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Four Weeks of Optimal Load Ballistic Resistance Training at the End of Season Attenuates Declining Jump Performance of Women Volleyball Players

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Abstract. Newton, R.U., R.A. Rogers, J.S. Volek, K. Häkkinen, and W.J. Kraemer. Four weeks of optimal load ballistic resistance training at the end of season attenuates declining jump performance of women volleyball players. *J. Strength Cond. Res. 20(4):955–961. 2006.*—Anecdotal and research evidence is that vertical jump performance declines over the competitive volleyball season. The purpose of this study was to evaluate whether a short period of ballistic resistance training would attenuate this loss. Fourteen collegiate women volleyball players were trained for 11 weeks with periodized traditional and ballistic resistance training. There was a 5.4% decrease ($p < 0.05$) in approach jump and reach height during the traditional training period (start of season to midseason), and a 5.3% increase ($p < 0.05$) during the ballistic training period (midseason to end of season), but values were not different from start to end of season. These changes in overall jump performance were reflective of changes in underlying neuromuscular performance variables: in particular, power output and peak velocity during loaded jump squats, countermovement jumps, and drop jumps. During the first 7 weeks of traditional heavy resistance training, it appears that the neuromuscular system is depressed, perhaps by the combination of training, game play, and skills practice precluding adequate recovery. Introduction of a novel training stimulus in the form of ballistic jump squats and reduction of heavy resistance training of the leg extensors stimulated a rebound in performance, in some cases to exceed the athlete's ability at the start of the season. Periodization of in-season training programs similar to that used in this study may provide volleyball players with good vertical jump performance for the crucial end-of-season games.

Key Words. strength, power, jumping, power, periodization

Introduction

Vertical jumping is integral to the game of volleyball, and therefore considerable training time is allocated to developing this component of neuromuscular performance. Various methods, including resistance and plyometric training, are used to increase maximal and explosive strength, with the aim to maximize the player's jump height. Although there are a number of anecdotal reports in the literature regarding the training of volleyball players, few studies have evaluated the conditioning and training of these athletes (8, 9, 13, 19). Newton et al. (19) trained national-level male volleyball players for a period of 8 weeks using either traditional squats or jump squats (JSs), which the authors described as ballistic training. Traditional training did not elicit any change; however, even the highly trained athletes in the ballistic training group produced increases in jump performance of around 6%.

The work of Newton et al. (19), although encouraging, formed the preseason preparation; in-season training requires additional considerations because of the increase in the amount of time devoted to competition and skill training, which may necessitate an alteration in training type, volume, or intensity, or in a combination of these acute program variables. Häkkinen (13) suggested that in order to maintain the level of explosive strength performance characteristics in female volleyball players, the magnitude of both strength and explosive training stimuli should be given careful attention during the entire course of the competitive season. In this study, it was reported that if heavy resistance training was stopped for too long a period (5.5 weeks) and only explosive strength training was performed, then there were significant decreases in both maximal strength and explosive strength as measured by jumping height (13). However, previous research involving female basketball players found explosive-type strength training to increase both vertical jump performance and isometric measures of rate of force development over a 22-week competitive season (12).

The ability to maintain or increase power and performance during the competitive season is an important consideration. A long competitive season, with its high volume of skill training and competition, has been reported to have detrimental effects on the power production of some athletes (13). The question remains as to whether this decrease in performance may be prevented by specific training interventions.

The purpose of this study was to determine whether the decline in jump performance over the competitive season could be avoided or at least minimized for the crucial games at the end of the season by manipulating the strength and conditioning program. Our hypothesis was that reducing the volume of heavy, slow resistance exercise for a short period of 4 weeks and replacing it with lighter-load, higher-power-output, ballistic training would result in rebound in jump performance. This information would be of great importance to add basic under-standing of the mechanism of strength and power development and to the strength and conditioning coach who desires to train his or her athletes in the most efficient manner during the competitive season in order to optimize athletic performance.

