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ORIGINAL ARTICLE

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Abstract

Background Individual's one-repetition maximum (1-RM) is required to calculate and prescribe intensity for resistance training, while testing protocols enhance the risk of injuries and are time-consuming.

Aims The aim of the present study was to assess the accuracy of 1-RM prediction from ratings of perceived exertion (RPE) of resistance exercises performed at submaximal sets (intensity and volume) in older adult males before and after a 12-week rehabilitation program.

Methods 18 untrained subjects (70.4 ± 4.5 years) first completed a 1-RM direct assessment with a horizontal leg press pre- and post-training. Thereafter, participants performed, in a random order, 2-repetition sets with loads unknown to them (corresponding to 20, 45 and 70 % of 1-RM). The RPE was recorded immediately after the sets. That RPE associated to its corresponding load was subjected to a linear regression analysis to extrapolate the maximal RPE score and its corresponding 1-RM.

Results RPE and relative intensities of sets appeared related pre- [$r^2 = 0.59$, standard error of estimate (SEE) = 13.3 %] and post-training ($r^2 = 0.83$, SEE = 8.1 %). Differences between measured and predicted 1-RM were reduced from the beginning to the end of training but standard deviations remained high (17.4 ± 11.8 vs. 4.2 ± 11.1 kg). Pre-training, 1-RM expressed relatively to body weight was negatively related with the errors of 1-RM predictions ($r^2 = 0.39$, $p = 0.03$).

Conclusions In older subjects, RPE may be used to predict 1-RM; however, the predicted value deviates considerably from the measured one, necessitating cautious application. Importantly, this method allows to capture training-induced change in 1-RM, thus making possible assessing training's effectiveness and allowing its modification if necessary.

Keywords Strength training · Aging · Perceived exertion · One-repetition maximum · Rehabilitation

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Introduction

Aging is associated with decreased strength and muscle mass that is defined as sarcopenia [1]. Strength training in the elderly increases protein synthesis, muscle mass and strength, and improves locomotor functions such as walking speeds and postural control [2, 3]. As a consequence, strength training in rehabilitation program for older adults is largely promoted [4].

Peterson et al. [5] suggested that, similar to that observed in healthy young individuals, higher intensities in resistance exercises for older patients provide best strength improvements. Therefore, individual's one-repetition maximum (1-RM) is required to calculate and prescribe intensity for resistance training, while 1-RM testing protocols may enhance the risk of injuries and are time-consuming. Obviously, these limitations of 1-RM testing may be enhanced in elderly [6, 7].

In training and rehabilitation fields, 1-RM is frequently predicted using submaximal tests and applications of equations for 1-RM prediction [8]. The accuracy of these equations has been linked to specific exercises, to the populations assessed and to the relative strength used for repetition maximum testing [8, 9]. Some studies reported that the use of such prediction equations for older adults may be valid for 1-RM estimate although errors of estimate may appear slightly high [6, 10, 11]. Furthermore, direct as well as indirect assessment of 1-RM require participants to perform repetitions until muscular failure which enhance muscular and cardiovascular health risks in untrained individuals and particularly elderly [6]. To avoid risks associated with tests performed until exhaustion in population at risk, including older adults, some authors supported the use of ratings of perceived exertion (RPE) during graded exercises to predict maximal oxygen consumption [12–14]. A similar use of RPE to predict 1-RM was reported as providing highly accurate estimates although the loads to lift were presented in a random order and was not apparent to subjects [15]. Older adults' ability to discriminate the weight of lifted object may appear reduced and their use of RPE for 1-RM prediction remains to be tested [16]. Notwithstanding, according to the reported training state influence on RPE, a rehabilitation training program for the elderly could increase the subject's ability in RPE use as suggested previously [17].

The protocol used in this study was similar to that proposed by Eston and Evans [15] using light to moderately heavy loads and a very low repetition number during resistance exercise sets. The aim of the present study was to assess the accuracy of 1-RM prediction from RPE of resistance exercises performed in submaximal sets in older adults at the beginning and the end of a 12-week strength training program.

Materials and methods

Subjects

Eighteen subjects (70.4 ± 4.5 years) volunteered to participate in the present study after being informed of the nature of the experiments. Each subject signed a consent form that outlined possible risks due to the procedure. The protocol was approved by the local Ethics Committee. None of the subjects had any background in regular strength and/or endurance training or competitive sports of any kind in the previous 10 years. All lived at home and were able to perform activities of natural daily life independently. Subjects were required to have medical approval before participating in the study. No medication was being taken by the subjects that would have been expected to affect physical performance.

