Fatigue contributes to the strength training stimulus

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ABSTRACT

ROONEY, K. J., R. D. HERBERT, and R. J. BALNAVE. Fatigue contributes to the strength training stimulus. Med. Sci. Sports Exerc., Vol. 26, No. 9, pp. 1160-1164, 1994. To investigate the role of fatigue in strength training, strength increases produced by a training protocol in which subjects rested between contractions were compared with those produced when subjects did not rest. Forty-two healthy subjects were randomly allocated to either no-rest group, a rest group, or a control group. Subjects in the two training groups trained their elbow flexor muscles by lifting a 6RM weight 6–10 times on 3 d each week for 6 wk. Subjects in the no-rest group performed repeated lifts without resting, whereas subjects in the rest group rested for 30 s between lifts. Both training groups performed the same number of lifts at the same relative intensity. The control group did not train. Subjects who trained without rests experienced significantly greater mean increases in dynamic strength (56.3% ± 6.8% [SD]) than subjects who trained with rests (41.2% ± 6.6%), and both training groups experienced significantly greater mean increases in dynamic strength than the control group (19.7% ± 6.6%). It was concluded that greater short-term strength increases are achieved when subjects are required to lift training weights without resting. These findings suggest that processes associated with fatigue contribute to the strength training stimulus.

WEIGHT TRAINING, RESISTANCE TRAINING, MUSCULAR STRENGTH, EXERCISE

The optimization of strength training programs is of interest both to professionals who prescribe exercise and to physiologists interested in the mechanisms by which training induces increases in strength. Experiments that have investigated the effects of factors thought to influence the magnitude of the strength training response indicate that strength increases produced by training are greatest when subjects train at high, but submaximal, loads (1,2,5). Other experiments suggest that the training response increases nonlinearly with the number of lifts performed in a training session (2), and probably also with the frequency of training (7).

Almost all of these experiments, and probably many of the training programs prescribed in practice, utilize training protocols in which subjects are required to repeatedly lift the training weight without resting, often until they are unable to perform further lifts. That is, these protocols utilize fatiguing contractions. Yet there is no experimental evidence that optimization of the training response necessitates either that subjects perform lifts without resting, or that they continue lifting until they are unable to perform further lifts. The purpose of this study was, therefore, to compare the strength increases produced by a training protocol in which subjects repeatedly lifted the training weight without resting with the strength increases produced by a protocol in which subjects rested between contractions.

METHODS

Subjects

Forty-two subjects, 18 males and 24 females, aged between 18 and 35 yr volunteered to participate in the study. Subjects were screened to ensure that they had no history of significant cardiovascular disease, that their resting arterial blood pressure was not more than 140/90, and that they were not undertaking or had not recently undertaken an upper limb strength training program. Written informed consent was obtained from subjects. All procedures were approved by the University’s Human Ethics Committee.

Strength Measurements

The strength of the elbow flexor muscles was measured on all subjects at the start of the study. Two measurements of strength were made. For the first measurement, dynamic strength was determined by asking subjects to lift a weight, held in the hand and supported on a bar, through the full range of elbow motion. Subjects were seated in a chair with their arms resting on a test bench. The largest weight which a subject could lift once, determined to the nearest 0.5 kg (4.9 N), provided a measure of that subject’s dynamic strength. The second measure was of isometric strength. For this measure,
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subjects were seated with their arms resting on the test bench and with the elbow supinated and the forearm horizontal. They were then encouraged to exert a maximal pull on a handle attached to a chain which was aligned approximately perpendicularly to the forearm and connected in series to a strain-gauge force transducer (XTRAN model 51W, Applied Measurement, Melbourne) bolted to the ground. The force signal was amplified and displayed on a chart recorder. Calibration with known weights performed before and after all testing sessions allowed the forces exerted on the chain to be later read from the chart recorder. Subjects were instructed to gradually build up the force with which they pulled against the chain until they were producing the largest force they could attain. The largest force which a subject could produce on three attempts was considered to be a measure of that subject's isometric strength.