METHODS

Experimental Approach to the Problem

This study was an 11-week longitudinal study completed over a normal collegiate competition season, which involved playing a mean of 3 games per week combined with volleyball practice sessions as well as strength and conditioning. The athletes were tested at the start of the season, at midseason (7 weeks), and at the end of the competitive season (11 weeks), using a variety of tests to determine lower extremity strength and power performance in a series of jumps designed to extract different aspects of neuromuscular performance. The first 7 weeks of the strength and conditioning program consisted of traditional resistance training performed 2 times per week. This traditional training was followed by a 4-week cycle during which the heavy resistance lower-body exercises were replaced with lighter-load, ballistic resistance training. A short period of only 4 weeks was chosen because previous research (13) has shown that 5.5 weeks without heavy resistance training was perhaps too long and resulted in significant reduction in both maximal strength and jump performance. Because of ethical considerations for the athletes, it was not possible to include a control group, so all athletes completed the same in-season resistance training program.

Subjects

Fourteen National Collegiate Athletic Association Division I female volleyball players from the same volleyball team were recruited for this study. The athletes were of a mean (± *SD*) age, height, and body weight of 20.0 (±1.2) years, 180.2 (±7.3) cm, and 70.5 (±6.2) kg, respectively. All participants were informed of the risks and benefits of the study, and signed an informed consent document approved by the Institutional Review Board of the university. All subjects were medically screened by team medical staff prior to the start of the study and found to have no medical or health problems that would affect their performance in the study.

Equipment

The approach jump and reach testing was done with a vertical jump testing device (Vertec; Sports Imports, Inc., Columbus, OH). A 3-step approach was used during testing.

Testing and training for the loaded jump squats were performed on a Smith machine (Calgym, Caloundra, Australia). A linear transducer was attached to the bar (model PT 9510; Celesco, Canoga Park, CA) that recorded bar movement to the accuracy of 0.001 m. A uniaxial force plate (Quattro Jump; Kistler, Winterthur, Switzerland) was placed under the Smith machine to record force applied through the feet. Data were collected at a frequency of 500 Hz. The information gathered from the force plate and the linear transducer was recorded by a computer, and a software package (Ballistic Measurement System; Fitness Technology, Adelaide, Australia) calculated bar displacement, velocity, acceleration, force, and power for the movements. The system was calibrated prior to and at the conclusion of each testing session.

The JSs, countermovement jumps (CMJs), and drop jumps were all performed on a force plate (model 9281C; Kistler) and data were recorded at a frequency of 500 Hz. A position transducer (model PT 9510; Celesco) was used to record displacement of the subject's center of mass (attached to waist by a Velcro strap), and these position and force measurements were recorded by a computer. A software package (Ballistic Measurement System; Fitness Technology) was used to calculate jump height, force production, contact time, and flight time. The system was calibrated prior to and at the conclusion of each testing session

Testing Protocols

Approach Jump and Reach Testing. Subjects were tested prior to volleyball practice, and therefore completed their regular warm-up prior to testing. Subject reach height was recorded by having subjects walk under a Vertec with arms extended and hands together (palm of 1 hand to back of opposite hand) above the head. The highest point touched in this position was recorded as reach height. Subjects were then given a 3-step approach and jumped for maximal height. Absolute jump height was recorded as the highest the subject could jump and reach with 1 hand. Actual distance jumped was recorded as absolute jump height minus reach height. Subjects were given a minimum of 1 minute of rest between successive attempts.

Loaded Jump Squat Testing. The subjects warmed up with 2 sets of 8 repetitions of squats at the start of each test session. Subjects then performed 3 jump squats in the Smith machine with the bar and no additional weight. The power production was recorded, 1.14 kg was added to the bar, a minimum of 1 minute of rest was imposed, and 3 jumps were again performed. This process was repeated as long as power production increased. Testing was ended when power production was lower than the previous set on 2 consecutive attempts at the same weight. Bar displacement with time was recorded using a linear transducer and force through the feet measured by a force platform as previously described for subsequent calculation of velocity, force, and power data.