Study design

Before the first session and at the end of the 12-week program, subjects heights were measured with a height measurement scale to the nearest cm, weight to the nearest 0.1 kg and body composition by an impedance weight scale (Tanita, SC-331). To decrease higher risk of injury occurring during the first weeks of strength training, subjects began by performing four sessions of familiarization to strength training and exercises during 2 weeks [18, 19]. Training sessions, as well as those dedicated to study measures, were all separated by at least 72 h.

The training program consisted of a total of 21.6 ± 2.2 training sessions over 12 weeks. The program was composed of exercises combining endurance (cycling, stairs climbing and rowing ergometers; 20–30 min per session) and strength training exercises. Strength training was composed of varied exercises (horizontal leg press, knee extension, knee flexion, chest press, seated row, elbow extension, and elbow flexion), intensities (from 40 to 80 % of 1-RM) and volumes (approximately, from 20 to 2 repetitions within 2–4 sets).

Subjects were tested during the 3rd and 12th weeks of the training rehabilitation program to determine their abilities to use RPE for 1-RM prediction in horizontal leg press (Technogym, Issy les Moulineaux, France) using a method described by Eston and Evans [15]. Horizontal leg press was chosen because it allows reducing the influence of technical abilities on 1-RM and the movement appeared very safe for subjects.

Session for 1-RM direct assessment and submaximal sets

Individual 1-RM on horizontal leg press was assessed at the end of 2nd and 11th training weeks. Subjects completed a light standardized warm-up as described by Kraemer and Fry [20] (a first set of 10 repetitions at an easy load followed by 1 min rest and then four repetitions at moderately heavy loads). Thereafter, subjects performed 3–5 attempts to reach 1-RM on the horizontal leg press (to the nearest 5 kg) with 5 min of rest period between each attempt (only one repetition performed in each attempt).

The sessions for submaximal sets completion and corresponding RPE records followed the protocol reported by

Eston and Evans [15]. In the 3rd and 12th training weeks, after the same warm-up described for direct 1-RM assessment, participants performed three sets of two repetitions on horizontal leg press; the sets were performed at a pre-determined intensity (approximately, 20 % of 1-RM:Int20, 45 % of 1-RM:Int45 and 70 % of 1-RM:Int70). The three loads were randomly presented to the participant and were applied without making them apparent to the participant. The RPE was recorded following each of these submaximal sets.

Ratings of perceived exertion

The RPE was measured with the Borg Category Ratio scale (CR-10; from 0 to 10) [21], as previously realized during strength training studies [22], without numerical rating of 0.5 and using the categorical ratings from "no exertion at all" to "maximal exertion" to facilitate the subjects' ability to appreciate the effort involved.

The CR-10 scale was explained to subjects at the beginning of the 2nd training week and was used during submaximal sets sessions (3rd and 12th training weeks): "You are about to undergo a weight lifting exercise test. The scale before you contains numbers from 0 to 10 and will be used to assess your perceptions of exertion while lifting these weights. The perception of physical exertion is defined as the subjective strain, discomfort, and/or fatigue that you feel during exercise. We use this scale so that you may translate into numbers your feelings of exertion while you exercise. The numbers on the scale represent a range of feelings from no exertion at all (0) to maximal exertion (10)".

Data analysis

The 1-RM predictions were calculated by entering individual participant RPE values and load (kg) from each submaximal set into a linear regression analysis that provided individual regression equation to extrapolate a theoretical 1-RM at CR-10 of 10 [15].

Linear regression was used to determine the relationship between the RPE and the relative intensities of all sets (1-RM percentage) pre- and post-training. Using pre- and post-training results, relationships between 1-RM errors of prediction and subjects' characteristics (absolute 1-RM, 1-RM increases, 1-RM expressed relative to body weight, age, weight, body mass index, fat-free mass) were analyzed by linear regression to identify the possible origins of load misperception. One-way analyses of variance for repeated measures were performed to detect differences between RPE, predicted and measured 1-RM in pre- and post-training periods. If a main effect was observed, the post hoc Tukey's test was applied to determine which condition provided differences. The accuracy of the 1-RM prediction was quantified by the explained variance (r^2) of the relationship between measured and predicted 1-RM and by the standard error of estimate (SEE). Statistical significance was accepted at $p < 0.05$ (two-sided for t tests). Data in the text are given as mean ± standard deviation (SD). R software (version 3.0.2, R Foundation for Statistical Computing, Vienna, Austria) was used for the analysis.

