Relationship Between Maximum Strength and Relative Endurance for the Empty-Can Exercise

Martha Walker, Donald Sussman, Michael Tamburello, Bonnie VanLunen, Elizabeth Dowling, and Beth Ernst Jamali

**Context:** A strength-endurance diagram predicts that a person should be able to perform 30 repetitions of an exercise if the resistance level is 60% of 1-repetition maximum (1RM). **Objective:** To compare the number of repetitions predicted by the diagram with recorded repetitions of a shoulder exercise. **Design:** Single-group comparison with a standard. **Setting:** University. **Participants:** 34 healthy adults (20 women, 14 men) with a mean age of 29 years (range 20–49). **Main Outcome Measures:** The number of repetitions that subjects could perform in good form of a shoulder exercise with resistance of 60% 1RM. **Results:** The mean number of repetitions was 21 (± 3, range 15–28), which was significantly different than the 30 repetitions that the diagram predicted. **Conclusions:** The strength-endurance diagram did not accurately predict the number of repetitions of a shoulder exercise that subjects could perform. **Key Words:** exercise repetitions, shoulder rehabilitation


There are many factors involved in devising an exercise program for rehabilitation of a muscle, group of muscles, or tendon. The choice of training mode, amount of resistance, number of repetitions and sets, velocity of movement, and frequency of exercise bouts must all be taken into consideration.\(^1\)\(^-\)\(^6\) The amount of resistance and number of repetitions are inversely related.\(^5\)\(^-\)\(^7\) For improving muscle strength, most protocols use a low number of repetitions at a resistance that is near the maximum amount that the person can lift 1 time.\(^1\)\(^-\)\(^5\) For muscle-endurance training, the resistance should be lower than for strength training, and the number of repetitions should be higher than 15.\(^5\)\(^-\)\(^7\) The actual amount of resistance used for improving

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muscle endurance has been left up to the trainer or clinician to set and can be based on the task that the subject is required to perform in a job, at home, or during a sport.

Fleck and Kraemer\(^7\) published a diagram regarding a theoretical repetition-maximum continuum (Figure 1). This diagram demonstrates that higher loads, which are associated with lower repetitions maximum, are related to strength training, whereas lower loads, which are associated with higher repetitions maximum, are related to endurance training.\(^7\) Fleck and Kraemer's diagram shows the general nature of the relationship between load, number of repetitions, and training effect.

Some recent publications\(^8-10\) have featured an exercise diagram developed in Europe that also relates type of training (strength or endurance) to load and number of repetitions (Figure 2). This diagram, attributed to Oddvar Holten, goes a step beyond the general relationship of load and repetitions by associating a particular number of repetitions with a particular percentage maximum load. We are at the disadvantage of not being able to find articles by Holten in English. Therefore, we cannot know the intentions of the originator; we can only look at how this diagram is being interpreted in recent publications in the United States.

In a chapter of *Therapeutic Exercise*, Hardin introduced the Holten diagram, stating that it "depicts the relationship between the maximum number of repetitions that can be performed and the percentage of maximal resistance in regard to muscle strength and endurance."\(^9,p^{125}\) The diagram and Harden's description of it imply that a given percentage of 1-repetition maximum (1RM) is associated with a particular number of repetitions, and

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**Figure 1**  A theoretical repetition-maximum continuum showing the relationship between load and training effect. Adapted with permission of Human Kinetics from Fleck SJ, Kraemer WJ. *Designing Resistance Training Programs*. Champaign, Ill: Human Kinetics; 1987:61.
vice versa. In a textbook on rehabilitation, Skyhar and Simmons include the strength-endurance diagram in their chapter on shoulder rehabilitation, stating that it is a practical way to “assess and treat any stage of muscle rehabilitation objectively.”

The Holten diagram, although it seems similar to Fleck and Kraemer’s diagram, is different enough to receive attention. The diagram implies that strength and endurance can be represented by a single, fixed relationship for all muscle groups at any point on the load spectrum. For example, at a load of 80% 1RM, subjects should be able to complete 11 repetitions, regardless of muscle group used or state of training, and at 60% 1RM they should be able to complete 30 repetitions. Previous studies provide evidence that the relationship between load and number of repetitions is not a single, fixed relationship.

We could find no evidence published in English to support the use of the Holten diagram. Therefore, we decided to test the use of the diagram as a guide for setting resistance levels using a common shoulder-rehabilitation exercise. Skyhar and Simmons advocated use of the diagram in treating shoulder patients, and we wanted to test it with a type of rehabilitation exercise for which it realistically might be used. We chose to target 30 repetitions for our exercise, because 30–40 repetitions of exercise were recom-
mended by Torstensen et al in a case study in which low-load high-repetitions exercise was successful in treating chronic supraspinatus tendinitis.\textsuperscript{16} The Holten diagram does not extend to 40 repetitions, thus limiting us to 30 repetitions. The authors focused on the “empty can” exercise of humeral elevation to 90° in the plane of the scapula with internal humeral rotation. This is a common exercise used in shoulder rehabilitation, and Townsend et al showed that it does activate the supraspinatus muscle.\textsuperscript{17} Using healthy individuals, we tested whether a resistance level of 60\% 1RM resulted in approximately 30 repetitions of the exercise.

\section*{Methods}

\section*{Design}

This study was a quasiexperimental, single-group comparison of results with a standard.

\section*{Subjects}

Subjects were healthy adults enrolled in classes or working at the university where the study was conducted. The subjects did not have shoulder pain or injury or any other neurologic or orthopedic condition that would prevent them from lifting a weight. They were volunteers, and the study was approved by the college’s Committee on Human Subjects Review in the spirit of the Helsinki Declaration.