Force Plate Testing. Force plate testing consisted of JSs, CMJs, and drop jumps from 30 and 60 cm (DJ30 and DJ60). Vertical ground reaction force and subject displacement was recorded using the system already described. The subjects performed each of the tests until 2 jumps had been recorded with a difference of no more than 5% in maximum height. Test 1 (JS): Standing erect with the hands on the hips, the subject dipped to a self-selected drop and paused for 3 seconds. The subject then jumped upwards with no countermovement for maximal height. If any preparatory dip was observed on the ground reaction force graph, the trial was discarded and the subject made a further attempt. Test 2 (CMJ): Standing erect with the hands on the hips, the subject dipped to a self-selected depth and then immediately jumped upwards for maximal height. Test 3 (DJ30 and DJ60): Subjects dropped down from boxes of 30 and 60 cm with the hands on the hips, landed on a force plate, and then attempted to jump for maximal height, landing back on the force plate.

TABLE 1. Means and standard deviations for approach jump and reach performance at the start of the competition season (Start), midseason (Mid), and end of the competition season (End).

	Start		Mid		End	
	Mean	*SD*	Mean	*SD*	Mean	*SD*
Jump distance (cm)	61.2	5.6	57.9*	5.3	61.0†	5.6
Absolute jump height (cm)	294.9	10.4	291.6*	10.2	294.6†	10.9

* Indicates significant difference between Start and Mid ($p < 0.05$).
† Indicates significant difference between Mid and End ($p < 0.05$).

TABLE 2. Means and standard deviations for loaded jump squat performance at the start of the competition season (Start), midseason (Mid), and end of the competition season (End). Jumps were performed against the load that produced the greatest mechanical power output.

	Start		Mid		End	
	Mean	*SD*	Mean	*SD*	Mean	*SD*
Peak force (N)	2,329	350	2,548	614	2,726	427
Time to peak force (s)	0.14	0.07	0.1	0.03	0.12	0.04
Average force (N)	1,686	193	1,724	273	1,896*†	281
Peak power (W)	3,895	379	3,964	445	4,157	572
Average power (W)	2,285	289	2,359	340	2,560*†	371
Peak velocity ($m \cdot s^{-1}$)	2.41	0.11	2.41	0.1	2.37	0.12
Minimum velocity ($m \cdot s^{-1}$)	−2.27	0.17	−2.37	0.17	−2.27	0.2
Load (kg)	12.8	1.5	12	1.2	12.8	1.2

* Indicates significant difference between Mid and End ($p < 0.05$).
† Indicates significant difference between Start and End ($p < 0.05$).

Training Protocols

All subjects completed the same resistance training program, which consisted of both upper- and lower-body exercises. However, the emphasis for the first 7 weeks was on heavy resistance training involving front and back squat, leg press, and deadlift. For weeks 8–11, these exercises were replaced by loaded jump squats performed ballistically on the Smith machine. During weeks 8 and 10, the subjects performed 3 sets of 6 repetitions. On weeks 9 and 11, the subjects performed 3 sets of 3 repetitions. The load used for training was determined based on the load that produced maximal mechanical power output during testing.

For the initial training session, the load that produced peak power during the first testing session was used for the first set. Based on the power output during this set and subsequent sets, the weight was modified. If the power output was lower than the power output during the previous session at the same load (first set) or lower than the previous set (subsequent sets), the load was reduced by 1.1 kg. If the power output was higher than the power output during the previous session at the same load (first set) or higher than the previous set (subsequent sets), the load was increased by 1.1 kg. The load was constantly modified during the training sessions so that it always represented the load that produced maximal mechanical power. Subsequent training sessions started with the load that produced peak power during the previous session, and were modified according to these same guidelines. All sets were completed with a minimum of 2 minutes of rest between consecutive sets.

Statistical Analyses

Means and standard deviations were calculated for all measurements using standard procedures. Repeated measures analysis of variance was then applied to examine within-subject changes over the course of the season. In the event that a significant main effect was found, least significant difference post hoc comparisons were made to determine at which test occasions the variable was significantly different. An alpha level of $p \leq 0.05$ was used as the criterion for significance in all statistical comparisons.

RESULTS

Subject Compliance

During the ballistic training period, the subjects completed 94% of all the sessions. Missed sessions were rescheduled, but because of injury not related to the experiment, complete compliance could not be achieved.

