The relationship between the number of repetitions performed at given intensities is different in endurance and strength trained athletes

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THE RELATIONSHIP BETWEEN THE NUMBER OF REPETITIONS PERFORMED AT GIVEN INTENSITIES IS DIFFERENT IN ENDURANCE AND STRENGTH TRAINED ATHLETES

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ABSTRACT: Prescribing training intensity and volume is a key problem when designing resistance training programmes. One approach is to base training prescription on the number of repetitions performed at a given percentage of repetition maximum due to the correlation found between these two measures. However, previous research has raised questions as to the accuracy of this method, as the repetitions completed at different percentages of 1RM can differ based upon the characteristics of the athlete. The objective of this study was therefore to evaluate the effect of an athlete's training background on the relationship between the load lifted (as a percentage of one repetition maximum) and the number of repetitions achieved. Eight weightlifters and eight endurance runners each completed a one repetition maximum test on the leg press and completed repetitions to fatigue at 90, 80 and 70% of their one repetition maximum. The endurance runners completed significantly more repetitions than the weightlifters at 70% (39.9 $\pm$ 17.6 versus 17.9 $\pm$ 2.8; $p < 0.05$) and 80% (19.8 $\pm$ 6.4 versus 11.8 $\pm$ 2.7; $p < 0.05$) of their one repetition maximum but not at 90% (10.8 $\pm$ 3.9 versus 7.0 $\pm$ 2.1; $p > 0.05$) of one repetition maximum. These differences could be explained by the contrasting training adaptations demanded by each sport. This study suggests that traditional guidelines may underestimate the potential number of repetitions that can be completed at a given percentage of 1RM, particularly for endurance trained athletes.

KEY WORDS: **weight lifting; exercise; adaptation, physiological; physical endurance; exercise prescription; one repetition maximum**

INTRODUCTION

In resistance training programmes, training load for a given set of an exercise is prescribed in terms of both intensity (the weight to be lifted relative to the person's capabilities) and volume (the number of repetitions) [24]. It has been clearly established that there is an inverse relationship between the weight to be lifted and the number of repetitions that can be performed [18,19]. This relationship is of key importance for a coach in prescribing the appropriate load. For instance, given a desired intensity, the coach needs to know an appropriate number of repetitions to create a session with the required difficulty.

In contemporary practice, there are two main ways of prescribing intensity; to prescribe it based on the individual's repetition maximum for a given exercise (the exercise is performed with a weight that would allow a given number of repetitions and no more) or to prescribe repetitions based on a percentage of that person's one repetition maximum (1RM – the greatest weight that the person can lift for one repetition while maintaining perfect form). If the former method is used the relationship between intensity and number of repetitions is clear. However, when using the latter method it is necessary to establish the number of repetitions that an athlete can complete at a given percentage of their 1RM.

Despite the ubiquity of "repetition maximum" tables that present the number of repetitions that an athlete can be expected to complete at a given percentage of their 1RM, the literature related to the topic is limited. In addition, some of the more commonly employed repetition maximum tables are based upon weight room observations or "guesstimates" [28] rather than empirical studies. An influential example of this is a table presented by Baechle et al. [3] which is often used to establish the relationship between 1RM and number of repetitions. In particular, the evidence on which this table is based is largely taken from non-peer reviewed literature (Table 1; [2,4, 5,8,17–19,27]). It should be noted that Baechle et al. do acknowledge the potential variability in this relationship and in the literature exploring it, and give appropriate caveats and guidelines for the use of the table. However, the lack of a scientifically established evidence base for such a table suggests that the relationship between 1RM and repetitions completed requires further, more rigorous quantification.

TABLE I. REFERENCES FOR THE REPETITION MAXIMUM TABLE OF BAECHLE ET AL. [3]

References	Background and detail of references
Baechle T.R. & Earle R.W. [2]	The book is no longer in print but in any case is not a piece of peer reviewed research literature.
Brzycki [4]	Not a piece of scientific research, but an article detailing strength testing. The author provides an equation for predicting a 1RM based on reps-to-fatigue, but does not say on what information this equation is based.
Chapman et al. [5]	The table presented in this study is a combination of other sources presented in this table [4,8,17].
Epley [8]	A poundage chart, not based on scientific research.
Lander [17]	This formula "began as a 'guess-timated' chart that was eventually published without the author's knowledge" [28]
Mayhew et al. [18]	A study evaluating the accuracy of estimating 1RM from submaximal repetitions.
Morales & Sobonya [19]	The first 1RM table is from "Strength Tech Inc" and is not a study. The second table does include repetitions achieved at percentages of 1RM based on the results of this study.
Wathen [27]	This reference is the previous edition of the book, which contains no peer reviewed research on the 1RM table data.

The determination of the relationship between intensity and number of repetitions is complicated by the fact that there may be a large variance in the repetitions completed at the same percentage of 1RM by different participants in different exercises. For instance, a number of studies (of varying quality) have shown that trained participants can lift more repetitions at a given percentage of 1RM than untrained participants [16,21], although there are some conflicting results [11].

