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TRAINING LEADING TO REPETITION FAILURE ENHANCES BENCH PRESS STRENGTH GAINS IN ELITE JUNIOR ATHLETES

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ABSTRACT. Drinkwater, E.J., T.W. Lawton, R.P. Lindsell, D.B. Pyne, P.H. Hunt, and M.J. McKenna. Training leading to repetition failure contributes to bench press strength gains in elite junior athletes. *J. Strength Cond. Res. 19(2):382–388. 2005.*—The purpose of this study was to investigate the importance of training leading to repetition failure in the performance of 2 different tests: 6 repetition maximum (6RM) bench press strength and 40-kg bench throw power in elite junior athletes. Subjects were 26 elite junior male basketball players ($n = 12$; age = 18.6 ± 0.3 years; height = 202.0 ± 11.6 cm; mass = 97.0 ± 12.9 kg; mean ± *SD*) and soccer players ($n = 14$; age = 17.4 ± 0.5 years; height = 179.0 ± 7.0 cm; mass = 75.0 ± 7.1 kg) with a history of greater than 6 months' strength training. Subjects were initially tested twice for 6RM bench press mass and 40-kg Smith machine bench throw power output (in watts) to establish retest reliability. Subjects then undertook bench press training with 3 sessions per week for 6 weeks, using equal volume programs (24 repetitions × 80–105% 6RM in 13 minutes 20 seconds). Subjects were assigned to one of two experimental groups designed either to elicit repetition failure with 4 sets of 6 repetitions every 260 seconds ($RF_{4\times6}$) or allow all repetitions to be completed with 8 sets of 3 repetitions every 113 seconds ($NF_{8\times3}$). The $RF_{4\times6}$ treatment elicited substantial increases in strength (7.3 ± 2.4 kg, +9.5%, $p < 0.001$) and power (40.8 ± 24.1 W, +10.6%, $p < 0.001$), while the $NF_{8\times3}$ group elicited 3.6 ± 3.0 kg (+5.0%, $p < 0.005$) and 25 ± 19.0 W increases (+6.8%, $p < 0.001$). The improvements in the $RF_{4\times6}$ group were greater than those in the repetition rest group for both strength ($p < 0.005$) and power ($p < 0.05$). Bench press training that leads to repetition failure induces greater strength gains than nonfailure training in the bench press exercise for elite junior team sport athletes.

KEY WORDS. Smith machine, repetition maximum, typical error of measurement, smallest worthwhile change, fatigue

INTRODUCTION

The development of strength and power is paramount to success in most sports, especially those involving short-term, high-intensity efforts. Traditional strength-training programs of 3–4 sets for 6 repetitions at an intensity of 80% of a subject's maximum lift (26) may compromise the development of speed in a given athlete (13), though it is important to recognize the role of strength in power (3, 23). Proposed stimuli for maximal strength adaptation include tension on the muscle (32), amount of time under tension (29), prolonged exposure to metabolites (11, 29), and fatigue (27). If high tension on the muscle is important for strength development, then fatigue should be avoided (11, 33), though such a theory would neglect the importance of training volume (26) and fatigue-induced metabolites (31) in the adaptation process.

As consecutive repetitions are performed, progressive fatigue elicits a gradual reduction in power output until no further repetitions can be performed (22). The term exercise to "repetition failure" or "task failure" (17) is preferred over exercise to "maximal fatigue," since the muscle is not entirely fatigued at the point of failure but, rather, cannot continue to move the given load beyond a critical joint angle (9). This "sticking point" corresponds to maximal fatigue only at that joint angle and does not necessarily represent maximal fatigue of the entire muscle (9). Therefore, training leading to repetition failure represents maximal voluntary fatigue for the muscle groups involved at their given sticking point with the mass being lifted, since no more work at that intensity can be performed. While the entire muscle may be experiencing high levels of fatigue at the point of repetition failure, to describe it as maximally fatigued would be inaccurate.

Several studies have explored training to failure but have not directly equated several important training variables within the experimental design, such as volume (3 sets of 10 repetitions not to failure vs. 1 set of 8–12 repetitions to failure) (21), duration of the training period (about 4 vs. more than 20 minutes) (11), or training intensities (60 vs. 100% maximal voluntary contraction [MVC]) (20). Other studies used only untrained subjects (2, 26) or single-joint movements and isokinetic or isometric machines (11, 19, 20, 27), which may not be directly relevant for most sporting applications that involve coordinating several joints for movements (2, 26). Therefore, a protocol that equates volume, time, and intensity of training in noncontact team sport athletes undertaking multiple-joint, free-weight training could elucidate valuable information about including training that leads to repetition failure into larger periodized programs.