Approach Jump and Reach Testing

Vertical jump height significantly decreased by 5.4% from start of season to midseason, but significantly increased by 5.3% from midseason to end of season. There was no significant difference in vertical jump and reach between start- and end-of-season testing (Table 1).

Loaded Jump Squat Testing

Average force and power were not significantly different from start of season to midseason, but end-of-season values were significantly higher than both start-of-season and midseason values (force, 9.9 and 12.4%; power, 8.8 and 12.0%). No other statistically significant changes were observed (Table 2).

Jump Squat Testing

Peak force in the JS did not change from start of season to midseason or midseason to end of season, but there was a significant increase of 5.7% over the course of the whole season. The only other significant changes were observed

TABLE 3. Means and standard deviations for squat jump (concentric only jump) performance at the start of the competition season (Start), midseason (Mid), and end of the competition season (End).

	Start		Mid		End	
Variable	Mean	*SD*	Mean	*SD*	Mean	*SD*
Peak force (N)	1,474	145	1,549	143	1,558†	147
Time to peak force (s)	0.3	0.07	0.26	0.05	0.27	0.06
Average force (N)	1,091	105	1,138	107	1,116	95
Maximum rate of force development ($N \cdot s^{-1}$)	5,681	1,554	6,240	1,670	6,032	2,272
Peak power (W)	2,897	367	2,780	254	2,928	369
Average power (W)	1,285	225	1,252	154	1,294	218
Maximum height (m)	0.38	0.03	0.36	0.02	0.37	0.03
Minimum height (m)	−0.27	0.04	−0.24	0.05	−0.24	0.05
Peak velocity ($m \cdot s^{-1}$)	2.19	0.14	2.04*	0.11	2.22†	0.15

* Indicates significant difference between Start and Mid ($p < 0.05$).
† Indicates significant difference between Mid and End ($p < 0.05$).

TABLE 4. Means and standard deviations for countermovement jump performance at the start of the competition season (Start), midseason (Mid), and end of the competition season (End).

	Start		Mid		End	
	Mean	*SD*	Mean	*SD*	Mean	*SD*
Peak force (N)	1,483	157	1,494	155	1,577†‡	138
Time to peak force (s)	0.42	0.16	0.4	0.15	0.35	0.09
Average force (N)	1,017	107	1,028	110	1,069†‡	99
Maximum rate of force development ($N \cdot s^{-1}$)	7,294	2,342	7,616	2,545	9,718†‡	2,832
Peak power (W)	3,058	368	2,836*	257	3,137†	339
Average power (W)	1,683	207	1,612	179	1,775†‡	176
Maximum height (m)	0.4	0.04	0.39	0.03	0.4	0.03
Minimum height (m)	−0.31	0.05	−0.28	0.03	−0.26†‡	0.04
Peak velocity ($m \cdot s^{-1}$)	2.34	0.16	2.17*	0.09	2.36†	0.11
Minimum velocity ($m \cdot s^{-1}$)	−1.26	0.18	−1.20	0.11	−1.30	0.14

* Indicates significant difference between Start and Mid ($p < 0.05$).
† Indicates significant difference between Mid and End ($p < 0.05$).
‡ Indicates significant difference between Start and End ($p < 0.05$).

in peak velocity, with a 6.8% decrease between start of season and midseason followed by an increase of 8.8% midseason to end of season. No other performance measure for the JS changed significantly over the course of the season (Table 3).

Counter Movement Jump Testing

Peak force in the CMJ exhibited significant increases from midseason to end of season (5.6%) and from start to end of season (6.3%). Average force also showed significant improvements, increasing 4.0% from midseason to end of season and 5.1% from start to end of season. Maximum rate of force development increased significantly, with a 27.6% increase from midseason to end of season and a 33.2% improvement from start to end of season. Peak power decreased significantly from start of season to midseason (7.3%); it recovered significantly from midseason to end of season (10.6%), but over the whole season the change was a nonsignificant increase of 3%. Average power displayed significant increases from both midseason to end of season and start to end of season (10.1 and 5.5%, respectively). Minimum height in the CMJ significantly increased by 7.1% from midseason to end of season, and by 16.1% from start to end of season. This means that the athletes did not dip as deeply when performing the countermovement over the course of the season. Peak velocity significantly decreased from start of season to midseason (7.1%), and then significantly increased from midseason to end of season (8.8%). Time to peak force, maximum height, and minimum velocity did not exhibit any significant changes across the test occasions (Table 4).

