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Increased Number of Forced Repetitions Does Not Enhance Strength Development With Resistance Training

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Abstract. Drinkwater, E.J., T.W. Lawton, M.J. McKenna, R.P. Lindsell, P.H. Hunt, and D.B. Pyne. Increased number of forced repetitions does not enhance strength development with resistance training. *J. Strength Cond. Res. 21(3):841–847. 2007.*—Some research suggests that strength improvements are greater when resistance training continues to the point at which the individual cannot perform additional repetitions (i.e., repetition failure). Performing additional forced repetitions after the point of repetition failure and thus further increasing the set volume is a common resistance training practice. However, whether short-term use of this practice increases the magnitude of strength development with resistance training is unknown and was investigated here. Twelve basketball and 10 volleyball players trained 3 sessions per week for 6 weeks, completing either 4 × 6, 8 × 3, or 12 × 3 (sets × repetitions) of bench press per training session. Compared with the 8 × 3 group, the 4 × 6 protocol involved a longer work interval and the 12 × 3 protocol involved higher training volume, so each group was purposefully designed to elicit a different number of forced repetitions per training session. Subjects were tested on 3- and 6-repetition maximum (RM) bench press (81.5 ± 9.8 and 75.9 ± 9.0 kg, respectively, mean ± *SD*), and 40-kg Smith Machine bench press throw power (589 ± 100 W). The 4 × 6 and 12 × 3 groups had more forced repetitions per session ($p < 0.01$) than did the 8 × 3 group (4.1 ± 2.6, 3.1 ± 3.5, and 1.2 ± 1.8 repetitions, respectively), whereas the 12 × 3 group performed approximately 40% greater work and had 30% greater concentric time. As expected, all groups improved 3RM (4.5 kg, 95% confidence limits, 3.1–6.0), 6RM (4.7 kg, 3.1–6.3), bench press throw peak power (57 W, 22–92), and mean power (23 W, 4–42) (all $p \leq 0.02$). There were no significant differences in strength or power gains between groups. In conclusion, when repetition failure was reached, neither additional forced repetitions nor additional set volume further improved the magnitude of strength gains. This finding questions the efficacy of adding additional volume by use of forced repetitions in young athletes with moderate strength training experience.

Key Words. Smith Machine, bench press throw, repetition maximum, repetition failure, concentric time

Introduction

Determining optimal training methods for the development of maximal strength is vital for elite athletes and has been the subject of many decades of research (20). We have recently demonstrated that greater gains in 6 repetition maximum (RM) strength occurred after bench press training to the point at which junior athletes (basketball and soccer) could no longer lift the weight on their own (i.e., repetition failure) compared with training that avoided repetition failure (11). Recent work by Izquierdo et al. (18) has disputed that failure training improves 1RM strength testing in bench press over nonfailure training, although failure training did improve the number of presses that could be performed. Rather than just training to the point of repetition failure, a common training practice for athletes and recreationally active individuals is to obtain the assistance of a spotter to continue several so-called forced repetitions after repetition failure has occurred. Although this technique is widely advocated (12), only a few anecdotal reports of the actual performance of forced repetitions exist (7, 30). Only 1 article exists in a peer-reviewed source investigating the effect of forced repetitions on hormone levels, demonstrating higher levels of cortisol and growth hormone when subjects trained using forced repetitions (1). Importantly, no studies have investigated whether performing multiple sets of forced repetitions enhances muscular strength adaptation (29). Therefore, the primary goal of this research was to determine whether training that included a high number of forced repetitions generated greater strength gains than training with only a low number of forced repetitions.

Modification of training variables, such as volume, intensity, and power, plays an important role in strength development (20). Although the adage "more is better" is tempting to coaches and athletes, greater volume and intensity have been shown to improve training-induced strength adaptations but not in a dose-dependent manner (14). Diminishing returns occurred when volumes exceeded 2 days per week, with 4 to 8 training sets per muscle group (23, 24). The indication that strength adaptations are dose dependent only to a defined volume questions the usefulness of additional volume, particularly if the volume is gained through forced repetitions. Thus, the second aim of the current study was to determine if volume of work performed would affect the magnitude of strength development when repetition failure was reached.