\section*{Procedure}

The study was explained to each subject, who then signed a consent form. The subject was positioned sitting on a chair with both feet flat on the ground and the back unsupported. The subject was then instructed on how to perform the empty-can exercise. The arm was lifted into elevation in the plane of the scapula with the shoulder internally rotated and the thumb pointed toward the floor. The subject lifted the arm to approximately 90° and then returned to the start position at a medium speed, taking approximately 3–4 seconds to complete the motion. The examiner controlled the speed of movement by verbally cuing subjects who went too quickly or too slowly. For a repetition to count as successful, it had to be performed in good form, meaning that the subject performed the correct motion and there was no leaning or substitution. The subject was not allowed to use substitution motions, and the motion was well controlled and pain-free. The same examiner tested all subjects to ensure that each subject did the exercise in the same manner. Each subject performed several correct repetitions of the motion before being tested for 1RM. This was the only warm-up that was performed.
To find a subject’s 1RM for the empty-can exercise, the examiner used small cuff weights. If it took 5 or more trials to determine 1RM, but if the subject expressed fatigue, the 1RM amount was recorded but the actual testing was done on a different day, when the subject affirmed that he or she had no muscle soreness. This occurred with only 2 subjects during the study. After 1RM was established each subject was given at least a 2-minute rest period before starting the test. Mellion, Walsh, and Shelton recommend a 2- to 4-minute rest period when training load is 1–3RM. After the rest period, 60% 1RM was calculated and used as the test weight. Once the weight for the endurance test was established, the subject was asked to perform as many repetitions of the empty-can exercise as possible, maintaining medium speed and good form. The examiner stopped the exercise when the subject broke form, began to lean, or was unable to complete a repetition. The number of repetitions performed was recorded.

**Statistical Analysis**

Descriptive statistics were calculated for age, 1RM, load at 60% 1RM, and number of repetitions completed at 60% 1RM. A single sample t test was used to determine whether the mean number of repetitions completed was significantly different than 30. A Pearson product-correlation coefficient was calculated to determine whether there was any relationship between the amount of weight for 1RM and the number of repetitions lifted at 60% 1RM.

**Results**

Data were collected from 34 healthy subjects (14 men and 20 women) whose mean age was 28.7 ± 7.8 years. The mean 1RM was 18.9 ± 5.6 lb, with a range from 11 to 31 lb. The mean number of repetitions completed at 60% 1RM was 20.6 ± 2.9. Performances ranged from a minimum of 15 repetitions to a maximum of 28 repetitions, which is a 13-point spread (Figure 3). A single sample t test indicated that the mean was significantly different from 30 (t = −18.65, df 33, P < .000). The Pearson product-correlation coefficient showed a weak positive correlation of .392 between the amount of 1RM and the number of repetitions completed (P < .05).

**Comments**

The Holten diagram for setting the resistance of a shoulder-endurance exercise was not useful in determining the 30-repetitions level. In fact, no subject was able to achieve 30 repetitions. More important, the number of repetitions completed at 60% 1RM ranged from 15 to 28. Although many of the subjects performed around 20 repetitions, this large range of repetitions
shows that exercises at the same percentage of maximum strength will not be equally difficult for all subjects.

There was a weak but significant positive correlation between maximum strength and number of repetitions completed at 60% 1RM. This correlation of .392 was not a strong one but showed a tendency for subjects with higher maximum strength for this exercise to also have higher relative endurance. Previous studies that have looked at a relationship between maximum strength and relative endurance have found either a moderate negative correlation or no significant relationship between the 2 variables.\textsuperscript{11-14} Nonetheless, previous studies used male college students as subjects rather than a mix of active and sedentary men and women from a broader age range. The wider variety of subjects in this study might account for the different outcome.

A limitation of this study is that it used healthy adults with no history of shoulder injury. There is a possibility that patients undergoing rehabilitation might show a different relationship between strength and endurance than do healthy individuals. Therefore, it would be interesting if future investigators continued this investigation using shoulder-rehabilitation patients for subjects. In addition, the determination of 1RM might more properly have been done several days before the testing event to ensure that the effort
of identifying 1RM did not adversely affect performance at 60% 1RM. We feel, however, that the way that 1RM was determined was typical of how it would be done in a clinical or training situation. In subsequent sessions, the training weight would be adjusted depending on client ability and reaction to the exercise, but the initial session might use similar testing procedures. We are unsure whether the Holten diagram requires a particular method of testing 1RM. If it does, we suggest that this information be published along with the diagram.

Hoeger et al studied the relationship between maximum strength and the number of repetitions performed at 40%, 60%, and 80% of maximum strength for 7 standard weight-lifting exercises. Thirty-eight healthy men with no previous strength-training experience performed the following lifts: arm curl, quadriceps lift, bench press, sit-up, leg curl, lateral pull-down, and leg press. After a 1RM was determined for each subject for each exercise, the number of repetitions that each subject could perform at each percentage was determined. Hoeger et al found that the number of repetitions that could be performed at 60% of 1RM varied from person to person and from exercise to exercise. The mean number of repetitions on the leg press, for example, was 33.9 ± 14.2. For the leg curl at 60% 1RM, the mean number of repetitions was only 11.2, although the standard deviation was smaller, at 2.9. Hoeger et al concluded from their results that a given number of repetitions is not always associated with similar percentages of 1RM when performing different weight-training exercises.

This study does not support the use of Holten’s diagram for determining load for a 30RM endurance exercise for the shoulder. It is accepted that as the load lifted is decreased as a percentage of 1RM there is an increase in the number of repetitions a person can perform. Clinicians and trainers might want to regard this as a general principle rather than a specific mathematical relationship. The exact number of repetitions that a person can perform at a given percentage of maximum might vary from muscle group to muscle group and from person to person. This research provides clinical and training professionals some evidence for evaluating the Holten diagram.

References