30 cm Drop Jump Testing

There were very few significant changes in variables derived from the DJ30 testing. Peak power increased significantly by 8.8% from midseason to end of season, but there were no significant differences from start of season to midseason or from start to end of season. Peak velocity decreased significantly from start of season to midseason (−5.7%), and then increased from midseason to end of season (7.0%), but the increase from start to end of season of only 0.9% was not significant. Minimum velocity increased significantly from start of season to midseason (6.0%), but then decreased between midseason and end of season (5.0%); the overall change through the season was not significant. This indicates that at midseason the athletes did not drop as rapidly into the depth jump as they did at the start or end of the season. There were no other significant changes (Table 5).

60 cm Drop Jump Testing

The results of the DJ60 testing are presented in Table 5. Average force did not change from start of season to mid-

Table 5. Means and standard deviations for 30- and 60-cm drop jump performance at the start of the competition season (Start), midseason (Mid), and end of the competition season (End).

	Height (cm)	Start		Mid		End	
		Mean	*SD*	Mean	*SD*	Mean	*SD*
Peak force (N)	30	1,729	270	1,776	306	1,870	343
	60	1,690	171	1,719	226	1,858	293
Time to peak force (s)	30	0.22	0.1	0.2	0.13	0.22	0.13
	60	0.17	0.04	0.17	0.03	0.16	0.04
Average force (N)	30	1,337	152	1,368	194	1,405	204
	60	1,432	104	1,453	170	1,559‡	204
Peak power (W)	30	3,094	384	2,954	299	3,214†	474
	60	2,930	209	2,873	306	3,155†‡	318
Average power (W)	30	1,802	222	1,726	212	1,869	299
	60	1,713	132	1,696	168	1,861†‡	244
Contact time (S)	30	0.47	0.11	0.47	0.12	0.45	0.1
	60	0.44	0.09	0.46	0.08	0.39†‡	0.07
Flight time (s)	30	0.48	0.03	0.48	0.03	0.49	0.02
	60	0.47	0.03	0.48	0.03	0.48	0.03
Flight:contact ratio	30	1.09	0.3	1.1	0.32	1.13	0.27
	60	1.12	0.26	1.08	0.23	1.25†	0.27
Maximum height (m)	30	0.4	0.05	0.39	0.03	0.41	0.04
	60	0.38	0.04	0.39	0.04	0.38	0.03
Minimum height (m)	30	−0.25	0.09	−0.23	0.08	−0.22	0.08
	60	−0.23	0.07	−0.23	0.07	−0.20	0.06
Peak velocity ($m \cdot s^{-1}$)	30	2.27	0.16	2.14*	0.11	2.29†	0.13
	60	2.19	0.15	2.11	0.16	2.24†‡	0.11
Minimum velocity ($m \cdot s^{-1}$)	30	−2.15	0.13	−2.02*	0.12	−2.12†	0.12
	60	−2.90	0.09	−2.77*	0.1	−2.85	0.12

* Indicates significant difference between Start and Mid ($p < 0.05$).
† Indicates significant difference between Mid and End ($p < 0.05$).
‡ Indicates significant difference between Start and End ($p < 0.05$).

season, or from midseason to end of season, but did display a significant increase over the entire season (8.9%). Peak power increased significantly from midseason to end of season and from start to end of season by 9.8% and 7.7%, respectively. Average power also changed significantly, with increases of 9.7% from midseason to end of season and 8.6% from start to end of season. Contact time increased slightly from start of season to midseason, though this was not significant. However, contact time decreased significantly from midseason to end of season by 15.2%, resulting in an overall decrease for the whole season of 11.6%; the overall decrease was not significant. As a result of the alterations in contact time, flight to contact ratio exhibited a similar pattern, being significantly higher (15.7%) from midseason to end of season. The 11.6% increase from start to end of season, although large, was not significant. Peak velocity increased significantly from both midseason to end of season (6.2%) and start to end of season (2.3%), whereas minimum velocity showed a significant increase of 4.5% from start of season to midseason (Table 5).

