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Abstract

We evaluated the muscular strength, endurance, and power responses of 12 college students, ranging in age from 19-40 years, who participated in a 6-wk high-intensity training program commonly used to improve muscular endurance. Muscular strength was measured by a one repetition maximum (1RM) bench press test and a 1RM Hammer bench press test; muscular endurance was measured by administering a 70-percent 1RM test to failure on the Hammer bench press; and upper body power was measured by administering a medicine ball throw test. We observed a 4.8-percent improvement of 2.7 kg on the bench press, a 14.6-percent improvement of 10.5 kg on the Hammer bench press, a 45.5-percent improvement with an average increase of five repetitions on the submaximal test to failure and an average improvement of ~ 20 percent, 60 cm, for the medicine ball throw. For our subjects, a commonly used high-intensity training muscular endurance program resulted in improved performance on tests measuring muscular strength, endurance, and power, and resulted in zero reported injuries during training or assessment procedures.

Key words: high intensity training, muscular endurance, strength, power

Introduction

There are two philosophies concerning performance-related power enhancement. One is that muscular hypertrophy, endurance, strength, and power result from different methods of training (Fleck and Kraemer 1997). The other philosophy holds that muscular hypertrophy, endurance, strength, and power are all interrelated, and improvements in these areas are based simply on improvements in strength (Brzycki 1995, Mannie 1999). Additionally, debate exists over effectiveness of free weights versus resistance training machines. Many strength and conditioning professionals believe free weight training is superior to using resistance training machines (Fleck and Kraemer 1997, Shepard 2004). Finally, some researchers believe that training to the point of muscular failure will not enhance strength, power or hypertrophy, but will cause injury (Stone et al. 1996).

With these thoughts in mind, we observed the effects of participating in a high-intensity muscular endurance weight lifting program over a 6-wk period in which each set of each exercise was taken to muscular failure, defined as that point when a repetition cannot be completed in good form due to physical exhaustion.

Research Questions

Did a high-intensity endurance strength training program have any effects on maximum strength or power as measured by a one repetition maximum bench press test on two implements (free weight and Hammer) and a medicine ball throw test of upper body power? Was there a transfer of strength from a machine bench press to a free weight bench press? Were there any reported injuries from participating in a weight lifting program that required completing each set to muscular failure? We consider the bench press exercise a "free weight" exercise in which participants support and balance the entire weight of the barbell throughout the full range of motion.

The Hammer bench press is considered a "machine" exercise in which participants do not have to balance the resistance. We explored these questions.

Methods

Subjects

This study was a non-experimental descriptive study that used a convenience sample of 13 college students ranging in age from 19 to 40 years. Experience level of each subject ranged from little to no experience in strength training to having over 28 years of experience lifting weights as a form of strength training. We analyzed data from a 6-wk high-intensity muscular endurance training program to determine effects on muscular strength, endurance, and power. The university approved all procedures, and each subject signed an informed consent document. All subjects volunteered for the project and completed a physical activity readiness questionnaire.

Procedures

All participants were assessed prior to the start of the program and again at the end after a 3-day rest from the final training day to ensure recovery, and followed procedures established by the American College of Sports Medicine (ACSM) (2006). Beginning with a warm-up and ending with a cool down, the initial and final assessments included (1) 1 repetition maximum (1RM) bench press test (BP) in which each individual performed a one-repetition maximum on the bench press; we allowed 5 min rest between 1 RM attempts; and weight was added in 5- to10-percent increments until participants could not complete the repetition, (2) following a 5-min rest from the BP test, participants completed a one-repetition maximum Hammer Incline Press Test (HBP) following the same procedures for the BP test, (3) following a 5-min rest, participants completed a set to momentary muscular failure with 70 percent of the 1RM of the Hammer test (SHBP), and (4) following a 5-min rest, participants completed the medicine ball throw test (MBT) to test upper body power.