Once measurements of isometric and dynamic strength had been made, subjects were stratified according to dynamic strength. Each of the strongest three subjects was randomly allocated to one of the three groups - either a "no-rest" group, a "rest" group or a "control" group. The next three strongest subjects were then randomly allocated to groups in the same way. This procedure was repeated until all subjects had been allocated to groups.

Training

For the ensuing 6 wk, subjects in the no-rest and rest groups participated in a strength training program three times each week, under individual supervision from one of the investigators. All subjects in these groups trained with a "6RM" load (i.e., the "six repetition maximum" load, which is the largest load which subjects could lift six times without resting). The 6RM load was determined at the first training session and at the first training session in the third and fifth weeks. The procedure used to determine the 6RM load was identical to that used to determine dynamic strength, except that instead of determining the largest load each subject could lift, the largest load the subject could lift six times was determined.

Subjects in the no-rest group trained in the usual way, performing repeated lifts at a preferred cadence without resting. In order to prevent the utilisation of "stretch-shortening cycles" (9), subjects in this group were asked to pause momentarily between lifts. Subjects in the rest group rested for 30 s between each lift. For the 30-s rest period the weight was taken from the subject by the supervising investigator. The expectation was that, by structuring training in this way, subjects in the rest group would train with less fatiguing contractions than subjects in the no-rest group. In order to ensure that subjects in the no-rest group continued to experience relatively fatiguing contractions, and that the two groups performed exactly the same number of lifts at the same relative intensity, the number of lifts which subjects performed was proscribed as shown in Figure 1. On occasions when subjects in the no-rest group were unable to perform the proscribed number of lifts, the supervising investigator provided the least amount of assistance necessary to enable the subject to complete the required number of lifts.

Subjects in group three constituted a control group. These subjects did not perform any upper limb strength training exercise for the 6 wk of the training period, but they undertook the same measurement of 6RM strength at the start of the first, third and fifth weeks as subjects in the two training groups.

Fatigue Experiment

A second experiment was performed to determine the magnitude of fatigue induced by the two training protocols. For this experiment, fatigue was defined as the decline in isometric strength which accompanied a single bout of training. Nine subjects attended the laboratory three times in 1 d. On the first occasion each subject's 6RM training load was determined using the procedures described above. Subsequently, subjects performed each of the two training protocols (i.e., six lifts of the 6RM load with and without a 30-s rest between lifts; see Fig. 2). A 2-h rest was given between performance of the two protocols, and the order in which subjects performed the two protocols was randomized. The degree of fatigue associated with each protocol was quantified by the decline in measurements of isometric elbow flexor strength made immediately before lifting and after lifting.

Data Analysis

The results of one subject from the no-rest group who failed to complete the training program were discarded. After testing for homogeneity of regression the mean strength gains in the three groups were compared using analysis of covariance with pre-training strength as the

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<tr>
<th>Week</th>
<th>Session</th>
<th>Load Details</th>
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<tbody>
<tr>
<td>Week 1</td>
<td>session 1 - 6RM measured</td>
<td>session 2 &amp; 3 - train with 6 lifts of the 6RM load</td>
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<tr>
<td>Week 2</td>
<td>session 1, 2 &amp; 3 - train</td>
<td>with 10 lifts of the 6RM load</td>
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<tr>
<td>Week 3</td>
<td>session 1 - 6RM rechecked</td>
<td>session 2 &amp; 3 - train with 6 lifts of the 6RM load</td>
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<tr>
<td>Week 4</td>
<td>session 1, 2 &amp; 3 - train</td>
<td>with 10 lifts of the 6RM load</td>
</tr>
<tr>
<td>Week 5</td>
<td>session 1 - 6RM rechecked</td>
<td>session 2 &amp; 3 - train with 6 lifts of the 6RM load</td>
</tr>
<tr>
<td>Week 6</td>
<td>session 1, 2 &amp; 3 - train</td>
<td>with 10 lifts of the 6RM load</td>
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Figure 1—Training protocol used for no-rest and rest groups.
covariate (8). For the analysis of covariance a probability of less than five percent was considered significant. Where significant differences were detected by analysis of covariance, post hoc two-tailed independent samples t-tests were performed using the Bonferroni correction to avoid an inflated Type I error rate.