A key consideration in strength research is control of important training variables, such as concentric time, power output, and total work performed (9). Unfortunately, resistance training research has been greatly limited by the difficulties in controlling these training variables (9, 29). With the recent development of optical encoder technology (10), monitoring these variables throughout the training program is now possible. How-

Table 1. Summary of age and anthropometric measures of participants (mean ± *SD*).

	Age (y)	Height (cm)	Body mass (kg)	Sum of 7 skinfolds (mm)	Estimated fat mass (kg)	Estimated muscle mass (kg)	Estimated muscularity (%)
Basketball, n = 12	18.6 ± 0.4	200.7 ± 11.0	96.5 ± 11.7	52.0 ± 13.4	8.5 ± 2.4	45.9 ± 5.9	46.8 ± 1.3
Volleyball, n = 10	24.4 ± 3.0	197.3 ± 6.5	92.7 ± 8.6	55.3 ± 5.5	8.5 ± 0.8	44.3 ± 4.7	46.8 ± 1.1

ever, no studies have controlled for potential differences between training groups in these variables, such as concentric time, power output, and total work performed. Therefore, a novel aspect of the study was application of an optical encoder to verify equality in concentric time, power output, and work completed between groups.

We therefore tested 2 hypotheses in athletes with resistance training experience undertaking a bench press training program: first, that training with a high number of forced repetitions (but the same training volume) would elicit similar strength development than training involving a low number of forced repetitions; second, that training with an increase in both number of forced repetitions and volume would fail to elicit substantially greater strength development.

Methods

Experimental Approach to the Problem

Each subject undertook a series of muscle strength and power tests, before and after a 6-week strength training intervention. These tests comprised the free-weight bench press 6RM and 3RM, as well as the maximal power generated during a 40-kg Smith Machine bench press throw. Both 6RM and 3RM testing were conducted to evaluate if training-specific responses to the number of repetitions the subjects performed in training were present. Each test was separated by at least 2 days. After pretraining testing, subjects were matched and then assigned to 1 of 3 free-weight bench press training groups comprising 4 × 6, 12 × 3, or 8 × 3 (sets × repetitions). Loads were designed to be heavy enough to elicit repetition failure by the end of the training session in all groups. The longer working duration of the 4 × 6 group (i.e., 6 repetitions compared with 3 in each set) and the higher training volume of the 12 × 3 group (i.e., 12 sets compared with 8) were purposefully designed to elicit more forced repetitions in the 4 × 6 than the 12 × 3 group and more forced repetitions in the 12 × 3 than the 8 × 3 group. After 6 weeks of training, all subjects were retested and evaluated for change in 6RM, 3RM, and 40-kg Smith Machine bench press throw, thus allowing an investigation of whether training with a higher volume of forced repetitions elicits a greater increase in strength.

Subjects

Subjects were male elite junior basketball players (n = 12) and elite senior volleyball players (n = 10). Subject physical characteristics are summarized in Table 1. All players were in the "maximal strength" training block of their respective periodized programs at the time the study began. Subjects provided written consent for testing as part of their scholarship arrangements 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.

Matching of Subjects Prior to Training

Prior to assignment into experimental groups, subjects were matched for sport, 6RM bench press, and training age for bench press. The matching process ensured that groups were similar for training background and training potential, with a balanced division of junior and senior athletes. The training age, defined as the amount of time each subject had been on a regimented resistance training program for bench press, was determined based on each athlete's individual weight room record.

Rationale for Experimental Groups

The program was designed such that 2 of the groups trained free-weight bench press at equal volume (4 × 6 and 8 × 3), while an additional group trained at a higher volume (12 × 3). In addition, 2 of the groups trained with a similar higher number of forced repetitions (4 × 6 and 12 × 3), while 1 group trained with fewer forced repetitions (8 × 3). A key aspect of this design was that 2 of the groups trained at equal mean power outputs (8 × 3 and 12 × 3) while 1 trained at a lower mean power output (4 × 6). To verify that expected differences in work, power, and concentric time between groups were present, movement kinetics for each repetition of every subject were measured for the duration of the training period with a GymAware optical encoder (Kinetitech Performance Technology Pty Ltd., Canberra, Australia).