The need for training leading to repetition failure to enhance strength is not universally accepted (11, 27), though it does have support. Several studies have demonstrated strength gains by using light weights (about 15–60% MVC) with multiple repetitions to train to failure (7, 8, 20, 25). Although it seems intuitive that equating the work volume and intensity would elicit equal strength gains, Rooney et al. (27) showed that subjects who performed biceps curls until repetition failure attained significantly greater 1 repetition maximum (1RM) gains than subjects training without assistance but permitted short rest intervals between repetitions.

The purpose of this study was to investigate the importance of training leading to repetition failure in the development of upper-body strength in elite junior athletes. By comparing 2 equal volume and intensity training programs, one to elicit repetition failure (high fatigue) and the other to allow completion of all repetitions, we sought to investigate the importance of training leading to repetition failure in improving 2 different measures of strength: 6RM bench press and mean power output of a 40-kg bench throw. We hypothesized that the training leading to repetition failure group would experience greater improvements in both 6RM bench press and bench throw power. With the exception of Rooney et al. (27), no research, to our knowledge, has standardized the number of repetitions performed, the number of repetitions performed at each intensity, and the duration of the training time.

METHODS

Experimental Approach to the Problem

Subjects were 26 highly trained junior basketball and soccer players. Each subject was assigned to one of two bench press–training programs consisting of 4 sets of 6 repetitions or 8 sets of 3 repetitions. Both groups trained an equal number of repetitions (24 total repetitions) at the same relative intensity of their 6RM (85–105%) in an equal amount of time (13 minutes 20 seconds), 3 times per week for 6 weeks. Pilot testing established that such training program designs elicited sufficient fatigue for the 4 sets of 6 groups to be unable to complete the final repetitions of the training program without the assistance of a spotter, while the 8 sets of 3 groups were able to complete all repetitions successfully. This allowed us to evaluate the importance of training that leads to repetition failure without adding the confounding variables of training volume, intensity, or time.

Subjects

The sample group consisted of 26 elite junior male team game players (basketball, $n = 12$; age = 18.6 ± 0.3 years, height = 202.0 ± 11.6 cm, mass = 97.0 ± 12.9 kg; soccer, $n = 14$; age = 17.4 ± 0.5 years, height = 179.0 ± 7.0 cm, mass = 75.0 ± 7.1 kg, mean ± *SD*). While this study was conducted on athletes in sports that do not typically have a major emphasis on upper-body strength, all subjects had moderate-to-extensive weight-training experience ranging from 6 months to 3 years, including the bench press. Subjects provided written informed consent for testing, training, data collection, and publication of results as part of their Scholarship Agreement with the Australian Institute of Sport (AIS), in accordance with requirements of the AIS Ethics Committee. Testing and training procedures were explained prior to the start of the study, and subjects were informed that they could withdraw at any time without prejudice.

Experimental Procedures

In the initial week of the study, subjects were tested on 2 separate days to determine the reliability of their 6RM bench press and maximal power generated during a Smith machine bench throw. Subjects were pair-matched for sport, 6RM, and number of years completed on an AIS scholarship and then randomly assigned to either the repetition failure or the nonrepetition failure groups. The matching process was intended to ensure groups were matched for training background and training potential. We can assert that subjects had not participated in extensive resistance-training programs prior to the commencement of their AIS scholarships. Thus, the number of years at the AIS was considered an accurate measure of resistance-training age. Furthermore, the training period for this research occurred during the in-season phase, so all players had been on a similar resistance and sport-specific training program for at least 4 months. The training groups consisted of either training 4 sets of 6 repetitions to repetition failure ($RF_{4\times6}$, $n = 15$) or training 8 sets of 3 repetitions not to failure ($NF_{8\times3}$, $n = 11$). Both groups undertook a 6-week training program of either training leading to repetition failure or nonrepetition failure training. Upon completion of the training intervention, subjects were retested on 6RM bench press and Smith machine bench throw power.

