Power Development Through Complex Training for The Division I Collegiate Athlete

Courtney A. May, MS, CSCS, NSCA-CPT,[1] Daniel Cipriani, PT, PhD,[2] and Kent A. Lorenz, MS, CSCS, NSCA-CPT[2]
[1]Warfighter Performance Department, Naval Health Research Center, San Diego, California; and [2]School of Exercise and Nutritional Sciences, San Diego State University, San Diego, California

SUMMARY

SPORTS REQUIRING EXPLOSIVE MOVEMENTS REQUIRE POWER PRODUCTION. A STRENGTH AND CONDITIONING PROGRAM SHOULD CONSIST OF EXERCISES THAT WILL PROMOTE POWER DEVELOPMENT IN THE ATHLETE. POWER CAN BE DEFINED AS THE PRODUCT OF A FORCE AND VELOCITY, WHICH CAN BE TRAINED AND INCREASED THROUGH RESISTED AND PLYOMETRIC MOVEMENTS. COMPLEX TRAINING CAN BE USED IN FORCE DEVELOPMENT AND YIELDS AN INCREASE IN POWER. THE PUBLISHED LITERATURE ON COMPLEX TRAINING DOES NOT NECESSARILY REFLECT THE PRACTICES OF COMPLEX TRAINING IN THE WEIGHT ROOM. THIS ARTICLE'S PURPOSE IS TO COMPARE THE SUGGESTIONS FROM THE LITERATURE AND STRENGTH AND CONDITIONING COACHES IN A PRACTICAL SETTING.

INTRODUCTION

Power is an element of athleticism that can assist an athlete with gaining success in a given sport. Lower-body power is beneficial for running, sprinting, swinging, kicking, changing direction, and jumping. Many strength and conditioning coaches use strength training to increase force production within the muscle and, therefore, increase the amount of power that can be produced (4). Training for power is an integral part of a strength and conditioning program. However, at the college level, strength and conditioning coaches have limited amount of time to work with student-athletes because of the bylaws set forth by the National Collegiate Athletics Association (NCAA) (bylaw 17.01.1) (20). Strength and conditioning coaches must work with team coaches to establish an amount of time to be allotted to strength and conditioning during the competitive season and during the off-seasons to remain within the time guidelines. With the amount of time allotted, strength coaches must create the greatest training potential for their athletes by developing the most successful and prudent training program possible. The purpose of this article is to examine the literature that is focused on training for power in the laboratory and examine the practical application of training for power development in the weight room.

WHAT IS POWER?

The definition of mechanical power (P) is the velocity (v) of a force (F), where force is the product of mass and acceleration, expressed mathematically as $P = Fv$ (4). In other words, mechanical power is a factor of both force production and the velocity of the force application. An alternate expression of mechanical power is $P = U/t$, where power is equal to the amount of work (U) achieved over a given period of time (t). In this case, mechanical work, which influences power, is the product of a force and its displacement ($U = Fd$). Thus, power can be developed by myriad of training techniques that elicits a response on the mechanisms used to create power, focusing on such elements as force production and movement speed (i.e., velocity) (21).

MECHANISMS THAT INFLUENCE POWER

Force production and the velocity of movement are influenced by the type of muscle action, namely, concentric and eccentric. A concentric contraction is a muscle action in which the sarcomere will shorten and generate force, whereas an eccentric contraction occurs when the sarcomere elongates because of the opposing force being greater than the force generated by the muscle. During a concentric muscle

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action, faster movements result in less force produced by the muscle because of the fact that the resistance will be reduced to allow for rapid movement. Conversely, when the muscle is experiencing a heavy load, the velocity of the movement will be slower. Eccentric training allows for an increased force (load) and an increased velocity, when compared with concentric actions, during a muscle contraction. The work from the eccentric action creates elasticity within the myosin cross bridges (12). Consequently, using the stretch-shortening cycle (SSC) can increase force production.