Anthropometric Measures

Stretched height was measured during inspiration using a stadiometer (Holtain Ltd., Crymych Dyfed, Australia). The typical error of measurement (TEM) for measuring height, including biological variation, was typically not more than 1% (22). Digital scales were used to measure body mass to the nearest 0.1 kg with a TEM between days, including biological variation, of 1% (22). Skinfolds comprised the sum of 7 skinfold thicknesses from triceps, subscapular, biceps, supraspinale, abdominal, front thigh, and medial calf measured with Harpenden calipers (British Indicators Ltd., West Sussex, UK), with a TEM of our anthropometrist of <2% (22).

Four-way fractionation of body composition was used to partition total body mass into 4 different constituent compartments: fat mass, residual mass, muscle mass, and bone mass according to methods outlined previously (31). The anthropometric profile consisted of the following measurements: height, mass, 7 skinfolds, 11 girths, 8 lengths, and 8 breadths. The 4 compartment masses were estimated individually by measuring a representative subset of lengths, breadths, and girths scaled for a known height and mass. The percent muscle mass was derived as the percentage of estimated muscle mass to the estimated total body mass. The TEM values of our anthropometrist for estimating the fractionation components were fat mass (0.1 kg, 1.4%), residual mass (0.2 kg, 0.9%), bone mass (0.2 kg, 1.3%), muscle mass (0.2 kg, 0.7%), and % muscle mass (0.2%, 0.5%). The same anthropometrist

TABLE 2. Summary of training group programs illustrating differences in training intensity as a percent of 6RM, starting time, and the number of repetitions performed in each set.

Training group	Training set	1	2	3	4	5	6	7	8	9	10	11	12	Total
4 × 6	Intensity (%)	90	95	100	100									End
(n = 7)	Cumulative start time (min:s)	0:00	2:45	5:30	8:15									8:45
	Number of repetitions	6	6	6	6									24
8 × 3	Intensity (%)	90	90	95	95	100	100	100	100					End
(n = 7)	Cumulative start time (min:s)	0:00	1:13	2:26	3:39	4:52	6:05	7:18	8:31					8:45
	Number of repetitions	3	3	3	3	3	3	3	3					24
12 × 3	Intensity (%)	90	90	90	95	95	95	100	100	100	100	100	100	End
(n = 8)	Cumulative start time (min:s)	0:00	1:13	2:26	3:39	4:52	6:05	7:18	8:31	9:44	10:57	12:10	13:23	13:37
	Number of repetitions	3	3	3	3	3	3	3	3	3	3	3	3	36

conducted all measurements both before and after training.

Six and Three Repetition Maximum Free-Weight Bench Press

To test 6RM and 3RM free-weight bench press, subjects completed a warm-up and were evaluated according to our previously described criteria (11). Briefly, athletes lowered the bar without a pause until the chest was touched lightly approximately 3 cm superior to the xiphoid process. The elbows were extended equally with the head, hips, and feet remaining in contact with the bench throughout the lift. 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 by an amount self-selected by the subject, typically by 2.5 or 5 kg, allowing a minimum of 180 seconds of rest between attempts. The 6RM, 3RM, and bench press throw tests were repeated on separate days to establish test-retest reliability for these measures through calculation of the TEM.

Smith Machine Bench Press Throw Power

Subjects were evaluated for maximal power output during a 40-kg Smith Machine bench press throw measured with an optical encoder. The absolute load of 40 kg for the bench press throw was utilized to compare results with Baker's studies of rugby league players (2). Subjects performed 2 sets of 2 bench press throws every 35 seconds in a Smith Machine against 40 kg for a total of 4 throws. The mean power output (W) was recorded for each throw. 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 1 minute of rest between sets. This procedure was repeated on separate days to establish test-retest reliability for power output of the bench press throw measures through calculation of the TEM.

Optical Encoder

A GymAware optical encoder was used for continuous monitoring of all repetitions during training of concentric duration and mean concentric power. The concentric duration and mean concentric power were collected on each of 11,000 bench press repetitions performed in the study, thus allowing us to confirm the equality between groups in power output and concentric time.

