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Original Article

Use of force–velocity relationship to estimate the one-repetition maximum leg press exercise among young females

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Abstract. [Purpose] This study aimed to determine the concurrent validity of using force at a velocity of 0 m/s when estimating the one-repetition maximum leg press and develop and assess the accuracy of an equation to estimate the one-repetition maximum value. [Participants and Methods] Ten untrained healthy females participated. We directly measured the one-repetition maximum during the one leg press exercise and developed the individual force–velocity relationship using the trial with the highest mean propulsive velocity at 20% and 70% of the one-repetition maximum. We then used the force at a velocity of 0 m/s to estimate the measured one-repetition maximum. [Results] The force at a velocity of 0 m/s was strongly correlated with the measured one-repetition maximum. A simple linear regression analysis revealed a significant estimated regression equation. The multiple coefficient of the determination of this equation was 0.77, while the standard error of the estimate of the equation was 12.5 kg. [Conclusion] The estimation method based on the force–velocity relationship was highly valid and accurate at estimating the one-repetition maximum for the one leg press exercise. The method provides valuable information to instruct untrained participants at the start of resistance training programs.

Key words: Maximum strength, Estimation method, Strength test

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INTRODUCTION

Resistance training is widely prescribed for both athletes and novices including healthy adults, older adults, and people with disabilities[1, 2]. The training intensity is one of the most important variables, and it is normally reported as a percentage of the individual one-repetition maximum (1RM)[3, 4]. The 1RM is used to promote muscle strength and mass for prescribing the appropriate intensity of resistance training. is defined as the heaviest load that can be successfully lifted only one time[5]. The 1RM can be determined using either direct or indirect approaches. In a direct approach, the participants progressively lift heavier loads until they fail[6, 7]. Although this approach is the gold standard, it has several disadvantages, such as increasing the risk of injury when performed incorrectly, as well as being time-consuming and requiring motivation[4, 8, 9]. Therefore, a direct approach may be impractical for older and untrained individuals. To overcome these limitations, a number of indirect approaches have been developed to estimate the 1RM[5, 7, 10–12]. The most common indirect approach is to estimate the 1RM using the relationship between the load and number of lifts performed until failure[12]. However, the accuracy of these equations depends on the type of exercise, the number of repetitions completed, gender, and training status[13, 14]. Furthermore, this approach requires several submaximal repetitions that induce excessive fatigue, which makes it difficult to begin exercise soon afterwards[4, 8]. Therefore, an alternative approach to determine the 1RM is required.

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Recently, the indirect approach that has received the most attention for estimating the 1RM is based on the force–velocity (F–V)[8] and load–velocity (L–V) relationships[4, 15] in multi-joint tasks. In particular, the F–V relationship is a linear relationship in multi-joint tasks[16], and an individual F–V relationship can be obtained from two loads[12]. When using the F–V relationship method, the force at a velocity of 0 m/s (F0) is used to estimate the 1RM[8]. In addition, the indirect method that is based on the F–V relationship has advantages during the testing procedure. The F–V relationship can be obtained from two sets of force and velocity values. Therefore, an indirect approach that is based on the F–V relationship is simpler, quicker, and less fatigue-inducing as a testing procedure to estimate the 1RM compared to the direct approach. A previous study reported a strong correlation between the 1RM and F0 and provided predictive equations for the 1RM during bench press exercises[8]. The leg press exercise is considered to be one of the basic exercises for lower limb muscles[17–19]. The leg press exercise is generally performed with the aid of a machine to increase muscle strength and mass in the lower limbs. Contrary to free-weight exercises, machine exercises help control the path of limb motions and reduce risk of injury. This is beneficial for untrained participants; however, the relationship between the 1RM and F0 in leg press exercises remains unclear. Therefore, the first purpose of this study is to determine the concurrent validity of using F0 when estimating the 1RM. The second purpose of this study is to develop an equation to estimate the 1RM and assess the accuracy of this equation.

PARTICIPANTS AND METHODS

A cross-sectional study was conducted to investigate the relationship between the 1RM and F0 and determine the 1RM estimation equation while using a leg press machine (Horizontal Leg Press COP-1201, SAKAI Medical Co., Tokyo, Japan). The participants attended the laboratory on three occasions, and these sessions were separated by at least 48 h. The first session was used to obtain body composition measurements, familiarize the participants with the 1RM test, and instruct them on how to properly perform the leg press exercise. The second session was used to determine the 1RM, and this was achieved by following the standard procedure that was proposed by Brown and Weir. The third session was used to develop an individualized F–V relationship. The participants performed leg press exercises for two loads in a random order. Once the individualized regression equation was determined, the force at a velocity of 0 m/s (F0) for that session was used in the regression equation to estimate the 1RM.