Previous research suggests that work output can be maximized when a concentric muscle action follows a muscle or tendon stretch (24). This type of muscle action is commonly referred to as the SSC (24). It is demonstrated in a movement such as a countermovement jump (CMJ). A CMJ is that in which a downward movement into approximately a half squat position precedes a jump. van Ingen Schenau et al. (24) suggest that the downward movement of the CMJ (eccentric phase) may permit the muscle to develop maximal force because of the type of muscle fiber (type II) and rate at which the central nervous system can elicit a signal to the muscle.

Power output is dependent on the velocity and external load placed on the movement. The external load consists of concentric and/or eccentric muscle action. The heavier the load, the slower the movement; by decreasing the load, the movement can be performed at a greater velocity. Therefore, with a concentric movement, there must be a sacrifice of force to produce a greater velocity.

TRAINING TO INCREASE POWER

PLYOMETRICS

Plyometric exercises are those exercises that require an explosive movement that result in an increase in power production (14). Power output has shown to be greater in plyometric exercises that use the SSC as a component of training (18,25). The principle behind plyometric training is to shorten the amortization phase, the part of the plyometric movement between the eccentric and concentric muscle actions (13). This type of training has been promoted as a means of increasing anaerobic power, particularly where lower-body power is a primary component of the activity (14,18).

The rationale for increased power output expressed after plyometric exercise is because of the increase in size of both type I and type II muscle fibers combined with the way in which motor units function (18). Inhibiting an antagonistic muscle coupled with the activation and contraction of synergist muscles may be an important aspect of the power output increases resulting from plyometric training (18). Second, plyometric training may induce changes in the elastic properties of connective tissue and muscle (25). Subsequently, there may be improvements in the reflex potentiation (25) because of the rapid movements associated with plyometric training. Because of the cross-sectional area (CSA) detected in type I and type II muscle fibers, it is thought that the morphology associated with plyometric training may be similar to the morphology associated with resistance training (25).

RESISTANCE TRAINING

Resistance training has been determined to be just as effective, if not more effective for power development, than plyometric training (13). Weightlifting lifts, the clean and the snatch, are aggressive movements (10) that are the most common forms of resistance training associated with increased anaerobic power (4). Strength and conditioning coaches have used weightlifting, the clean and snatch, for many years to help individuals produce more force, change direction, and coordinate muscle contractions (3), and coordinate movements of the upper and lower body (10), which assists athletes with becoming more athletic on the field or court. The greatest amount of force associated with weightlifting is found between the middle to end phase of the second pull (22) (Figure 1).

Weightlifting is used for 2 specific reasons: (a) assist in power production because of the intensity of the movement combined with the resistance and (b) reiterate the triple extension of the hip, knee, and ankle. Triple extension is present in running, sprinting, jumping, and any other movement that requires power.

Indications from studies reveal that multijoint movements of moderate resistance coupled with high velocity yield the greatest power output (3,4,21). However, the load associated with these movements is highly controversial. Carlock et al. (4) found that the greatest power output was achieved with a load of 70–80% of a 1 repetition maximum (1RM) for weightlifting for experienced lifters. However, Thomas et al. (23) found that only 30–60% of 1RM may be needed for hang pulls to elicit peak power. They found that for a resisted movement (i.e., squat jump and bench press), men achieved peak power between 30 and 40% and women achieved peak power between 30 and 50% of 1RM (23). Therefore, a moderate percentage of 1RM can be used in programming for an individual experienced in weightlifting, but a lower percentage should be used for inexperienced athletes.

COMPLEX TRAINING

Complex training is defined as a resisted movement followed by a biomechanically similar plyometric exercise, such as jumping (15,19). Figure 2 illustrates a lower-body complex training combination of exercises consisting of a split squat and a jumping lunge. The theory behind complex training is that the stimulus for the plyometric training will be heightened because of an increased motor neuron excitability from the load placed on the body before the plyometric movement (15). Two major components of muscle force production are the speed of the muscle stretch and the amount of force developed at the end of the stretched