The displacement and velocity of each bench press repetition was measured with an optical encoder. This device consisted of a spring-powered retractable cord that passed around a pulley mechanically coupled to an optical encoder, with the end of the cord attaching to the barbell. The device was positioned on the floor perpendicular to the movement of the barbell and measured velocity and displacement of the barbell. The device gives 1 pulse approximately every 3 mm of load displacement. Each displacement value is time stamped with a 1-millisecond resolution. Position-time data points are generated at a maximum rate of 25 Hz. The entire displacement (mm) and time (ms) for the movement were used to calculate mean values for power.

Training Program

Each group trained free-weight bench press 3 times per week on alternate days over the 6-week training block. The 6-week training intervention was chosen to correspond to the maximal strength training phase in the team's strength and conditioning program within their annual cycle.

Experimental groups trained 6 weeks of free-weight bench press as follows: 4 sets of 6 repetitions with each set commencing every 2 minutes, 45 seconds (4 × 6, n = 7), 8 sets of 3 repetitions commencing every 1 minute, 13 seconds (8 × 3, n = 7), or 12 sets of 3 repetitions commencing every 1 minute, 13 seconds (12 × 3, n = 8). All groups trained at the following intensities of their 6RM in each session: 90% for the first 25% of their sets, 95% for the next 25% of their sets, and 100% of their 6RM for the final 50% to ensure repetition failure towards the end of the training session (Table 2). Training sets of 3 or 6 repetitions were used to elicit different amounts of fatigue, but no group consistently trained at 100% of their 3RM (only at 90 to 100% of their 6RM). As each subject's strength gradually increased over the duration of the study, the weights were systematically adjusted to ensure repetition failure was reached in each session for the duration of the study. Spotters were instructed to provide only a minimum amount of assistance necessary to allow the subject to continue the set. Subjects were instructed to complete all repetitions in all sets, even if assistance on several repetitions was required. The number of assisted repetitions was recorded in the athlete's training diary. All training was directly supervised by the investigators to ensure quality and compliance of training (21). Subjects performed all bench press training in a free-

TABLE 3. Summary of pretraining strength and power testing comparing groups (mean ± *SD*).

Test	12 × 3 (*n* = 8)	4 × 6 (*n* = 7)	8 × 3 (*n* = 7)	*p* Value
6RM (kg)	75.0 ± 10.5	77.1 ± 6.0	75.7 ± 10.9	0.91
3RM (kg)	80.9 ± 11.1	82.9 ± 6.8	80.7 ± 11.9	0.91
Bench press throw peak power (W)	597.5 ± 67.9	582.9 ± 82.6	584.5 ± 152.6	0.96
Bench press throw mean power (W)	318.6 ± 24.9	334.6 ± 63.5	317.6 ± 54.3	0.77

weight setting on an official Paralympic power bench using a standard 20-kg barbell.

Weights used in each session were rounded to the nearest 2.5 kg. Other weight room training by all groups involved 5 to 10 minutes of stationary bicycling as warm-up, a traditional 60 minutes of whole-body routine involving all major muscle groups of the body, and 10 minutes of stretching on cooldown. No other lifts in their training program specifically targeted similar muscle groups in a task-specific way to bench press (e.g., incline dumbbell presses, etc.), but we cannot entirely rule out the synergistic involvement and therefore potentially additional training effects of the triceps, pectoral groups, and deltoids during other lifts. Regardless, with the exception of the bench press, all athletes performed training programs based on the same design, so any additional effects would have presumably affected all subjects. Other sport-specific training by all subjects involved daily team practices and skills sessions in their respective sport appropriate to elite-level (i.e., international-level) players.