Discussion

The primary aim of this study was to examine the changes in jumping performance during a competitive season experienced by a group of elite female volleyball players. It was hypothesized that if the resistance exercise program were periodized, the declines over the competition season in jump performance previously reported for volleyball athletes (13) could be reduced or even eliminated. To this end, from the eighth week onward, heavy resistance exercises for the lower extremities were replaced with high-power-output, ballistic jump squats using much lighter loads. During the traditional resistance training portion of the study, there was no increase in jump performance, and many of the measures relating to high velocity and power actually decreased. However, during the ballistic training period, the force, velocity, and power production during the various jump tasks increased, all measures that had decreased during the first 7 weeks had recovered or even exceeded the values at the start of the season, and there were no significant decreases noted in any of the measured variables during this time. Interestingly, although several measures of jump performance did increase during some of the tested jumps, jump and reach height did not change significantly between the start and the end of the season.

Based on previous research by the authors (13, 19) it was expected that power production and velocity would remain unchanged or increase during the traditional resistance training period; however, there were several factors indicative of high velocity and power output that actually decreased during this time. The JS, CMJ, and DJ30 all showed significant decreases in velocity of 5.8–7.1% during this period. This was in contrast to a similar study (13) that reported significant increases in JS (30.3 ± 1.7 to 31.6 ± 1.3 cm) and CMJ (32.8 ± 1.6 to 34.3 ± 1.3 cm) during the course of the competitive season and accompanying traditional resistance training. In the current study, there was then a reversal of this effect during the ballistic training period, wherein the losses in maximal velocity were either recovered or increased beyond the levels of the start of the season. Such results may be indicative of the velocity-specific training effects that have been previously observed (4–7, 12, 14, 15, 17–19). Along with these changes in velocity were similar changes in power production. For the CMJ, there was a decrease in power output (−7.3% and −10.1% for peak and average respectively) during the traditional training period, which recovered to exceed start-of-season levels (3.0% and 5.5% for peak and average respectively) during the ballistic training period. Performance in the drop jumps is indicative of the athlete's ability to tolerate high loads during stretch-shortening cycle movements. The DJ30 revealed some training effects, with a general suppression of performance during the first part of the season followed by recovery over the later part. However, these effects were much more apparent during the DJ60, in which power increased significantly during the ballistic training period, resulting in higher output in both peak (7.7%) and average (8.6%) power compared to the start of the season. Much of this increase in power output was caused by reduced contact time, which has been reported as an important outcome of jump training (19, 23). Contact time for the DJ60 also reflected the depression of explosive performance that appeared to occur over the first part of the season as it increased slightly, though nonsignificantly, but then decreased 15.2% during the ballistic training phase. These results show promise for the use of this easily measured performance variable for tracking power performance in athletes, and are similar to our previous findings (19) that contact time, flight time, and flight to contact ratio are indicative of vertical jump ability.

Approach jump and reach height is often considered the gold standard for jump performance in volleyball, and an important outcome of this study was the result that performance in this test was unchanged over the course of what was a quite arduous competition season. As stated earlier, the combination of playing games, skills practice, strength, and conditioning has been reported (13) as causing a meaningful decline in jump performance over the course of the season. The fact that the alteration in resistance training permitted the athletes to recover the performance losses experienced over the first part of the season suggests that the periodization strategy was effective. In previous seasons, the team would have continued with the traditional heavy resistance training program, and this might explain the continuing declines in jump performance to the end of the season, perhaps because of staleness with the lack of variation no longer providing an adequate stimulus.