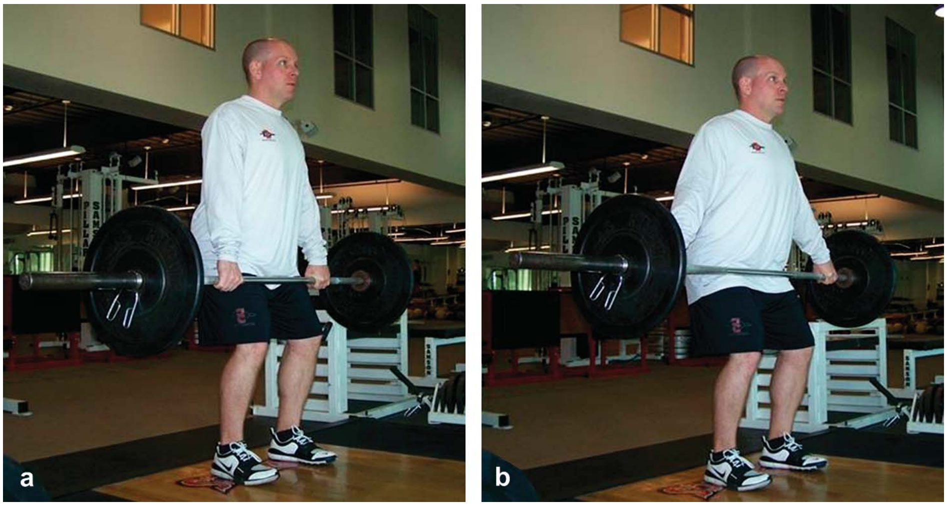

Figure 1. Photographs of the middle to end phase of the second pull of (a) the clean and (b) snatch. The greatest amount of force is associated with the triple extension of the hip, knee, and ankle.

muscle (11). Complex training uses both of these principles and has thus been the focus of many strength and conditioning programs. Complex training can be used for lower-body (Figures 3, 4) and upper-body (Figure 5) power development. Table 1 provides suggestions for lower-body complex training, and Table 2 provides suggestions for upper-body complex training.

The plyometric component of complex training will cause a rapid contraction of the working muscle that increases the speed of the stretch and the force produced. The resistance training component uses the resistance placed on the muscle at various points of a movement to assist in increasing force production at the end of the range of motion. Therefore, the long-term adaptations of training will result in greater power output. The power is created by the increase in muscle fiber

Figure 2. Photographs of the (a) starting positioning of the split squat and (b) ending position of the split squat. This movement is weighted with dumbbells. (c) The plyometric movement begins with the athlete in the similar position to the starting position of the resisted movement. (d) During the ending position of the jumping lunge the athlete has switched the position of his feet in the air after jumping from the starting position.

Figure 3. Photographs of the lower-body complex training combination of a single-leg exercise of a step-up and a box blast. (a) The starting position consists of the athlete placing 1 foot on the box and 1 foot on the ground while holding dumbbells. (b) The athlete will apply force to the box, extending the hip, knee, and ankle and ending with the flexion of the hip, knee, and ankle of the leg with the foot starting on the ground. The height of the box is dependent on the height of the athlete. (c) The starting position of a box blast consists of one foot on the box with the other foot on the ground. (d) By applying force to the box, the athlete propels himself or herself upward and switches feet in the air with the foot that started on the box landing on the ground, and the foot that started on the ground landing on the box.

hypertrophy and the neuromuscular adaptations that occur because of the training (19).

Plyometric training primarily focuses on improving eccentric muscle action, whereas traditional resistance training focuses on concentric muscle action (9). Because eccentric muscle strength is greater than concentric strength, the plyometric movement is performed rapidly, whereas the resisted movement is slower by comparison and function because of the weaker concentric strength. Vissing et al. (25) examined the effect of plyometric and resistance training on muscle adaptations. The subjects were 16 untrained men ranging from 21 to 29 years of age. The 2 training groups included plyometric and resistance training independently, for a 12-week protocol (25). Results of the 12-week protocol indicate an increase in CSA of the whole muscle (measured at midthigh via magnetic resonance imaging) for both the resistance training and plyometric training groups. However, the resistance training group demonstrated significant hypertrophy of type I and IIa muscle fibers, whereas the plyometric group had nonsignificant increases in fiber-specific CSA (25). Both groups experienced similar gains in maximal strength, and the plyometric group saw significant improvements in muscular power. This may provide support for the theory that improvements in power seen with plyometric training are because of enhanced neural recruitment and efficiency and not because of hypertrophy of high-threshold motor units.