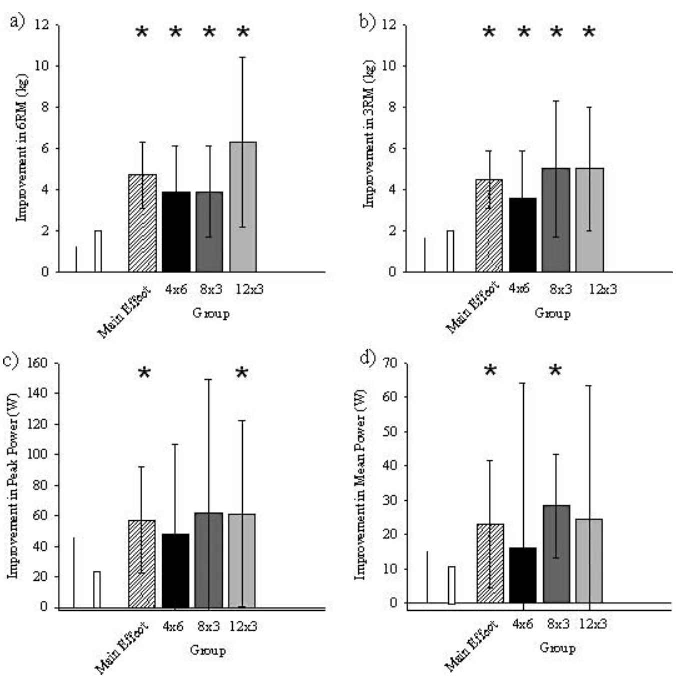

FIGURE 1. Change scores in different tests comparing the 4 × 6 (*n* = 7), 8 × 3 (*n* = 7), and 12 × 3 (*n* = 8) groups after 6 weeks of bench press training. Tests were (a) 6RM, (b) 3RM, (c) bench press throw peak power, and (d) bench press throw mean power. Individual lines represent the smallest worthwhile change (SWC), and open bars represent the typical error of measurement (TEM) of the test. Main effect refers to the change score for all groups combined. Error bars represent 95% confidence limits, and asterisks indicate statistically significant improvement ($p < 0.05$) compared with pretraining.

Statistical Analyses

All raw data are expressed as mean ± *SD*. Estimates of mean change and difference scores are expressed as mean with 95% confidence limits to establish the precision of the estimate (95% CL). After collecting dependent variables and assigning them to groups prior to training, groups were compared for statistically significant differences by 1-way analysis of variance (ANOVA) to ensure that the groups were evenly matched. Change scores after the training intervention of the 3RM and 6RM bench press (kg) and the maximum 40-kg bench press throw power (W) were analyzed using a 2-way ANOVA with repeated measures and Tukey HSD posthoc analysis. Significance was accepted at $p \leq 0.05$.

Pre- and posttraining data were pooled for each dependent variable, and Pearson-Product Moment correlation was used to assess the degree of association between 6RM, 3RM, and Smith Machine bench press throw measures. The TEM was calculated from the standard deviation of the change score (difference) between trials divided by the root of 2. The TEM is a measure of variation within each subject and represents the magnitude of variability within an athlete in repeated test results (17). We also calculated the smallest worthwhile change of estimated changes in 6RM, 3RM, and bench press throw power (SWC = 0.2 × between-subject *SD*) (8). Comparison of the magnitudes of the TEM and SWC can be used to establish the practical importance of the results by distinguishing between trivially small changes and those changes large enough to have a meaningful or worthwhile effect on performance.

RESULTS

Pretraining Testing

Relationship Between Strength and Power. The 3 groups were equivalently matched in bench press strength and bench press throw power prior to the training intervention program, with no statistically significant differences found between groups (Table 3). Pooled measures of bench press strength (6RM and 3RM) and bench press peak and mean power were highly correlated ($r = 0.77$ for both 6RM and 3RM to mean power; $r = 0.83$ and 0.85 for 6RM and 3RM to peak power, respectively, all $p < 0.01$).

Assessing Magnitudes of Change. The smallest worthwhile changes in this sample of basketball and volleyball players were Smith Machine bench press throw peak power 23.2 W (~4.0%); Smith Machine bench press throw mean power 10.3 W (~3.1%); free-weight 6RM 2.0 kg (2.5%), and 3RM 2.0 kg (~2.5%). The TEM of the 6RM, 3RM, and Smith Machine bench press throw peak and mean powers were 1.1 kg (1.7%), 1.8 kg (2.0%), 46.2 W (15%), and 16.3 W (11.2%), respectively, for all measures (Figure 1, *n* = 22), results similar to previously reported data on a comparable sample (11). These data indicate a greater likelihood of strength testing showing a substan-

TABLE 4. Comparison between groups on kinetic analysis. Data represent the group mean (± *SD*) per training session in each kinetic property assessed.