6RM Bench Press

Subjects were evaluated on 2 tests, a free-weight 6RM bench press for strength and a 40-kg Smith machine bench throw for maximal mean power. We defined strength as the capacity to displace a known mass (kilograms) for a designated number of repetitions that met our technical criteria for the selected lift irrespective of the time taken to move the mass. Prior to testing, subjects performed a thorough warm-up involving 10 minutes of stationary cycling and 3 sets of bench press comprising 12 repetitions at 50%, 6 repetitions at 75%, and 3 repetitions at 90% of their 6RM. Previously documented training records were used as a guide for selecting the first test mass for determination of 6RM. Mass was progressively increased with each successful set of 6 repetitions, allowing a minimum of 180 seconds of rest between attempts.

Our technical criteria for bench press specified a pronated grip with hands spaced so that the subject's forearms were perpendicular to the bar when the bar was resting on the chest. The subject was required to lower the bar without a pause until the chest was touched lightly approximately 3 cm superior to the xiphoid process. The bar was not permitted to stop at any point throughout the lift off the chest. The elbows were extended equally, with the head, hips, and feet remaining in contact with the bench throughout the lift. Failing to meet any of these technical criteria constituted an unsuccessful attempt.

Bench Throw Power

On a day separate from the 6RM bench press testing, subjects were evaluated for maximal power output during a Smith machine bench throw. The Smith machine (Life Fitness, Victoria, Australia) consisted of a horizontal barbell mounted on 2 vertical rails, thereby keeping the bar level and allowing it to move only in the vertical plane. We used the 40-kg bench throw power as an independent test for maximal strength because of its high correlation with maximal strength (4) and performance in other power events (23). Prior to testing, each subject completed a thorough warm-up involving 10 minutes of stationary cycling and 3 sets of bench press comprising 12 repetitions at 20 kg, 6 repetitions at 30 kg, and 3 repetitions at 40 kg with a 1-minute rest between sets. Subjects then performed 2 sets of two 40-kg bench throws every 35 seconds for a total of 4 throws.

Mean power was measured with a Micro Muscle Lab Power linear encoder (Ergotest Technology a.s., Langesund, Norway) attached to the bar. One end of the linear encoder cord was attached to the barbell, and the other end was coiled around a spool on the floor positioned perpendicular to the movement of the barbell. The linear encoder measures velocity and displacement of the barbell from the spinning movement of the spool, while mass is entered via a keypad into the device. The sensitivity of load displacement was approximately 0.075 mm, with data sampled and velocity calculated at a frequency of 100 Hz. Power was calculated as the product of force and velocity. The entire displacement and time for the concentric phase were used to calculate the mean values for velocity, force, and power. Subjects had 2 separate attempts performing 2 maximal throws. The mean power output was recorded for each throw, and the highest mean power was used for analysis.

Both the 6RM and bench throw tests were repeated at least 2 days apart to establish test-retest reliability for these measures through calculation of the typical error of measurement (TEM) (23) and intraclass correlation *R* scores (ICC). The TEM is calculated from the standard deviation of the change score (difference) from trial 1 to trial 2 divided by the square root of 2.

Determining the Extent of Fatigue

The Smith machine bench throw was also used to evaluate the extent of muscle fatigue induced by each training protocol, since training leading to repetition failure does not necessarily represent maximal fatigue (27). Each subject performed the bench throw for power and then either the $RF_{4\times6}$ or the $NF_{8\times3}$ protocol. Bench throw power was then repeated 3 minutes after completion of the final repetition of the training protocol. At least 3 days apart, subjects performed the other training protocol. The percent decrement in bench throw power between the pretraining and posttraining throws was used as an index of muscle fatigue from each protocol.

Training Program

Both groups completed a total 24 repetitions of the barbell bench press in a fixed time of 13 minutes 20 seconds per training session at a frequency of 3 times per week, on alternate days, during a 6-week training period. Prior to training, subjects performed 5–10 minutes of stationary cycling as warm-up. Training intensities were assigned on the basis of a percentage of the athlete's 6RM testing (5). The $NF_{8\times3}$ group performed 8 sets of 3 bench presses at intensities ranging from 80 to 105% of their 6RM (Table 1), with each set commencing every 113 seconds. The $RF_{4\times6}$ group performed 4 sets of 6 bench presses at the same intensity of their 6RM bench press (Table 1), with each set commencing every 260 seconds. The purpose of this design was for the failure group to work less frequently (i.e., 4 sets vs. 8) but for longer periods (i.e., 6 repetitions vs. 3) while resting less frequently but for longer periods (i.e., 100 vs. 230 seconds) than the nonfailure group. By each group starting on zero seconds and continuing each set on the assigned time and allowing 12 seconds to complete 3 repetitions or 20 seconds to complete 6 repetitions, each group completed the training program in 13 minutes 20 seconds. Subjects performed all bench press training in a free-weight setting on an official Paralympic power bench using a standard 20-kg barbell.