In the fatigue experiment, the decline in isometric force for the two training conditions was compared with the one-sample Wilcoxon signed-rank test.

RESULTS

Both training protocols induced fatigue as measured isometrically. However the isometric fatigue induced by the no-rest protocol (mean decrease of isometric strength of 3.0 kg, or 20.2 ± 15.2%) was significantly greater than that induced by the rest protocol (mean decrease of 1.6 kg, or 10.4 ± 8.8%; P = 0.042).

All three groups experienced a mean increase in dynamic strength over the 6-wk training period (Table 1 and Fig. 3). The no-rest group increased in dynamic strength by 7.0 kg (56.3% ± 6.8%; these and all subsequent group means and standard deviations are adjusted by analysis of covariance), the rest group increased in dynamic strength by 5.1 kg (41.2% ± 6.6%), and the control group increased in dynamic strength by 2.5 kg (19.7% ± 6.6%). The difference between groups was significant (P = 0.002). Post-hoc analysis showed that the no-rest group experienced a significantly greater mean increase in dynamic strength than both the rest group (P < 0.001) and the control group (P < 0.001), and that the rest group experienced a significantly greater increase in dynamic strength than the control group (P < 0.001).

The isometric strength increases were smaller than the increases in dynamic strength, but they showed similar trends (Table 1 and Fig. 4). The no-rest group increased in isometric strength by 6.6 kg (22.1% ± 4.3%), the rest group increased in isometric strength by 6.0 kg (19.8% ± 4.1%), and the control group increased in isometric strength by 2.0 kg (6.7% ± 4.1%). Again, the difference between groups was significant (P = 0.027). Post-hoc analysis showed that both the no-rest and rest groups experienced significantly greater mean increases in iso-

| Table 1: Mean (±SD) dynamic and isometric strength before and after a 6-wk training program. Also given are gains in strength adjusted for initial strength by analysis of covariance. All data are in kilogram units. |

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<th>Dynamic</th>
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<td>Post</td>
<td>Gain</td>
<td>Pre</td>
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<tr>
<td>No-rest</td>
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<td>16.5</td>
<td>7.0</td>
<td>29.9</td>
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<td></td>
<td>(0.4)</td>
<td>(0.2)</td>
<td>(0.9)</td>
<td>(5.9)</td>
</tr>
<tr>
<td>Rest</td>
<td>13.9</td>
<td>15.4</td>
<td>5.1</td>
<td>31.6</td>
</tr>
<tr>
<td></td>
<td>(0.6)</td>
<td>(0.2)</td>
<td>(0.8)</td>
<td>(1.8)</td>
</tr>
<tr>
<td>Control</td>
<td>11.1</td>
<td>13.2</td>
<td>2.5</td>
<td>23.7</td>
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<tr>
<td></td>
<td>(0.8)</td>
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metric strength than the control group ($P < 0.001$ for both comparisons). However, the difference between the no-rest and rest groups was not significant ($P = 0.147$).

**DISCUSSION**

The major finding of this study was that subjects who trained by repeatedly lifting the training weight without resting experienced substantially greater increases in strength than subjects who trained with rests between lifts. This indicates that, if short-term training programs for untrained subjects are to be optimally effective, subjects should not be permitted to rest between contractions.