Results

Each subject's weight was unchanged post-training ($p = 0.08$) but fat-free mass was slightly increased after 12 weeks of training ($p = 0.04$); subjects' characteristics and 1-RM are presented in Table 1. Relative intensities of submaximal sets and RPE recorded following these sets are presented in Table 2. At the beginning and the end of the period, RPE significantly differed between Int20, Int45 and Int70 ($p \leq 0.001$) and after training, post-training RPE was reduced at Int20 and Int45 sets (respectively, $p = 0.01$ and $p = 0.02$). Measured 1-RM was increased after 12 weeks of training ($p = 0.001$). RPE and relative intensities of sets (1-RM percentage) were related before training ($r^2 = 0.59$, SEE = 13.3 %) and post-training ($r^2 = 0.83$, SEE = 8.1 %). When the analyses were conducted separately for each intensity (i.e., Int20, Int45 and Int70), the relationships were not significant ($p > 0.05$). Measured and predicted 1-RM values differed at the beginning (110.5 ± 8.8 vs. 93.1 ± 15.9, $p = 0.001$) but not at the end of the training period (132.2 ± 10.1 vs. 127.6 ± 18.6, $p = 0.07$). The mean prediction errors at the beginning of the study appeared high (17.4 ± 11.8 kg) and were reduced after training (4.6 ± 11.1 kg) but standard deviations remained elevated. Relationships between measured and predicted 1-RM values appeared slightly improved by training (respectively, $r^2 = 0.45$, SEE = 10.2 vs. $r^2 = 0.52$, SEE = 8.2 kg; Fig. 1). Pre-training, 1-RM expressed relative to body weight was negatively related with errors of 1-RM predictions ($r^2 = 0.39$, $p = 0.03$; Fig. 2); this relationship was not significant post-training ($p = 0.1$) and no other relationship appeared between

Table 1 Subjects' anthropometrical characteristics and leg-press one-repetition maximum (1-RM) pre- and post-training

Weight (kg)	Height (kg)	Fat-free mass (%)	Measured 1-RM (kg)
Pre-training			
74.8 ± 7.9	170.9 ± 4.3	56.1 ± 6.4	110.5 ± 8.8
Post-training			
74.9 ± 6.9		57.6 ± 6.3*	132.2 ± 10.1*

* Significantly different to the pre-training measures

Table 2 Pre- and post-training recorded RPE, relative intensities used in submaximal sets (Int20 about 20 % of 1-RM, Int45 about 45 % of 1-RM and Int70 about 70 % of 1-RM)

Int20		Int45		Int70	
1-RM (%)	RPE	1-RM (%)	RPE	1-RM (%)	RPE
Pre-training					
21.3 ± 2.3	4.5 ± 1.0[§]	46.5 ± 4.1	6.7 ± 1.3[¤§]	70.9 ± 4.0	8.0 ± 0.9[¤#]
Post-training					
23.1 ± 1.3	3.1 ± 0.9[*§]	46.4 ± 2.9	5.3 ± 1.0[*¤§]	71.4 ± 2.5	7.4 ± 0.8[¤#]

[*] Significantly different to the pre-training measures

[¤] Significantly different to Int20

[#] Significantly different to Int45

[§] Significantly different to Int70

1-RM prediction errors and subjects' characteristics ($p > 0.05$).

Discussion

The present study was the first to demonstrate an older adult's ability to discriminate the intensity of strength exercises by using RPE. The prediction of 1-RM from RPE although statistically significant presents high individual prediction errors suggesting a careful use of loads determined by such a method in older adults.