When resistance training and plyometric training are combined, the results are controversial. Duthie et al. (8) found that after completing the first set of complex training, consisting of 3RM half squats followed by jump squats, peak power decreased. Between each set of half squat and jump squats, a rest period of 5 minutes was implemented to permit the nervous system to recover (8). The extended rest period will also allow the energy to be restored within the muscle (8). It is maintained that complex training may result in the weakest argument for increasing explosive strength (8), which may be accurate when using complex training as a means of acute power production. When used in practice, complex training may help increase force development that may yield long-term adaptations of increased power output. Additionally, the literature has noted that no significant differences

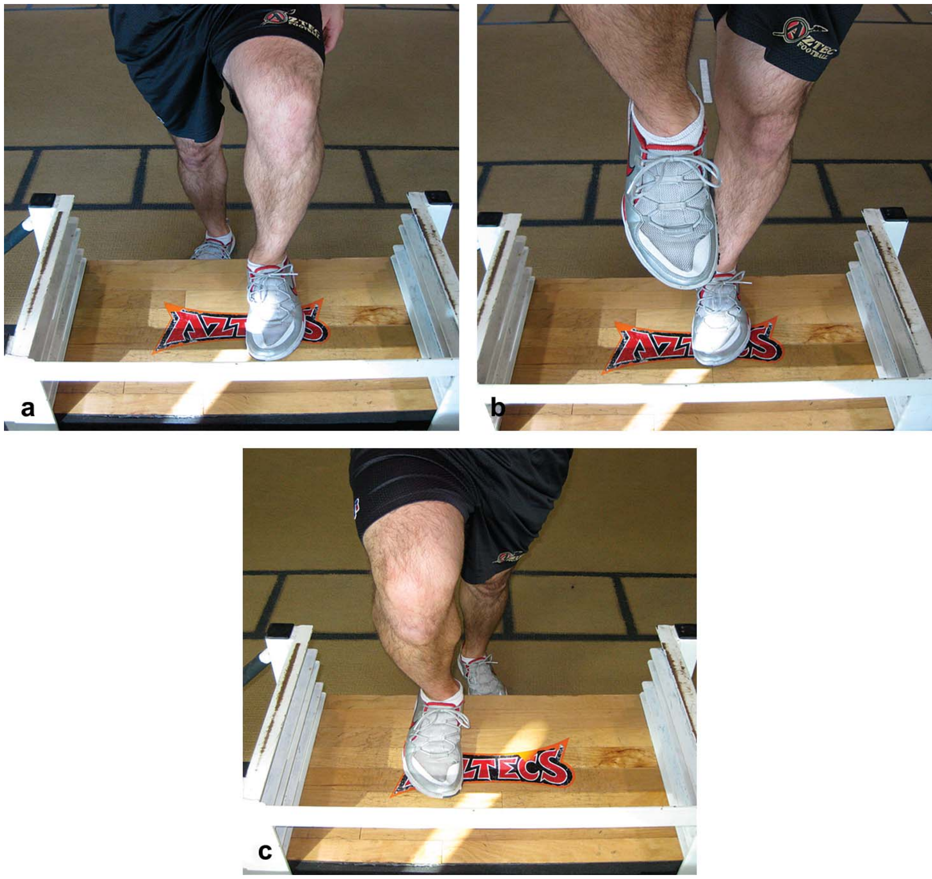

Figure 4. Photographs of the foot positioning of the box blast. (a) The athlete begins with his right foot on the box and his left foot on the ground. Force is applied to the box with the right foot combined with upward arm action, which propels the athlete upward. (b) When propelled upward the athlete's left foot will leave the ground. (c) The athlete switches the positioning of his feet in the air and lands with the right foot on the ground and left foot on the box.

exist between mean or peak ground reaction forces of complex training (9). However, complex training may optimize the desired training effect in 2 ways: (a) causing an increased excitation of motor neurons and (b) causing the nervous system to have a greater involvement (5).