This result suggests that the processes which bring about fatigue during high-intensity muscle contractions provide a stimulus which brings about increases in strength. An assumption underlying this interpretation is that subjects in the no-rest group experienced greater levels of fatigue than subjects in the rest group. Ideally, we would have liked to have been able to estimate the amount of fatigue subjects experienced using a measure which utilized dynamic contractions, but dynamic measures of fatigue could not be used in the context of this study. Instead, we used isometric measures of fatigue to demonstrate that while subjects in both groups experienced fatigue, subjects in the no-rest group experienced on average about twice the isometric fatigue as the rest group.

Our findings complement and extend the findings of Berger and Hardage (3). Berger and Hardage compared the strength increases produced by bench-press training programs which utilized either ten repetitions of the 10RM load or 10 repetitions of the maximal possible load for each repetition. In the latter program, subjects performed the first lift with the 1RM load and subsequent lifts with near maximum loads that were made progressively smaller to accommodate fatigue. After 8 wk of training three times per week, subjects in the group which trained with maximum loads experienced a 60% greater increase in strength than subjects who trained with the 10RM load. Berger and Hardage argued that the greater increase in strength in the group that trained with maximum contractions could not be attributed to a greater training intensity because the mean training load in this group was less than the 10RM load. However, as the two groups trained both at different intensities and with differing amounts of fatigue it was not possible to be certain whether the different increases in strength were due to different training intensities or to fatigue. Our findings strongly suggest that fatigue induced by high intensity contractions can provide a stimulus for increases in strength, which implies that training with ten repetitions of maximal loads is more effective than training with the 10RM load at least partly because training with maximum loads induces greater fatigue.

The mechanisms by which fatiguing contractions could facilitate training-induced increases in strength are unclear. One possibility, which is consistent with the prevailing view that short-term training-induced strength increases are brought about largely by neural mechanisms (see references 6,13 and 14 for reviews), is that high-intensity fatiguing protocols bring about greater activation of motor-units than high-intensity non-fatiguing protocols, and that the degree of activation of motor units determines the magnitude of the strength training response. A number of studies investigating fatigue during submaximal isometric contractions have shown that as muscles fatigue they experience a progressively greater activation (4,10). Perhaps, then, fatiguing high-intensity contractions provide a better way of activating high-threshold motor units than non-fatiguing high-intensity muscle contractions. Alternatively, fatiguing contractions might induce a greater training response because they provide a better context in which to learn more appropriately activate synergistic and antagonistic muscles. Another explanation could be that fatigue-related events trigger adaptations of muscle.

No physiological mechanism has yet been proposed which satisfactorily explains the fatigue experienced during the performance of a 6RM set. Changes which have been thought to be responsible for fatigue include a failure of excitation-contraction coupling, depletion of metabolic fuels, ATP or creatine phosphate, or an accumulation of metabolites such as lactic acid or IMP. However, a recent study in our laboratory has shown that when trained subjects repeatedly lift 10–15RM weights or weights greater than the 6RM until they can no longer
perform further lifts, the decreases in ATP and creatine phosphate and the increases in lactate are not sufficient to be implicated in fatigue (Marsden and Balnave, unpublished observations).

A secondary finding of this study was that the relative increases in isometric strength which accompanied the dynamic training were substantially smaller than (about one third of) the increases in dynamic strength. This is in agreement with previous studies (11,12), and is consistent with the principle of training specificity which holds that strength increases will be most evident with the type of muscle contractions employed in training (13). In the prevailing view of the mechanisms of short-term increases in strength, this arises because people learn to activate muscles effectively with training, and the activation strategies used in training may not always be as effective at increasing force production during other types of muscle contraction (14).

In conclusion, the findings of this study indicate that the strength increases associated with short-term dynamic strength training programs will be greater if subjects are not permitted to rest between contractions. This suggests that processes associated with fatigue contribute to the stimulus by which training induces increases in strength.

We would like to acknowledge the helpful comments made by John Marsden on an earlier draft of this paper.

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REFERENCES