations based in gender differences. Collins et al. presented the relation among workload, HR and VO_2 in a discontinuous circuit with free weight at 10 RM and pointed out that the relation between HR and VO_2 is different according to the activity. Although our study differs in protocol and objectives, we show equations relating HR, work load and intensity. In the study of Hiilloskorpi et al. (2003), the best variables to predict EE were body mass, gender and daily physical activity.

In men as in women the equations explain a high variance percentage, although the small sample might suggest reproducing the experiments with a greater number of subjects, to confirm its validity and obtain more global equations for other populations. Moreover, a specific problem inherent in this study could be related with using work load intensity as dependent variable, since EE seems to be more useful to explain the circuit intensity (Robergs et al., 2007; Scott, 2006; Lazzer et al., 2005; Loucks, 2004).

The relation between external load (weight lifted) and the expended energy seems to be linear. Recent works have shown, evidence that energetic equivalents are being under estimated in strength training (Robergs et al., 2007), and additionally, the contribution of anaerobic energy in this type of exercise it is remarkable even in light efforts (Scott, 2006). Additional studies are warranted to evaluate the sum both energetic metabolism (aerobic and anaerobic).

In summary, even thought data should be considered with caution due to this work is a pilot study and other work desestimate HR as predictor of the intensity during strength training (Beckham & Earnest, 2000), significant differences exist in EE during CWT, even when it is expressed relative to MM. In addition, HR, work load and body weight can estimate suitably the intensity during CWT.

A great number of people involved in strength training, and more specifically, personal trainers and sport performance coaches, need to quantify daily training loads. However, the estimation through conventional 1RM protocols may be inappropriate for beginners and too time consuming to calculate.

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It should be kept in mind that with the proposed equations trainers will be able to know the intensity of their client's workout with the utilization of a polar hart rate monitor in the exercises included in our study. Because the heart rate values are averages of each circuit, the order of the exercise should not influence the outcome, but the numbers of exercises, repetitions and equipment have the potential to confound the accuracy of the prediction equations.

The application of strength training programs in the modification of body composition and weight loss is more frequently being utilized (Ibanez et al., 2005; Knuttgen, 2007; Kraemer et al., 1999). Therefore, in these programs the uses of these new equations are one more tool that can quantify the relationship between load lifted and the intensity of the exercise.

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