The assigned intensities by sets, sessions, and weeks of the program (Table 1) gradually increased the overall intensity during the course of the study while decreasing the intensity within each week. While the supramaximal loads used in the final weeks of the training program were used to ensure that failing intensities continued to be experienced as each subject's strength increased during the study period, the lower intensities later in the week were used to avoid potential injuries of sustained failure training. Each training week (i.e., weeks 1–6) (Table 1) involved 3 training sessions (i.e., sessions 1–3) (Table 1). Each set was undertaken at an assigned intensity of the subject's 6RM. During training weeks 1–3, subjects in the $RF_{4\times6}$ group trained at intensities increasing from 85, 90, 95, and 100% in session 1 for the week (e.g., Monday) (Table 1). Subjects in the $NF_{8\times3}$ group trained at each of these intensities twice (i.e., sets 1–8 were at intensities of 85, 85, 90, 90, 95, 95, 100, and 100%, respectively). The second training session of weeks 1–3 (e.g., Wednesday) (Table 1) involved training all sets at 90% of the subject's 6RM. In session 3 of the week (e.g., Friday) (Table 1) during weeks 1–3, all sets were trained at 80% of the subject's 6RM. In training week 4, the training intensity increased, with the first training session of the week (i.e., Monday) (Table 1) being trained entirely at 95% of the subject's 6RM, while session 2 was trained at 90%, and session 3 was trained at 80%.

Spotters were instructed that if assistance was required, they should provide only the minimum amount of assistance required to continue the set. If assistance from the spotter was necessary, the number of assisted repetitions was recorded in the athlete's training diary, but all repetitions were completed, even if assistance was required on several repetitions. Weights used in each session were rounded to the nearest 2.5 kg. Apart from the formal requirements of this study, both groups performed similar whole-body weight room–training programs in-

TABLE 1. Number of sets trained in each session at each of the weekly training intensities expressed as a percentage of 6RM.*

	Training weeks 1–3				Training week 4				Training weeks 5 and 6			
$RF_{4\times6}$ set	1	2	3	4	1	2	3	4	1	2	3	4
$RF_{8\times3}$ set	1 and 2	3 and 4	5 and 6	7 and 8	1 and 2	3 and 4	5 and 6	7 and 8	1 and 2	3 and 4	5 and 6	7 and 8
Session 1	85	90	95	100	95	95	95	95	90	95	100	105
Session 2	90	90	90	90	90	90	90	90	95	95	95	95
Session 3	80	80	80	80	80	80	80	80	85	85	85	85

* 6RM = 6 repetition maximum strength.

volving all major muscle groups of the body in a single 1-hour training session.

Statistical Analyses

All raw data are expressed as mean ± *SD,* while estimates of change and difference score are expressed as mean with 95% confidence limits (CLs). A 2-way analysis of variance with repeated measures was used to identify significant differences between groups in bench throw power for determining the extent of fatigue induced by each protocol. To establish the precision of the estimate of change, 95% confidence intervals were also calculated (18, 23). The correlation coefficient between the 6RM and 40-kg bench throw was calculated using Pearson product moment correlation. *P*-values were considered significant at $p \leq 0.05$.

The repeat tests of bench throws and 6RM bench press collected in the first week of the study were analyzed for TEM and ICC to quantify the variation in testing a subject during multiple test sessions (23). TEM is an important measure to distinguish between a real result and the noise of a test; a change smaller than the TEM could simply be noise in the test. To determine the practical significance of observed changes, we estimated the smallest worthwhile change (SWC; equivalent to a small Cohen effect size) as 0.2 of the between-athlete standard deviation for each variable (SWC = 0.2× *SD*) (23). The SWC is a useful tool to establish the clinical (practical) significance and especially in distinguishing between trivially small changes and those changes large enough to have a meaningful or worthwhile effect on performance (23). Further analysis beyond statistical analysis was conducted to assess the likelihood of potential differences between programs on each test (23).