Pre and post-training, RPE appears related to the relative intensities of submaximal sets that are in accordance with the reported ability of RPE to describe the intensity of resistance exercises in youths and healthy individuals [23, 24]. To our knowledge, this study is the first to show that RPE could be used to identify intensities of resistance exercises in older adults although some studies reported a possible use in endurance exercise [25–27]. The relationship between RPE and set intensities requires considering the three relative intensities performed (Int20, Int45 and Int70). Previously, the ability of older adults to discriminate the weight of the lifted objects has been reported to be reduced when compared to younger adults, whereas their ability to perceive weight ratio (weight difference between two objects) may be preserved [28]. RPE provided by our subjects differed for sets performed at Int20, Int45 and Int70 underlining the subjects' capacity to discriminate objects weights. Therefore, our results suggest that RPE of a unique set may be insufficient to accurately identify the relative load that the subject lifted, while the discrimination of several loads improves the relationship between exercise intensity and RPE. This result supports the construct of an individual RPE regression equation to estimate 1-RM as proposed by Eston and Evans [15]. When this is performed, our results show that RPE from submaximal sets can be used to provide a quite good estimation of 1-RM.

Nevertheless the statistical significance of our results, individual error of prediction as well as SEE of regression analyses appears high in both pre- and post-training sessions. Prediction errors previously reported by Eston and Evans [15] were about few kilograms, but in our results when expressed in percentage of 1-RM, they are higher than 10 %. These errors of prediction could be assumed as quite high for older populations according to the health perspective of rehabilitation programs.

The origins of load misperception are difficult to identify and should be linked to several factors. However, the negative relationship between errors of prediction and 1-RM expressed relative to body weight suggested that subjects with the lower relative strength were the ones presenting the lower ability for load perception. The influence of training state and fitness on RPE ability to describe endurance physical effort has already been demonstrated [29, 30]. We previously reported that, in strength training, the relationship between relative exercise volumes and RPE was enhanced in trained individuals [22]. The relationship between errors of prediction and 1-RM relative to body weight strength observed during pre-training was not significant during post-training suggesting that strength training could alter loads misperception particularly in weaker subjects. Until the present study, such training effect on the accuracy of RPE use by older adults has mainly been suggested rather than demonstrated [17].

However, the 12-week rehabilitation program results not only increase the 1-RM but also improved the ability to discriminate strength levels. Explained variance of the relationships and SEE demonstrate a higher accuracy for post-training 1-RM estimates than for pre-training estimates. For similar relative intensities, sets of RPE at Int20 and Int45 were higher in pre-training than in post-training underlining over-estimation of light loads at the beginning of the training period. This over-estimation of the strength in older adults that required to lift or grip objects has been previously reported [11, 31]. Moreover, after recent hip

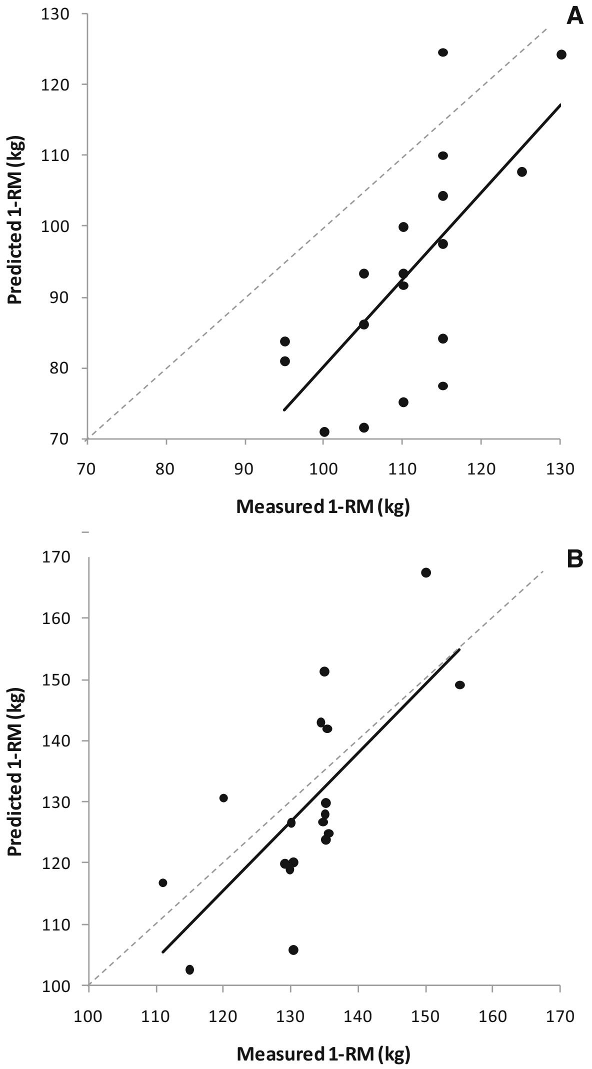

Fig. 1 Relationship between measured and predicted 1-RM from RPE of submaximal sets pre- (**a**) and post-training (**b**). Regression line in *continuous black line* ($r^2 = 0.45$, $p = 0.02$ for **a** and $r^2 = 0.52$, $p = 0.01$ for **b** and *dashed gray line* for identity line