OPTIMAL REST

There has been much debate on what the optimal rest interval should be between the resisted exercise and plyometric exercise. Recent literature proposes that a 4-minute rest period between the resisted movement and the plyometric movement is necessary to produce the greatest amount of power (6,15). Analysis of complex training including a 5RM squat followed by a squat jump or CMJ yielded the greatest ground reaction force (15) and flight time (6), respectively. Alternative rest periods have been examined to determine the optimal rest for the greatest power production. However, a reduction in ground reaction force of the squat jump was observed at 10 seconds and 1, 2, and 3 minutes after 5RM squat (15). Additionally, a reduction in flight time was observed at 30 seconds, 2 minutes, and 6 minutes after 5RM (6). Results indicate that without an ample amount of rest, or too much rest, power production may be decreased. Additionally, Jones and Lees (16) observed no increase in height of a CMJ or drop jump after a 3-, 10-, or 20-minute rest period when following heavy resistance training. Results indicate that there were slight increases in power output before decreasing below the baseline measurements (16).

Recent studies from Bevan et al. (2) and Kilduff et al. (17) suggest that 8-minutes of rest yields significant increases in peak power output (PPO). Furthermore, Kilduff et al. (17) observed significant increases in PPO after 12 minutes of rest. A rest period of 4, 8, or 12 minutes has been observed as the optimal rest period for complex training between the resisted movement and the plyometric movement (2,6,15,17). Results indicate that there were no significant increases in performance after an 8- or 12-minute rest period (17). However, a 2007 study by Dodd and Alvar revealed that there