The resistance training program used was a modified form of Kelso's (2000) muscular endurance training recommendations and included two options. Option one consisted of performing two sets of one exercise, the Hammer Incline Press, twice/week. The sets and repetitions varied according to the following schedule: (1) 2 wks of 2 sets of 15-17 repetitions, (2) 2 wks of 2 sets of 12-15 repetitions, and (3) 2 wks of 2 sets of 10-12 repetitions. If the subjects chose option two they performed the following exercises: (1) Abdominal Curls, (2) Bicep Curls, (3) Hammer Deadlift (optional), (4) Hyper-extensions, (5) Tricep Extension, (6) Leg Extension, (7) Leg Curl, (8) Lat Pull Down, and (9) Wrist Curls (optional) .

Two subjects chose to participate in option one and the rest of the subjects chose to participate in option two. Option two required one set of each exercise during two sessions/week and followed the same repetition scheme for option one, i.e., a target repetition range of 15-17 for the first 2 wks. The target repetition range for weeks 3 and 4 was 12-15, and for weeks 5 and 6 the range was 10-12. Each subject was given personal instruction in the performance of each exercise and, during this time, the subject was directed to take each set to muscular failure, i.e., the point at which they could no longer complete a repetition without deviating from the posture required of the exercise. The teaching points that were emphasized for safety included (ACSM 2006) (1) slow movements, (2) full range of motion, (3) breathing, (4) posture, (5) proper warm-up, and (6) proper cool-down.

Each week subjects handed in performance sheets that included the number of repetitions and amount of weight used for each exercise performed. Subjects were also questioned about the development of any injuries. This ensured that communication about the program was maintained throughout the 6-week period in case there were any questions, comments or concerns.

All necessary measures were put into effect to ensure the safety of each participant. A health screen evaluation, the physical activity readiness questionnaire (PAR-Q), was

used for each subject to ensure that he/she had no adverse health risks that would affect the participant during activity. Also, to ensure the privacy of these participants, we assigned a random number to each subject to maintain confidentiality and used an informed consent form that stated the participant's willingness to allow us to use their results in this case study.

Results

Because we did not meet the assumption of the central limit theorem with only 13 subjects, we chose to describe results in a case study format. Out of 13 original participants, 12 completed requirements of the 6-wk study. Results of the 1RM bench press (BP) suggested a 4.8-percent improvement of 2.7 kg (Table 1), and the Hammer bench press test (HBP) showed 14.6-percent improvement of 10.5 kg. The submaximal test to failure (SHBP) resulted in a 45.5-percent improvement with an average increase of five repetitions. Eleven of 12 subjects improved on the SHBP, whereas subject eight finished with a decrement of two repetitions. Nine subjects improved performance on the MBT test; average increase for the 12 subjects was 60 cm for ~ 20 percent improvement. There were no injuries reported during the training or assessment procedures.

Discussion

The principle of overload states that for a system to improve its function, it must be exposed to a stimulus greater than it is

Table 1. Performance Results.

Subject	BP pre*	BP post*	HBP pre*	HBP post*	SHBP pre*	SHBP post*	MBT pre+	
1	29.5	31.8	31.8	40.9	11	20	3	3.4
2	38.6	40.9	54.5	59.1	10	11	2.9	2.9
3	100	104.5	131.8	136.4	9	11	4.8	5.1
4	47.7	50	59.1	70.5	13	16	2.9	2.9
5	72.7	75	95.5	104.5	14	16	3.7	4.9
6	75	77.3	81.8	95.5	12	20	3.9	4.6
7	25	25	18.2	27.3	15	23	2	2.2
8	70.5	65.9	86.4	86.4	12	10	3	2.9
9	38.6	43.2	40.9	54.5	14	21	2.7	3.1
10	75	79.5	104.5	113.6	7	9	3.7	4
11	102.3	113.6	122.7	154.5	6	14	3.1	4
12	29.5	29.5	29.5	36.4	12	16	2.2	2.6
Mean	58.6	61.4	71.4	81.9	11	16	3.1	3.7
% change		4.8		14.6		45.5		20

* units in Kilograms (kg).