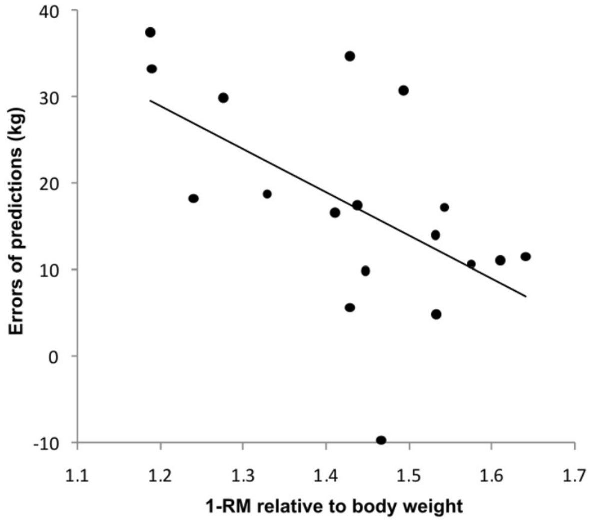

Fig. 2 Relationship between errors of prediction and one-repetition maximum (1-RM) expressed relative to body weight pre-training. Regression line in *continuous black line* ($r^2 = 0.39$, $p = 0.03$)

arthroplasty in older patients, a period of habituation to exercise has been proved necessary to observe a significant relationship between RPE and heart rate when exercising [26]. Such delay for an accurate RPE use could be linked to age but also to patients' pathology [32, 33]. Post-training, differences between measured and predicted 1-RM appear more balanced with under- and over-estimation of 1-RM. This 1-RM over-estimation observed during post-training may enhance the muscular risks associated with exercise. Therefore, at the beginning of training, RPE provides under-estimations of 1-RM rendering low accuracy for 1-RM predictions but remaining safe. Conversely, the higher prediction accuracy observed during post-training was combined with over-estimation that could be associated with enhanced potential risks for older subjects. It could be hypothesized that in pre-training, over-estimating loads may have a protective role against risks associated with physical tasks in older subjects.

We assumed that the protocol, used in the present study, cannot be applied in practice as relative loads of submaximal sets cannot be known. Our results demonstrate that 1-RM predictions could be calculated by recording RPE after several sets of resistance exercises performed at light to moderate loads and with low repetition number. A practical method of 1-RM estimation from RPE should correspond to ratings of unknown light to moderate loads. To preserve older subject from any risks, testing loads should be modified according to previous rating to avoid high loads (i.e., maximal rating about 7–8 in CR-10 scale). After 1-RM estimation and loads determination, loads to lift should be tested by subjects before being included in the sets of strength training programs. Furthermore, it is of importance to note that enhanced strength capacities were identified by RPE underlining the fact that RPE may be an easy tool for the assessment of training effects or even for individual training monitoring in a day or week basis as proposed for young adults and athletes [34].

Conclusion

Despite aging negative effects, the present study reported that in the elderly, RPE may be used to estimate 1-RM with fairly reasonable accuracy despite using sub-maximal loads and only two repetitions. Pre-training, the 1-RM is rather underestimated, especially in weaker subjects, than overestimated thus rendering the method safe. In addition, RPE also allow detecting training-induced increase in 1-RM. The present method paves the way to a practical method where 1-RM will be predicted neither with prior knowledge, nor with later determination of actual 1-RM.

Conflict of interest On behalf of all authors, the corresponding author states that there is no conflict of interest.

Human and Animal Rights All procedures performed in studies involving human participants were in accordance with the ethical standards of the institutional and/or national research committee and with the 1964 Helsinki declaration and its later amendments or comparable ethical standards. This article does not contain any studieswith animals performed by any of the author.

Informed consent Informed consent was obtained from all individual participants included in the study.

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