At least seven participants were required on the basis of an a priori power test with an effect-size correlation of 0.712, alpha level of 0.05, and power of 0.80. Ten healthy females, with ages ranging from 22 to 30 years, were recruited for this study (24.7 ± 2.5 years, 159.0 ± 5.4 cm, 55.9 ± 6.4 kg). The inclusion criteria for the participants considered participants with no physical limitations, health problems, or musculoskeletal injuries that could prevent testing, and the participants had not been involved in a strength training program during the last six months. All participants were sedentary or moderately active (i.e., regular physical activity such as involvement in recreational sports was less than twice a week for at least six months prior to the study). The study protocol was approved by the Medical Ethics Committee of the Shinshu University School of Medicine (approval number: 4297). All participants were informed of the experimental procedure and the purpose of the study before the study began. In addition, all participants provided written informed consent.

The first and second sessions were used to measure the 1RM during the leg press exercise. In the first session, the participants were informed about the testing procedures and had their height, body mass, and starting position of the leg press exercise measured. The starting position was defined as the participants sat on a reclining seat with their foot on the plate and their knee flexed at 90°, and the reclining angle of the seat was set at 60°. They were stabilized at the pelvis with straps and at the shoulders with adjustable pads. The 1RM was determined according to the established procedures[6]. The participants completed a standardized warm-up that consisted of light jogging and stretching, followed by a leg press protocol that comprised eight repetitions at 50% 1RM (as estimated by the participants) and three repetitions at 70% 1RM. Subsequently, a standard procedure for the 1RM assessment was applied. After performing the warm-up, a standard procedure was used to determine the leg-press 1RM. The initial external load of the 1RM test was set to 80% 1RM. The magnitude of the increment was determined by the investigator after reaching a consensus with the participant. This procedure was repeated until the participant failed to lift. At failure, a weight that was approximately midway between the last successful and failed lifts would be attempted. The highest successfully lifted weight was recorded as the 1RM leg press result. The 1RM test was performed within three to five attempts. The rest interval between trials was between 1 and 5 min and was determined based on the participants' perceived fatigue.

The F–V profiling test was conducted in three sessions. F–V profiling was performed under two load conditions that corresponded to 20% and 70% 1RM. The measurement order was randomized. The participants were instructed to extend their legs as fast as possible until their knees were at full extension without raising their hip from the seat. Prior to the measurements, the participants performed several trials under each loading condition. The participants performed three repetitions of each load. The rest interval between the trials was 1 to 5 min. A three-axis accelerometer (Pocket-IMU 2; Tamagawa Seiki, Nagano, Japan) was fixed to the top of the weight to measure the acceleration in the vertical direction. The sampling rate was 100 Hz.

The data were analyzed using a lowpass Butterworth filter with a cutoff frequency of 10 Hz. The vertical velocity was calculated by integrating the vertical acceleration with respect to time. The force was calculated from the weight and inertia of the total load lifted. The averaged force and velocity data within the propulsive phase were used for further analyses. The propulsive phase was defined as the portion of the concentric phase during which the acceleration of the loads was greater than the acceleration due to gravity. The highest mean propulsive velocity at each load was used for further analyses. The individual F–V relationships were obtained from a linear regression that was applied on the basis of the collected data points, and F0 was obtained. Custom-designed software that was developed using MATLAB R2017a (The Math Works Inc., Natick, MA, USA) was used to process the data.

The data are presented as the mean and standard deviation. The data normality was assessed by using the Shapiro–Wilk test. The reliability of the 1RM and F–V relationships was determined considering the magnitude of the intraclass correlation coefficient (ICC), standard error of the measurement (SEM), and coefficient of variation (CV). The acceptable reliability was determined from a correlation that was >0.70 and CV <10%[20, 21]. Pearson's correlation analysis was used to examine the relationship between F0 and 1RM. The accuracy of the regression was assessed using the multiple coefficient of determination (R2) and the standard error of the estimate (SEE). The strength of the correlations was determined using the following criteria: trivial (<0.1), small (0.1 to 0.3), moderate (0.3 to 0.5), high (0.5 to 0.7), very high (0.7–0.9), or practically perfect (>0.9)[22]. Confidence limits were set at 95% for all reliability and validity analyses. The significance level was set at an alpha level of $p<0.05$. The statistical analysis was performed using the statistical computing R language version 4.0.2 (rms)[23] and psych packages[24].

RESULTS

The mean one-leg press 1RM for the familiarization session was 81.5 ± 18.1 kg. The mean measured 1RM was 87.0 ± 24.5 kg, and this variable demonstrated a high degree of test–retest reliability between the two trials (ICC=0.99, CV=0.9%).

Table 1 demonstrates the test–retest reliability of the repetitions that were performed at each of the individual velocities that were used to develop the F–V relationship, as well as the velocity for the 1RM repetitions. All parameters of the F–V relationship achieved ICC >0.70 and CV< 10% (Table 1). The mean F0 was 1,099.3 ± 262.2 N.

The Pearson correlation coefficients between the measured 1RM and F0 were 0.88 (95% CI: 0.55–0.97), $p<0.05$ (Fig. 1). Using the collected data, the following estimation equation was developed: estimated 1RM=0.08 × F0–3.00 (R^2=0.77, SEE=12.5 kg) (Fig. 1).

DISCUSSION

This study examined the concurrent validity of a 1RM estimation method that is based on the F–V relationship and assessed the accuracy of this method using a leg press machine. The main finding of the present study was that in untrained participants, F0 strongly correlated with the measured 1RM and could be used to estimate the actual 1RM. The accuracy of the estimates was moderate.