Training group	12 × 3 ($n = 8$)	4 × 6 ($n = 7$)	8 × 3 ($n = 7$)
Concentric time (s)	57.2 ± 13.2*	39.2 ± 6.1	39.4 ± 9.8
Total work (concentric + eccentric J)	26,591 ± 3020*	15,871 ± 1985	16,655 ± 2502
Concentric mean power (W)	281 ± 57	251 W ± 41†	280 ± 54
Failure rate per training session	3.1 ± 3.5§	4.1 ± 2.6‡§	1.2 ± 1.8

* Statistically higher than 4 × 6 and 8 × 3 groups ($p < 0.001$).
† Statistically lower than the 8 × 3 and 12 × 3 groups ($p < 0.001$).
‡ Statistically higher than the 8 × 3 and 12 × 3 groups ($p \leq 0.03$).
§ Statistically higher than the 8 × 3 groups ($p < 0.01$).

tial improvement, given the relatively larger TEM for power.

Training Analyses

Training Compliance. There were no significant differences in the number of training sessions attended by each subject over the course of the study (4 × 6 = 81%, 8 × 3 = 80%, 12 × 3 = 78%, $p = 0.30$). The reasons subjects missed training sessions included injury, illness, and/or absence from the gymnasium due to other specified training, travel, education, or competition commitments.

Number of Forced Repetitions. All subjects completed all prescribed repetitions of all training sessions. The number of failed repetitions indicates the number of repetitions per training session that the subject needed assistance from the spotter to complete the prescribed total repetitions. Both the 4 × 6 and 12 × 3 groups achieved the desired outcome of a higher number of repetitions to failure than the 8 × 3 group. The 4 × 6 group failed on a greater number of repetitions than the 12 × 3 group (1.0, 95% CL 0.07 to 1.9, $p = 0.03$) and the 8 × 3 group (2.9, 95% CL 2.0 to 3.8, $p < 0.01$), while the 12 × 3 group failed more than the 8 × 3 group (1.9, 95% CL 1.0 to 2.8, $p < 0.01$) (Table 4).

Kinematic Analysis of Bench Press

Concentric Time. The high-volume 12 × 3 group had significantly greater concentric time than the other 2 equivalent groups. The mean concentric time per training session was similar between the 4 × 6 and 8 × 3 groups (0.2 s, 95% CL −5.0 to 4.6, $p = 0.99$). In contrast, the concentric time was higher in the 12 × 3 than in the 4 × 6 group (18.0 s, 95% CL 13.2 to 22.8, $p < 0.01$) and the 8 × 3 group (17.8 s, 95% CL 13.2 to 22.4, $p < 0.01$) (Table 4). These data verify that the groups assigned the same training volume exercised for a similar concentric time, but the 12 × 3 high-volume group also had a higher concentric time.

Total Work. The high-volume 12 × 3 group performed greater work than the other 2 groups, which were equivalent. The total work performed per training session did not differ between the 4 × 6 and 8 × 3 groups (784 J, 95% CL −413 to 1,982). However, the 12 × 3 group performed more total work than the 4 × 6 group (10,720 J, 95% CL 9,527 to 11,913) and the 8 × 3 group (9,935 J, 95% CL 8,784 to 11,087) ($p < 0.01$, Table 4).

Concentric Mean Power. There were no significant differences in the concentric mean power output per training session between the 8 × 3 and the 12 × 3 groups (0.6 W, 95% CL −23.8 to 22.7, $p = 0.99$). In contrast, the concentric mean power of the 4 × 6 group was significantly lower than both the 8 × 3 groups (−29.1 W, 95% CL −5.0 to −53.3, $p = 0.01$) and the 12 × 3 groups (−29.7 W, 95% CL −5.6 to −53.8, $p = 0.01$) (Table 4).