A range of jump tests and variables derived from them was used in this study to try and determine which aspects of neuromuscular performance are being impacted by the demands of a volleyball season. Clearly, changes in the ability to develop force rapidly, produce high power output, and minimize ground contact time reflect these changes well and explain the shifts in jump and reach performance. Although further research is required, it appears that slow, heavy resistance training with no variation, on top of volleyball playing and practice and continued for more than 5–6 weeks, may be detrimental to jump performance. Perhaps the demands of heavy muscle contractions by the leg extensors or lack of recovery between sessions results in the depression of explosive performance. Alternatively or compounding this effect might be the lack of variation resulting in less than optimal stimulus to the neuromuscular system. However, coaches and athletes must be cautious in regard to the period of time in-season for which traditional heavy resistance exercise is de-emphasized. Häkkinen (13) has reported considerable loss of both strength and explosive jump performance after 5.5 weeks of cessation of such training, so it is clear that some level of maximal strength training must be continued throughout the competitive season.

Other research has found increases in vertical jump height associated with slow traditional resistance training, but these studies have utilized untrained subjects (2). Newton et al. (19) examining these measures in elite athletes, found no increase in vertical jump height with male volleyball players during the preseason when utilizing slow traditional training. Therefore, it seems that more elite subjects, with their longer training history and plyometric background, may need a more unique stimulus in order to elicit gains. One possible explanation for the approach jump and reach height measure being maintained but not increased has been previously observed (12) during in-season competition, and involves the time frame of the training. In the present study, the ballistic training cycle lasted 4 weeks, whereas in other research in which explosive training elicited increases in vertical jump height, the subjects trained for a period of 8 or 22 weeks (12, 19). If the explosive cycle in the present study had been continued for 8 weeks or more, the increases observed from midseason to end of season might have continued, and significantly greater gains might have been realized. Another factor to consider is the phase of training of the athletes. Newton et al. (19) and Fry et al. (10) used subjects not involved in the competitive season, when training volume is typically lower than during the in-season. The increased training and competition volume during the present study may have interfered with any increases in performance. In an experiment involving a group of elite basketball players, explosive power was shown to decrease during the competitive season, and an interfering effect of aerobic activity was suggested as one possible cause (11). This same effect could be another reason that jump height did not increase during the training period.

Although some knowledge can be gained from the present experiment, further research questions remain to be answered. One question to be addressed is the effect of periodization on power training. Although a number of studies have compared periodized programs to 1-set and multi-set nonperiodized programs (1, 16, 20–22) none of these experiments have explored the application of periodization to explosive training and whether this is different than typical strength training programs. The typical linear periodization model includes a beginning cycle of hypertrophy and maximum strength with minimal emphasis on explosive strength, with the idea that a base level of strength needs to be achieved before any explosive training should take place (20). However, it has been demonstrated through a computer model (3) that coordination must be acquired along with strength gain before it translates into improved performance. Therefore, it may be more beneficial to train strength and power simultaneously. Further, as Häkkinen (13) suggests, in order to maintain strength and power during prolonged periods the training stimulus must include both heavy resistance and explosive-type training or otherwise a detraining effect will be observed, resulting in decrements in performance.

Because there were numerous decreases in performance measures associated with traditional resistance training, this is another area that needs to be explored. Does in-season strength training, without an emphasis on fast movement speeds, produce negative neuromuscular adaptations in athletes that are too difficult to overcome in the course of the in-season? It could be theorized that athletes should be made as strong as possible before the season starts, and then a much larger emphasis should be placed on explosive exercises for the duration of the competitive season.

There also remains the question of the appropriate length of the explosive cycle. In the present study, a 4-week cycle was not long enough to produce significant improvement in approach jump and reach height, although experiments with cycle lengths of 8 weeks or more did see improvement. What is the ideal length of the cycle in order to produce maximum results? However, there is also the concern that maximal strength may fall over the season, leading to reduced performance (13) and possibly to higher injury risk, suggesting that a portion of training time should be devoted to maintaining this characteristic as well. Future research should address what the optimal level of strength vs. power training is that is appropriate in-season.

Practical Applications

This study has demonstrated that in-season ballistic training using the load that maximizes power output can improve the performance of elite female athletes in speed related variables. It also appears that a 4-week ballistic training cycle is not sufficient to improve approach jump and reach height of female volleyball players during in-season competition, but that it can maintain start-of-season levels. This information is valuable to strength and conditioning coaches who are trying to improve the performance of their power athletes during the competitive season.

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