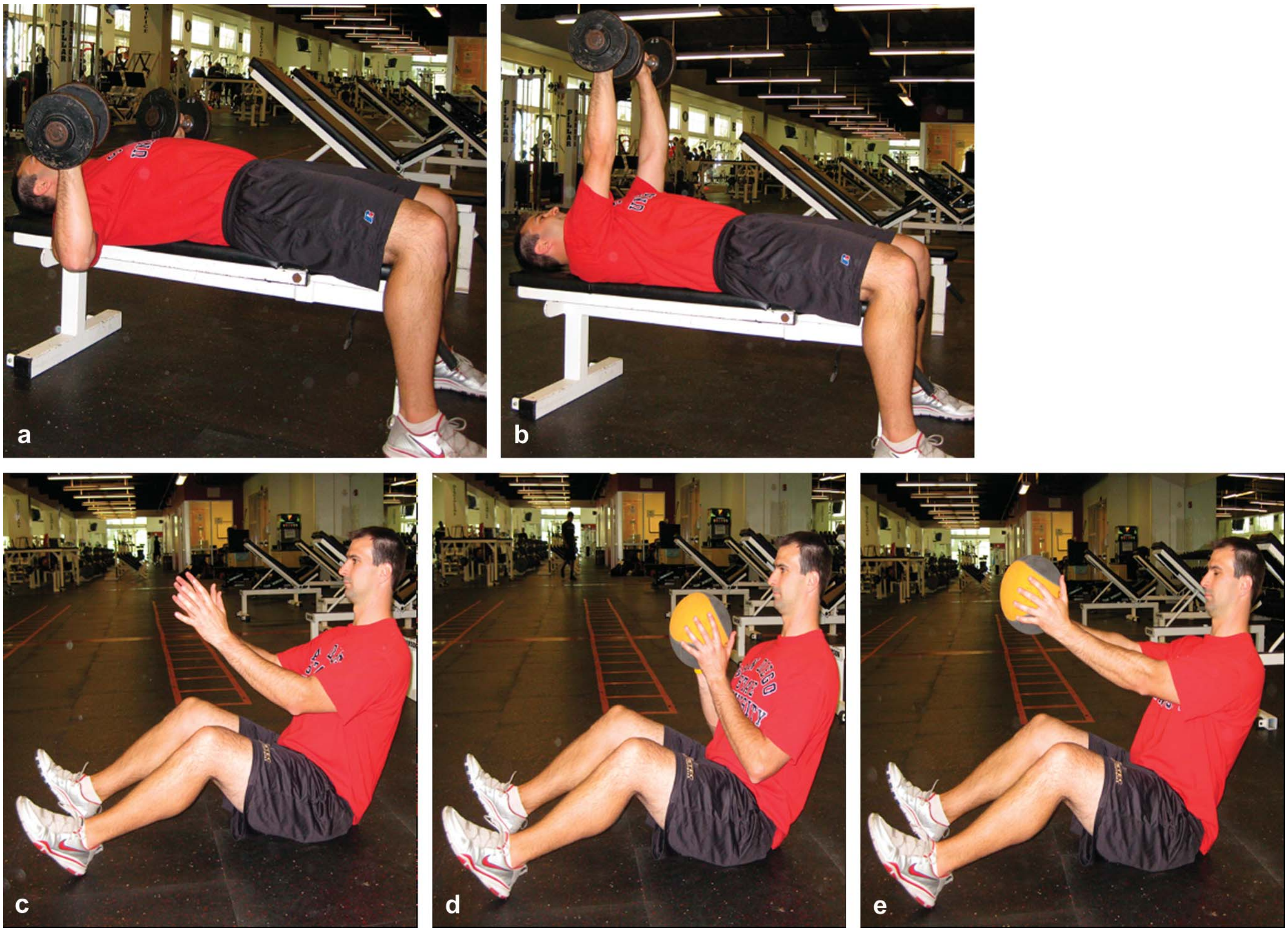

Figure 5. Photographs of the upper-body complex training combination of a dumbbell press and a seated medicine ball chest pass. (a) Starting with the elbows bent and dumbbells around chest level, the athlete will (b) extend his elbows and press the dumbbells over his chest. The seated medicine ball chest pass (c) begins with the athlete sitting with arms extended ready to catch the medicine ball. (d) The medicine ball is caught and brought to the chest. (e) The final phase of the movement consists of the athlete extending his arms while passing the medicine ball back to the person tossing it.

was a greater increase in power and performance percentages for complex training when a rest period of less than 10 seconds was used as opposed to heavy resistance training or plyometric training. A greater amount of rest may provide the working muscles with enough recovery time to replenish the phosphocreatine stores; however, the neural adaptations that are theorized with complex training may not be achieved with a greater amount of rest (7).

Table 1
Suggestions for biomechanically similar lower-body complex training combinations

Resisted movement	Plyometric movement
Squat	Tuck jump
Squat	Box jump
Split squat	Jumping lunges
Step-up	Box blast

Table 2
Suggestions for biomechanically similar upper-body complex training combinations

Resisted movement	Plyometric movement
Bench press	Clapping push-ups
Dumbbell press	Seated MB chest pass

MB = medicine ball.

IMPLEMENTATION OF COMPLEX TRAINING

Complex training is a form of training that can be used throughout the year with the intent to increase power and athletic performance. It may be beneficial to the athlete to use complex training more during certain phases of training. Complex training may be most beneficial to use during the strength-power phase before the competition phase because of the goal of the phase (7). Table 3 represents a linear

Table 3
A general representation of a linear periodization of a strength-power phase using upper- and lower-body complex training

Day	Exercise	Sets	Repetitions	Intensity
Week 1				
Monday	Clean pull	4	3	77%
	Single-leg exercise and lower-body plyos	3	5 each leg	
	Pull-ups	3	8	
	Push-ups	3	8	
	Military press	3	6	
Tuesday	Off			
Wednesday	Squat	4	3	85%
	Hamstring exercise	3	5	
	Bench press and upper-body plyos	4	3	85%
	Renegade row	3	6	
	Biceps and triceps	3	6	
Thursday	Off			
Friday	Power clean and lower-body plyos	4	3	77%
	Single-leg exercise	3	5 each leg	
	Inverted row	3	8	
	Incline dumbbell press	3	8	
	Shoulder combination	3	8 each exercise	
Week 2				
Monday	Clean pull	4	3	80%
	Single-leg exercise and lower-body plyos	3	5 each leg	
	Pull-ups	3	8	
	Push-ups	3	8	
	Military press	3	6	
Tuesday	Off			
Wednesday	Squat	4	3	87%
	Hamstring exercise	3	5	
	Bench press and upper-body plyos	4	3	87%
	Renegade row	3	6	
	Biceps and triceps	3	6	
Thursday	Off			
Friday	Power clean and lower-body plyos	4	3	82%
	Single-leg exercise	3	5 each leg	