It also seems intuitively sensible to suggest that there may be differences between distinct sporting populations due to the adaptations that they gain in training for their sport although only one study has compared these differences. Desgorces et al. [7] tested 4 groups of athletes (powerlifters, handball players, rowers and swimmers) in a 1RM test using the bench press. Repetitions to fatigue at 20, 40, 60, 75 and 85% of 1RM were then conducted. Although no significant difference was found between the groups, when the powerlifter and handball player groups (strength based sports) were paired against the rowing and swimming groups (endurance based sports), the endurance group performed significantly more repetitions at all percentages. In a very recent study, Panissa and colleagues [20] showed that aerobically trained participants performed significantly more repetitions at 80% of their 1RM in a Smith machine half squat than their strength trained counterparts.

There is thus preliminary evidence that suggests that there might be a difference in the number of repetitions completed at a given percentage of 1RM between athletes with different training backgrounds, but this fact has yet to be definitively established. Hence the primary aim of this study was to test the difference in repetitions completed on the leg press machine between two different groups of athletes (strength trained and endurance trained) at given percentages of their 1RM. It was hypothesized that there would be a significant difference between the two groups, with the endurance trained group being able to achieve more repetitions at every percentage of 1RM. The secondary aim of this study was to compare the repetitions achieved at each percentage to those suggested in the coaching literature in order to assess their likely veracity.

MATERIALS AND METHODS

A total of sixteen male participants were purposively recruited from the student body of St Mary's University College to take part in a cross-sectional observational study. The weightlifting group (WT; n=8; age 22.4 ± 3.3 years; weight 79.8 ± 10.8 kg; height 177.1 ± 3.9 cm) consisted of athletes with at least two years of weightlifting experience and who regularly train with maximal or near maximal loads (≤ 6RM). The endurance running group (ET; n=8; age 20.9 ± 1.5 years; weight 63.3 ± 1.5 kg; height 176.3 ± 3.0 cm) consisted of runners with at least two year's experience of training for track and/or cross country running (≥ 800m). Participants were also required to be free from injury and to have had no sustained training experience in the other group's mode of training. The participants provided written informed consent and the study was approved by the ethics committee of St Mary's University College. The experiment reported here was performed in accordance with the ethical standards of the Helsinki Declaration.

At the first testing session participants were taught a standardised technique for the leg press [9]. The participants were instructed to keep their head, shoulders and hips in contact with the leg press machine and if technique failed the repetition was not counted. To ensure all participants lifted with the same range of movement in the leg press, the end range of the leg press movement was when the participants' femurs were parallel to the leg press footplate. To ensure correct depth and speed of every repetition, participants were given cues as when to start the concentric phase and feedback on speed. Cadence was set at three seconds for the eccentric portion to encourage controlled lifting, with the concentric portion completed as fast as possible until the legs were fully extended.

Participants' 1RM was obtained during the first testing session, after performing a standardized warm up. Participants then attended a further three testing sessions, separated by at least 48 hours. Testing was kept at the same time of day for all participants, to decrease the effect of the known diurnal fluctuations in strength [6]. In each testing session, the participant performed a trial to establish the maximum number of repetitions that could be completed at a given percentage of 1RM. The percentages chosen were 90, 80 and 70% of 1RM and the order of testing was randomised for each participant. These particular percentages were chosen as they are those most commonly used in resistance training programs [3]. The same standardised warm up used for the 1RM test was com-

pleted and then three warm up sets of three to five repetitions were completed at thirty, twenty and ten percent below the actual percentage used in the trial. Two minutes rest was taken between each set.

Statistics

A comparison between the two groups of the number of repetitions completed at 90, 80 and 70 percent of participants' 1RM was performed with the software package Statistical Package for Social Science (SPSS Inc version 15.0, Chicago, IL). A repeated measures ANOVA with post-hoc Bonferroni adjusted t-tests was conducted to test for differences with the level of significance set at $p \leq 0.05$ a priori.

RESULTS

Resistance training experience and 1RM of the participants are detailed in Table 2, with higher 1RM scores and weight training experience found in the WT group. In both groups (within group analysis) the amount of repetitions completed increased significantly as the percentage of 1RM decreased. Comparison of the two groups revealed that the ET group completed significantly more repetitions than the WT group at 70% 1RM and 80% 1RM, however no significant difference was found in repetitions to fatigue at 90% 1RM (Table 2 and Figure 1).

TABLE 2. COMPARISON OF LEG PRESS PERFORMANCE BETWEEN ENDURANCE (ET) AND WEIGHTLIFTING (WT) GROUPS

	Endurance group	Weightlifting group
Resistance training experience (years)	0.0 ± 0.0	4.1 ± 1.0*
1RM leg press score (kg)	188.4 ± 13.8	335.6 ± 48.6*
Repetitions completed:		
@ 70% 1RM	39.9 ± 17.6 †	17.9 ± 2.8 †*
@ 80% 1RM	19.8 ± 6.4 †	11.8 ± 2.7 †*
@ 90% 1RM	10.8 ± 3.9 †	7.0 ± 2.1 †

Note: * = significant difference between ET and WT - $p < 0.05$; † = significant difference within group – $p < 0.05$