\+ units in meters (m).

normally accustomed to. Some strength coaches prescribe strength and power programs with a range of three to five sets for multi-joint exercises, and prescribe two to six repetitions, while other strength coaches adhere to a single set training protocol with higher repetitions, usually anywhere from 6-20 repetitions. Though they are employing different acute program variables, each is attempting to progressively overload the musculoskeletal system to improve muscular strength, endurance, and power. There has been much debate over the effectiveness of these various strength and conditioning programs.

This particular protocol, commonly thought of as a muscular endurance training program, effectively improved one repetition maximum bench press strength on two different implements for all but two of the subjects; subjects eight and twelve. Subject eight actually decreased performance on the BP, SHBP and the MBT. Though we instructed all subjects to maintain normal activity, it was not until after the 6-week study that the subject told us that she began a rigorous cardiovascular endurance-training program that involved running over 6 mi/day, 6 days/week during the study. This may have been a factor in her performance decrement.

There were limitations in our study design. One limitation was the small non-representative sample with no control group, and the other is the age range of 19-40 years, which is quite large. Another limitation was a range of little to no previous training experience to an advanced level of previous training. This may possibly have had some effect on the physiological response to this training program and/or their performance on the tests. Also, the 6-wk duration of the study is a relatively short period of time.

Any conditioning in unfit individuals will usually produce changes in physiological variables up to a certain level of performance competency. Some strength and conditioning specialists believe that beyond moderate performance competency, usually only more specialized conditioning including higher volume training and power training, will produce further performance improvements. This was not the case in our study. Subjects three and eleven had the most previous training experience of all the subjects. Based on common perceptions described above, this kind of low volume program would have less of an effect on subjects with more previous experience. These two subjects, however, improved performance on all measurements. Likewise, subjects one, two, four and seven had the least amount of previous training; yet their performance improvements were relatively modest.

Another limitation of this study was the fact that we were unable to supervise every training session the subjects participated in. Often, motivation in the form of personal supervision can have an influence on how far individuals will push themselves. When a "coach" is present and expects improvement from one training session to the next, subjects may push themselves further than they would during a training session with no supervision. Though training sheets were turned in on a weekly basis and verbal encouragement was given to ensure each subject was training to a point of complete muscular failure, some people were more or less able to withstand the discomfort that accompanies this type of training.

Subject number six was almost eliminated prior to the beginning of the study because of a pre-existing non-specific shoulder condition that was identified during the pre-participation screening. Because the subject was enthusiastic about participating in the project we allowed him to continue and monitored him closely. His performance during the six weeks showed steady improvement, and the post program assessment was impressive with improvements in each test. Though we did not conduct post study interviews, subject number six emailed us with subjective perceptions of his experience and we felt it was appropriate to include this qualitative aspect within this manuscript. "Before the strength program," he wrote, "I worked for the beer distributor and stocked shelves. I could not lift a single 6 pack above my head without pain (7-8 on a scale of 1-10). It also hurt to do the bench press, bad enough that

I hit my max on the first try. The Hammer press didn't hurt though. After the [final] strength tests, I have had ZERO pain in my shoulder. Not even when I lay on my side on it in bed. Also, doing the bench press for the second time, we started with my old max and I pushed it up, and moved on to the next weight, with very little pain. I have had no pain since the strength training and am loving it. Thanks!"

This subject's statement, combined with the fact that there were zero injuries reported, indicated that training to muscular failure may not cause injury, as some strength and conditioning specialists suggest.

We expected muscular endurance to improve, but the researchers were unaware of the effects this training program would have on strength and power, or whether there would be transfer of strength from one implement to another. Strength and conditioning coaches should be aware that higher repetition ranges may be effective in improving strength and power.

Additionally, higher repetitions require lower weights and reduce orthopedic stress and risk of injury; this may be an important consideration to coaches who want their athletes to remain healthy and injury free. For future research we recommend use of matched control groups using various higher volume programs, and using participants who are all experienced weight lifters.

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