RESULTS

Bench Press

The TEM, ICC, and SWC of the 6RM bench press were 1.1 kg (1.7%), 0.86, and 1.8 kg (2.6%). Prior to training, there were no significant differences between the $RF_{4\times6}$ and $NF_{8\times3}$ groups in 6RM bench press (69.3 kg ± 10.3 vs. 67.5 kg ± 8.2, respectively, $p = 0.62$).

The $RF_{4\times6}$ group experienced a substantial increase in strength in 6RM (7.3 kg, 95% CL, 6.0–8.7 kg, $p < 0.001$) (Figure 1) after training that was twofold greater ($p = 0.001$, 95% CL, 1.2–6.2 kg) than the increase in 6RM in the $NF_{8\times3}$ group (3.6 kg, 95% CL, 1.6–5.7 kg, $p < 0.005$) (Figure 1). Calculation of likelihoods shows that there is a 92% probability that the true difference between the 2 groups is worthwhile in practical terms.

Bench Throw

The TEM, ICC, and SWC of the bench throw power were 14 W (4.0%), 0.92, and 10 W (2.6%), respectively. We found no significant differences between the repetition failure and nonrepetition failure groups in the 40-kg bench throw (343 ± 67 W vs. 342 ± 62 W, respectively, $p = 0.97$).

The $RF_{4\times6}$ experienced a substantial increase in bench throw power (40.8 W, 27.5–54.1 W, $p < 0.001$) (Figure 2) that was, on average, 15.8 W more ($p < 0.05$, 3.1–34.7 W) than the increase experienced by the $NF_{8\times3}$ group (25 W, 12.2–37.8 W, $p < 0.001$) (Figure 2). Calculation of likelihoods showed that differences between the 2 training protocols are not only statistically significant but also 96% likely to be practically worthwhile. While a likelihood of more than 75% should be considered likely to be beneficial, a likelihood of more than 95% indicates that the difference between the 2 training protocols can be described as being "very likely" (23).

There was a strong correlation ($r = 0.89$, $p < 0.01$) between the 6RM bench press and 40-kg bench throw. With such a high dependence of bench throw power on strength, we decided that the Smith machine bench throw would be a more sensitive test of strength than 1RM testing.

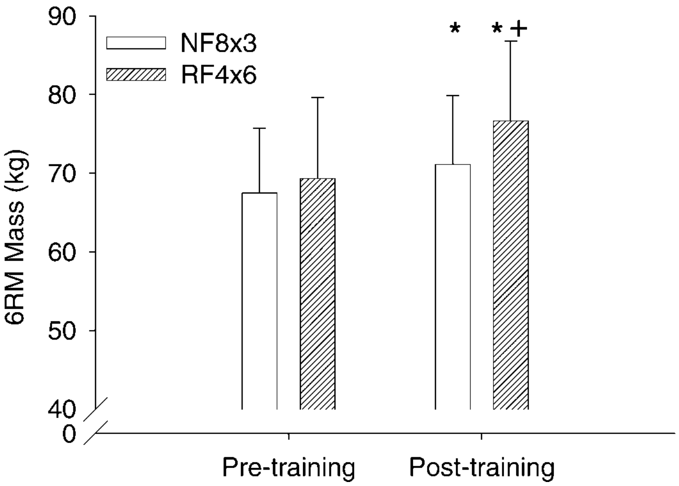

FIGURE 1. Comparison of 6 repetition maximum (6RM) strength (in kilograms) made by the repetition rest and repetition failure groups. Bars represent the load of 6RM ± *SD* in each training group before and after the training program. * Indicates $p < 0.05$ greater than the pretest. + Indicates $p < 0.05$ difference between groups. Error bars represent the standard deviation of the group.