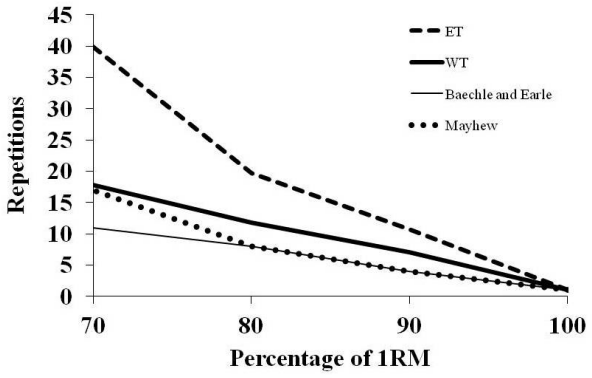

FIG. 1. COMPARISON OF WEIGHTLIFTING AND ENDURANCE GROUPS WITH BAECHLE AND EARLE [3] AND MAYHEW ET AL. [18] FOR AMOUNT OF REPETITIONS COMPLETED AT SELECTED PERCENTAGES OF 1RM.

DISCUSSION

The main finding in this study was that the ET group completed significantly more repetitions at 70 and 80% of 1RM than the WT group, although there was no significant difference between the two groups at 90% of 1RM. The ability of the ET group to perform more repetitions than the WT group at lower percentages of 1RM is likely to be explained, at least in part, by the specificity of adaptations gained from training in their sport. Increases in capillarisation [1], mitochondrial content [13], muscle phenotype [26] and lactate buffering [12] have all been found in participants who have completed endurance training protocols, and all of which may have helped the endurance athletes perform more repetitions at submaximal intensities. The present study also suggests that the difference between the two groups' repetitions to fatigue widens at lower percentages of 1RM. This is also consistent with the notion that endurance specific adaptations in the runners (that would be expected to be more influential when the number of repetitions performed was higher) improved their ability to complete a greater number of repetitions.

It should be noted however, that there is potentially an alternative explanation for this trend. It might be that the lack of familiarity of the ET group with training at higher loads prevented them from achieving the level of arousal necessary for maximal performance in the 1RM test [25]. This would then mean that the weight used for each repetition maximum test would be relatively lower in comparison to the WT group.

The findings of this study are consistent with the work of Desgorces et al. [7]. They found that at 75% of 1RM and below, the high endurance group (swimmers and rowers) achieved more repetitions than the high strength group (powerlifters and handball players). This difference increased as the intensity decreased to 20% of 1RM, with the authors proposing this difference between the two groups may be because of training adaptations gained and the genetic makeup of the athletes. One limitation of the Desgorces study was that the tests to fatigue at different percentages of 1RM were completed on the same day after only a 15 minute recovery. This incomplete recovery of the participants could explain why lower repetitions were found in the Desgorces study as compared to this work. The findings of this study may also be consistent with studies that found that resistance trained participants were able to perform more repetitions in resistance exercises than untrained participants [16,21]. Both of these studies pointed to the specificity of training adaptations achieved by the resistance trained group which would permit them to achieve a greater number of repetitions when compared to untrained participants. It is possible that the resistance trained participants in the present study would also outperform untrained participants, but they are simply outperformed in turn by the endurance trained athletes.

In this study the endurance runners and weightlifters performed 19.8 ± 6.4 and 11.8 ± 2.7 repetitions respectively at 80% of 1RM. This is consistent with the results of previous research [11,14]. For instance, Hoeger et al. [11] found that untrained and trained subjects

completed 15.2 ± 6.5 and 19.4 ± 9.0 repetitions respectively at 80% of 1RM whereas Jacobs et al. [14] found that trained subjects completed 13 ± 5 repetitions with the same relative load. Figure 1 presents a comparison of the relationship between intensity and number of repetitions found in this study and other commonly quoted relationships. It is apparent that these oft quoted relationships had poor predictive power for the leg press in the athletes studied here (and also for the amount of repetitions at 80% of 1RM found in the other studies referred to here).

The comparison of the different findings in Figure 1 suggests a need for the scientific community to revisit this issue to produce more robust, sport-specific estimates. It is the authors' opinion that the wide variation in the number of repetitions that a given individual can complete with a given relative load is not adequately recognised by coaches. This need is magnified by the fact that differences have been found in the relationship between intensity and repetitions completed between upper body and lower body exercises [11], between single-joint exercises and multi-joint exercises [10,23], and between males and females with the same exercise [15]. An alternative is for practitioners to use alternate methods of prescribing intensity. In a review by Tan [24] it is suggested that the repetition maximum (RM) method is more appropriate, as it focuses more on the individual, rather than a marker of maximal strength they may have achieved sometime in the past. Poliquin [22] also recommends this method of prescription and suggests it can also reduce the risk of unintentional under or over-training in a session which may happen when prescribing intensity by normative 1RM data.

CONCLUSIONS

This study demonstrates the importance of using sport-specific estimates of the relationship between repetitions and percentage of 1RM. In addition, this study suggests that traditional guidelines may underestimate the potential number of repetitions that can be completed at a given percentage of 1RM, particularly for endurance trained athletes.

Conflict of interest: Authors declared no conflict of interest.

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