Effects of Strength Training on Muscle Strength

Strength and Power Test. The main effect of training illustrated improvement in all tests of strength and power. The free-weight 6RM improved from 75.9 to 80.6 kg ($p < 0.01$), while 3RM improved from 81.5 to 86.0 kg ($p < 0.01$). Smith Machine bench press throw peak improved from 589 to 646 W ($p < 0.01$), and mean power improved from 323 to 346 W ($p = 0.02$). All changes exceeded the TEM and SWC and consequently could be considered as real and worthwhile. There were no significant differences between groups on any of the improvements (Figure 1a–d).

Anthropometric Changes. Several of the changes in anthropometric measures were statistically significant but unlikely to have been practically worthwhile. Over the study, chest circumference increased by a mean of 0.5 cm (0.03–0.89, $p = 0.04$) for all subjects, although the SWC was 0.9 cm. Estimated muscle mass increased by 0.6 kg (0.36–0.90, $p < 0.01$), although the SWC was 1.1 kg. There was a 0.2-kg decline of fat mass (0.0–0.4 kg, $p = 0.05$), although the SWC was 0.4 kg. However, there was a 0.4% increase in percent muscularity (0.1–0.6%, $p < 0.01$, SWC = 0.24%). There were no significant differences between the groups in muscularity.

DISCUSSION

These results have important practical implications for the design of optimal training programs in challenging the efficacy of the widespread training practice of increasing the number of forced repetitions and set volume to enhance strength gains. A major finding was the absence of any differences in the magnitude of the strength or power gains when the number of forced repetitions was increased and training volume was held constant. This observation indicates that increasing the number of forced repetitions does not further increase strength or power gains with training. A second finding of the study was that increasing both the number of forced repetitions and training volume did not enhance strength or power gains. Hence, the lack of effect with number of forced repetitions cannot be explained by a failure to increase training volume. These results indicate that there is no additional benefit to strength or power development when training repeated sets of forced repetitions compared with ceasing training sets once the point of repetition failure has been reached.

The perceived benefit of forced repetitions in the resistance training community is that the extra volume of training will enhance training adaptations, even if the added volume is performed with assistance. Training to the point of repetition failure has received some empirical support for developing strength and power (11, 25). The results of the current study clearly do not support any additional benefit of repeated forced repetitions or the need for additional volume with respect to enhancing the development of strength, power, or hypertrophy. Although higher volumes of training are important to developing muscular strength and hypertrophy in athletes, the effect does not appear to be entirely dose dependent (24, 27).

An important feature of this study was the implementation of the optical encoder to quantify bench press kinetics of the subjects for each repetition and to quantify the total volume of work performed, total concentric time, and mean power exerted by each group per training session. These measurements verified that training volume, time, and number of repetitions were indeed greater in the 12 × 3 group and were matched in the 4 × 6 and 8 × 3 groups (Table 4). These findings permit us to exclude the possibility that the observed results were influenced by differences in total volume of work, power output, concentric time, or the rates of failure. It is rare in resistance training studies investigating the relevance of fatigue and failure to control for such variables as time to completion (13) and training intensity (1, 19). Even when such variables are controlled, there is no assurance that key training variables, such as concentric time, total work, and power output, are also equivalent (9). Thus, our study substantially advances the methodological approaches taken in the literature. Finally, given the importance of manipulating volume, intensity, and power in eliciting different resistance training responses (20), continuous kinetic monitoring could become a regular part of free-weight resistance training studies (9).

Improvements in strength and power in the current study were greater than the magnitude of anthropometric changes, a phenomenon that has primarily been linked to neural adaptations (4). Other researchers have previously reviewed the neural (4), metabolic (26), and ionic (15) mechanisms proposed to contribute to muscle fatigue and failure. The dominant cause of failure during very high intensity training has been linked to central and neural mechanisms, such as antagonist (co-) activation and agonist (recurrent) inhibition (4, 5). Although neural adaptations traditionally are perceived to occur only in the initial weeks to months of training in novice strength-trained athletes before stabilizing after this period (4), electromyographic studies have demonstrated that even experienced lifters make neural adaptations when presented with new, higher intensity training loads (16). Therefore, the improvements demonstrated in the current study are more likely derived from neural adaptations. Improved membrane excitability, consequent to upregulation of muscle Na^+, K^+-ATPase, may also underpin the improvement seen with training (28).