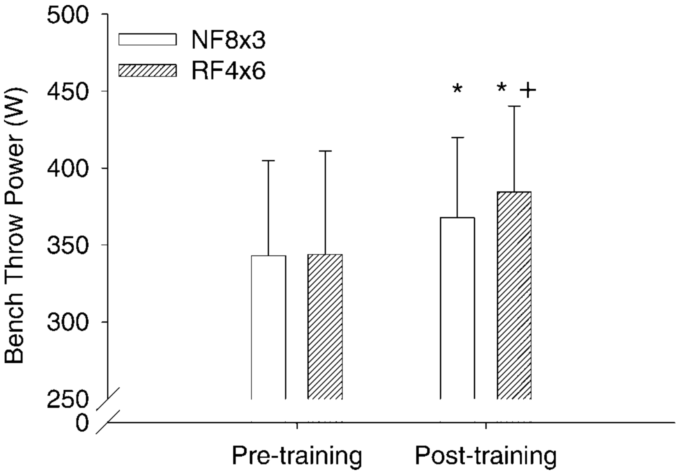

FIGURE 2. Comparison of Smith machine bench throw (W) made by the repetition rest and repetition failure groups. Bars represent the power of Smith machine bench throw ± *SD* in each training group before and after the training program. * Indicates $p < 0.05$ greater than the pretest. + Indicates $p < 0.05$ difference between groups. Error bars represent the standard deviation of the group.

Fatigue and Failure

The $RF_{4\times6}$ group failed on more repetitions per training session (1.0 ± 1.3 repetitions) than the $NF_{8\times3}$ group (0.0 ± 0.2 repetitions) ($p < 0.01$). This indicates that while the $NF_{8\times3}$ group rarely failed on any repetitions, the $RF_{4\times6}$ group usually failed on at least 1 repetition of the 24 attempted. This observation confirms the intent of the program design in equating the volume of work in an equal amount of time to induce repetition failure by the end of each training session in the $RF_{4\times6}$ group but not in the $NF_{8\times3}$ group.

The decrement of power in the 40-kg bench throws was 19.6% after the $RF_{4\times6}$ training protocol (62.9 W, 35.9–89.9, $p < 0.01$) compared with 7.8% for the $NF_{8\times3}$ group (25.6 W, 7.7–43.6, $p < 0.01$). While there were no significant differences between pretrials ($p = 0.47$), the power in the $RF_{4\times6}$ group was 15.9% lower after training (48.4 W, 24.7–72.0, $p = 0.001$). There was no order effect in which the protocols were tested.

DISCUSSION

The major findings of this study were that the $RF_{4\times6}$ group experienced substantially larger gains in 6RM bench press and bench throw power than the $NF_{8\times3}$ group. Our findings clarify the role of training leading to repetition failure in strength training. The first advantage of our protocol was that we equated training intensity (i.e., percentage of 6RM), training volume (i.e., total number of repetitions), and duration of training time (13 minutes 20 seconds). Second, we used multijoint dynamic contractions over multiple sets (11, 27), and third, we investigated training effects in elite team sport athletes with weight-training experience. By using 8 sets of 3 repetitions for the $NF_{8\times3}$ protocol, no external assistance by a spotter was required to complete the prescribed number of repetitions. In contrast, repetition failure occurred in at least one of the four sets of 6 repetitions performed by the $RF_{4\times6}$ group. This experimental design therefore allowed us to attribute the $RF_{4\times6}$ group's greater improvement in strength to incorporating greater fatigue to the point of failure.

While a determination of statistical significance is important for assessing probability, a calculation of likelihoods is useful in determining the degree of practical (clinical) benefit of each training program (23). The calculated likelihoods indicate that the practical difference between the 2 training programs can be described as "likely" for the 6RM test and as "very likely" for the bench press throw test (23). By calculating the TEM and SWC for both tests, we provided boundaries for the interpretation of our results. The improvements obtained from the $RF_{4\times6}$ training protocol (strength = 9.6%, and power = 10.6%) and the $NF_{8\times3}$ training protocol (5.1 and 6.8%) can be considered real, because their magnitude was greater than the magnitudes of both the TEM and SWC of the 6RM and (1.7 and 2.6%) and bench throw (4.0 and 2.6%).

To ensure that the training effect of improving 6RM was not simply a task-specific response to training sets of 6 repetitions, we measured bench throw power output as a novel test of strength. We found a high correlation between bench throw power and 6RM, supporting the notion that a task with a large resistance is dependent on strength to generate power (3, 23). The bench throw has several advantages over a traditional 1RM test of strength. Primarily, the bench throw is a dynamic movement that is largely independent of the strength of a single-joint angle, giving it context validity to the ballistic movements of team sports. The bench throw can also be measured with much greater precision (i.e., in watts) than a 1RM bench press, which is typically measured to the nearest 2.5 kg. The greater improvements of the $RF_{4\times6}$ group demonstrated that the strength improvements in bench press existed throughout the bench press range of motion.