Table 1. Reliability of the force–velocity parameters

% 1RM	Parameters	Trial 1	Trial 2	Trial 3	ICC (95% CI)	CV	SEM
20% 1RM	Velocity (m/s)	0.37 ± 0.07	0.38 ± 0.07	0.37 ± 0.06	0.88 (0.73–0.96)	6.2 ± 2.4	0.02
	Force (N)	200.8 ± 63.1	200.0 ± 58.6	200.0 ± 61.1	0.99 (0.99–1.00)	1.8 ± 0.8	4.6
70% 1RM	Velocity (m/s)	0.19 ± 0.02	0.18 ± 0.03	0.18 ± 0.03	0.71 (0.45–0.88)	8.2 ± 7.1	0.01
	Force (N)	642.5 ± 181.0	639.5 ± 180.3	638.1 ± 177.0	1 (1–1)	0.8 ± 0.7	5.5

1RM: one-repetition maximum; ICC: intraclass correlation coefficient; CV: coefficient variation; 95% CI: 95% confidence interval; SEM: standard error of measurement.

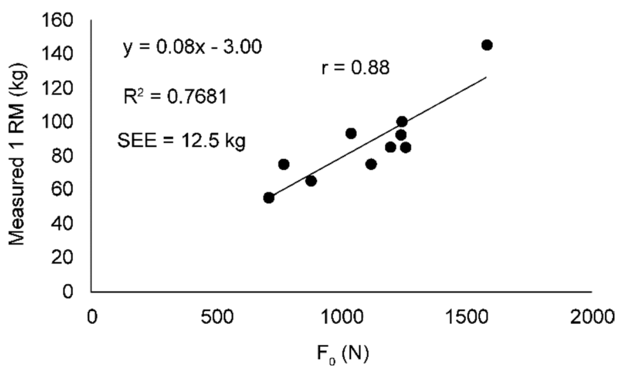

Fig. 1. Relationship between F_0 and the measured 1RM for the leg press exercise.

This study examined the concurrent validity of F0 for estimating the 1RM. The correlation between the 1RM and F0 was very high (r=0.88)[22]. This result indicates similarly strong relationships between the estimated and measured 1RM scores obtained by Ramos et al.[8], who reported that the correlation between the 1RM and F0 in the Smith machine bench press exercise were almost perfect (r=0.92). Although the majority of studies that have investigated 1RM estimations have used correlational analyses, it is important to accurately represent the error of the magnitudes because correlational analyses represent the linear association of the investigated system[25], which can be influenced by the variance of the difference across the samples[26]. The SEE is a measure of the variability of the estimations in a regression. In this study, the SEE revealed a moderate value of 12.5 kg. There is no reference value for the SEE when using the relationship between F0 and 1RM because Ramos et al. did not investigate the SEE in the Smith machine bench press exercise[8]. Conversely, several studies using indirect approaches reported the SEE in lower limb exercises. Ware et al. reported the SEE using the relationship between the load and number of lifts performed until failure occurred while performing squat exercises. The SEE was 11.2 to 26.6 kg when using the relationship between the load and number of lifts that were performed until failure[27]. When using isometric methods, the SEE was 13.8 kg[5] and 11.2 kg[10] in the squat exercise. Therefore, the SEE of this study was similar to that of a previous study and indicated a moderate error.

The estimation errors were derived from the measurement errors with respect to force and velocity. F0 is an intercept defined by the linear regression calculated from two different points. This indicates that the force and velocity errors cause variability in F0, even if these errors are small.

Many devices have been proposed to obtain the F–V relationship during multi-joint movements. An accelerometer is a valid and reliable tool used to obtain the F–V relationship when using a machine-based exercise[28]. This study used an accelerometer to measure the acceleration and calculate the velocity and force (mechanical measurements). The mean force during the leg press exercise when using the 20% and 70% 1RM exhibited an excellent reliability (ICC=0.99 to 1.00, CV=0.8% to 1.8%). The mean velocity during the leg press exercise when using the 20% and 70% 1RM exhibited relatively excellent reliability (ICC=0.71 to 0.88, CV=6.2% to 8.2%). These results are in agreement with those that were reported by Ramos et al.[11] and Hughes et al.[29] Ramos et al.[8] examined the reliability of the velocity of each load during the bench press exercise. They reported that the CV of the velocity was larger for heavier loads. Hughes et al. also reported that the CV of the velocity was larger under heavier loads. These results provide evidence that the F–V relationship obtained when performing the leg press with an accelerometer is valid.

The equation presented in this study was limited to one leg press exercise that was performed by untrained, young females. Because the regression equation provided in this study was obtained considering untrained young females, the application of this equation is limited to them and cannot be applied to men and other age groups. We believe that in future studies, the equation and accuracy of the 1RM estimation method in terms of its relationship to exercise, age, gender, or training status should be examined.

Based on the results of the present study, the developed F–V estimation method for the one-leg press 1RM is a highly valid approach for estimating the 1RM, and the accuracy of this equation was similar to those of alternative indirect approaches.

Funding and Conflicts of interest

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