PRACTICAL APPLICATIONS

The present study has demonstrated that multiple sets of forced repetitions convey no further benefit to strength development over ceasing training when failure is reached, even when higher volumes of both successful and failed repetitions are completed. Although repetition failure is an important inclusion to a strength development program (11, 25), failure training should not be maintained year-round, because manipulating training intensity is an important part of strength development (3, 16). Strength and conditioning coaches are well aware that training at high intensities for prolonged periods can lead to athlete burnout, injury, and overtraining syndrome (6). This study suggests that the common practice of utilizing forced repetitions is not beneficial and should therefore be minimized when strength development is the goal. Limiting the number of forced repetitions would also reduce the stress on athletes and contribute to a more manageable training load. In conclusion, in this study in which repetition failure was reached in each training session, further increasing the number of forced repetitions or set volume did not affect the magnitude of the strength gains.

The application of this research focuses on athletes who have moderate levels of resistance training experience and a short training cycle to develop maximal strength. For example, a collegiate sport coach may recruit a young player (e.g., 17 years of age) at the end of a school year (e.g., June). The player performs a home training program for general strength over the summer months prior to the start of the collegiate program (e.g., September) in order to begin the sport training program with a basic level of strength. At the start of the scholastic year, the team sport coach therefore has only a limited time (e.g., 8 weeks) to begin a supervised resistance training program on an athlete with a moderate training background prior to the commencement of the competitive season (e.g., November). The current research findings illustrate that the team coach or the team conditioning staff should not use valuable preparation time in high-volume, high-forced repetition training in the hope of developing greater strength, power, or muscularity. This study has investigated strength development in athletes who are not specifically trained for strength. Although strength, power, and hypertrophy are important aspects of such sports as basketball, American football, and rugby, these athletes are not ranked on strength, power, and size alone as in power lifting, Olympic weightlifting, or bodybuilding. Coaches and sport scientists should be cautious when applying the results of this research to pure strength, power, and hypertrophy athletes.

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A common strength training practice is to decrease the number of repetitions and increase the amount of weigh t you can safely lift. For example if you would like to build strength on your chest, you may select the Bench Press as your exercise and complete 3 sets of 5 repetitions at a weight about 75% of your 1RM (one repetition maximum).Â When you do strength, weight, or resistance training, your body demands more energy based on how much energy youâ€™re exerting (meaning the tougher youâ€™re working, the more energy is demanded).Â Powerlifting has no equal in strength development. In my practice, after about 7 years of strength training, I added another challenge to my routines. Original Editor - Lucinda hampton Top Contributors - Lucinda hampton. Original Editor - Your name will be added here if you created the original content for this page. Top Contributors - Lucinda hampton. The main difference between Power Training vs Strength Training is, that strength refers to the ability to overcome resistance, while power refers to the ability to overcome resistance in the shortest period of time. What is Strength? The definition of strength is Prescribing the proper resistance training (RT) program is critical to optimize skeletal muscle hypertrophy and strength. Periodization is a strategy that entails planned manipulations of training variables to maximize fitness adaptations while minimizing the risk of overtraining.Â Muscular strength can be defined as a muscleâ€™s ability to exert force on an external resistance (Suchomel et al., 2018). While muscular strength is suggested to be a critical attribute for many athletic disciplines (Suchomel et al., 2016), it is also an essential component of functionality in daily living (Kraemer et al., 2002 ; Hunter et al., 2004 ; Westcott, 2012).Â Is Periodized Resistance Training Necessary to Maximize Skeletal Muscle Hypertrophy? Forced repetitions are assisted movement by a training partner, or spotter. They are typically performed with heavy weight or near the end of a set at the onset of failure. Like other similar advanced-training methods, forced repetitions may lead to overtraining if overused or implemented for an extended period of time. Forced repetitions may bring about short-term progress, but more sustained progress can be achieved with small, systematic increases of repetitions and resistance (see Systematic Progress Methods and periodic exercise changes.Â Increased Number of Forced Repetitions Does Not Enhance Strength Development With Resistance Training, Journal of Strength and Conditioning Research, 2007, 21(3), 841â€“847. Negatives.