Fatigue represents a decreased ability to produce power (10). We demonstrated that greater fatigue was induced by the $RF_{4\times6}$ protocol, since a greater decrement in bench throw power occurred after the $RF_{4\times6}$ protocol than after the $NF_{8\times3}$ protocol. Some authors conclude that fatigue should be avoided for strength development, since fatigue reduces the force a muscle can generate (11, 32). Previous data from our laboratory have demonstrated that decrements of power are greater in the 4 × 6 group than in the 8 × 3 group (22). While no measurements of force were taken during training or testing, we can infer that velocity is lower (i.e., there was negative acceleration), and thus force is lower, in the 4 × 6 group. We therefore conclude that declining force induced by fatigue does not inhibit strength development.

Other authors suggest that fatigue is a necessary component of resistance training (8, 27). Motor units are recruited in response to a submaximal contraction in an assigned order so that not all motor units are active at once (12). Repeated submaximal contractions elicit fatigue of the active motor units such that additional motor units must be progressively recruited in order to maintain force output (27, 28). Therefore, at the point of repetition failure, the maximal number of motor units was presumably activated, especially during assisted repetitions, a point that our repetition rest group did not reach. Since the activating and overloading of a high number of motor units are important in facilitating strength development (30, 32), the repetition failure group presumably experienced greater strength gains as a result of maximizing the recruitment of active motor units (24). Training to failure might enable an athlete to maximize the number of active motor units and therefore the magnitude of the adaptations made by the nervous system.

While no measures of neuromuscular activity or hypertrophy were collected in this study, the large magnitude of changes in 6RM for the $NF_{8\times3}$ (5.1%) and $RF_{4\times6}$ (9.5%) groups and bench throw (mean = 6.8 and 10.6%, respectively) in a 6-week training period, coupled with the slow rate of hypertrophic (2) and architectural (1) improvements of muscle in trained individuals, leads us to speculate that most strength changes were related to neural adaptations. It is generally concluded that neural adaptations are predominant in strength-training studies, where strength and/or electromyogram (EMG) increase disproportionately more than changes in muscle hypertrophy (6, 15). Neural adaptations are most commonly presented in relation to the rapid strength development in novice weightlifters (6). However, Häkkinen et al. (14, 16) have demonstrated increases in EMG even in experienced lifters when increases in training intensity occur. Increasing the intensity elicits neural adaptations in a greater number of motor units by maximizing the number of active motor units active at one time.

One limitation of this design was that all subjects were involved in daily team practices and skill sessions in their respective sport appropriate to elite junior players. The researchers had no control over possible differences in training volume between subjects. Such a limitation is a necessary compromise to explore training interventions in elite athletes in a real weight room situation compared with a controlled laboratory investigation. To minimize any effect of training variations, subjects were matched between groups for sport, training experience, and 6RM bench press. Additionally, although the subjects of our study were highly trained athletes, they had only modest weight-training experience, particularly in upper-body training. Therefore the results still likely reflect reasonably early adaptations to strength training.

For many team sports, a combination of strength and speed are necessary physical attributes. However, with increasing physical demands on athletes and time demands on coaches, specific training methods that elicit concurrent improvements in both strength and power are clearly desirable. Our results suggest that coaches of junior team sport athletes are able to maximize strength gains in their athletes by using a conventional weight-training program (e.g., 4 sets of 6 repetitions on barbell bench press) where the intensity is high enough to lead to repetition failure. Athletes often periodize heavy and light weights because frequent training to failure for extended periods of time is both physically and mentally challenging. Since no subject exhibited a decrement in 6RM or power test performance after either training intervention, we also conclude that team sport athletes do not necessarily have to train to failure to maintain and improve existing levels of strength.

PRACTICAL APPLICATIONS

By training barbell bench press using a more conventional weight-training program (4 × 6 repetitions) with assisted repetitions, coaches can maximize strength gains in their athletes. The current research highlights the potential benefits of training leading to repetition failure by demonstrating larger strength and mean power gains during a 6-week training period. Further research to clarify the mechanism by which training leading to repetition failure promotes maximal strength gains is warranted. Additionally, we found that during a 6-week training phase, athletes are able to maintain strength levels without training to failure. Such an outcome is important to allow athletes to periodize their strength-training program for training blocks of failure and nonfailure. Such an application would be appropriate in a setting involving young male team sport athletes with modest upper-body strength-training experience for a 6-week block of a larger periodized program of free-weight training.

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