Table 3
(continued)

Day	Exercise	Sets	Repetitions	Intensity
	Inverted row	3	8	
	Incline dumbbell press	3	8	
	Shoulder combination	3	8 each exercise	
Week 3				
Monday	Clean pull	4	3	85%
	Single-leg exercise and lower-body plyos	3	5 each leg	
	Pull-ups	3	8	
	Push-ups	3	8	
	Military press	3	6	
Tuesday	Off			
Wednesday	Squat	4	3	90%
	Hamstring exercise	3	5	
	Bench press and upper-body plyos	4	3	
	Renegade row	3	6	
	Biceps and Triceps	3	6	
Thursday	Off			
Friday	Power clean and lower-body plyos	4	3	85%
	Single-leg exercise	3	5	
	Inverted row	3	8	
	Incline dumbbell press	3	8	
	Shoulder combination	3	8 each exercise	
Week 4				
Monday	Clean pull	4	3	90%
	Single-leg exercise and lower-body plyos	3	5 each leg	
	Pull-ups	3	8	
	Push-ups	3	8	
	Military press	3	6	
Tuesday	Off			
Wednesday	Squat	4	3	92%
	Hamstring exercise	3	5	
	Bench press and upper-body plyos	4	3	92%
	Renegade row	3	6	
	Biceps and triceps	3	6	
Thursday	Off			

(continued)

Table 3 (continued)				
Day	Exercise	Sets	Repetitions	Intensity
Friday	Power clean and lower-body plyos	4	3	90%
	Single-leg exercise	3	5	
	Inverted row	3	8	
	Incline dumbbell press	3	8	
	Shoulder combination	3	8 each exercise	
Week 5				
Monday	Clean pull	4	3	77%
	Single-leg exercise and lower-body plyos	3	5 each leg	
	Pull-ups	3	8	
	Push-ups	3	8	
	Military press	3	6	
Tuesday	Off			
Wednesday	Squat	4	3	80%
	Hamstring exercise	3	5	
	Bench press and upper-body plyos	4	3	80%
	Renegade row	3	6	
	Biceps and triceps	3	6	
Thursday	Off			
Friday	Power clean and lower-body plyos	4	3	77%
	Single-leg exercise	3	5 each leg	
	Inverted row	3	8	
	Incline dumbbell press	3	8	
	Shoulder combination	3	8	

Plyos = plyometrics; shoulder combination = front raise, side raise, and bent raise in succession.

periodization using complex training, whereas Table 4 represents an undulating periodization.

The suggested loading parameters of complex training are greater than 80% for the resisted movement and less than 30% for the plyometric movement (7). Given the guidelines of writing a periodization for the strength-power phase, a set and repetition scheme of 3–5 sets and 2–5 repetitions are recommended because of the intensity of the training phase (1).

PRACTICAL APPLICATION OF TRAINING FOR POWER

The evidence presented suggests that the optimal rest period for complex training between the resisted movement and the plyometric movement is 4, 8, or 12 minutes (2,6,15,17). However, this is not always practical for strength and conditioning coaches. According to bylaw 17.01.1 of the NCAA Division I manual for the academic year of 2008 through 2009, a college or university must limit the amount of time student-athletes participate in sports-related events to prevent hindrance of progress in academics. A sports-related event includes that which includes "any required activity with an athletics purpose involving student-athletes and at the direction of, or supervised by one or more of an institution's coaching staff (including strength and conditioning coaches)…" (bylaw 17.02.1) (20). Furthermore, when an athlete is in his or her given season of competition,

Table 4
A general representation of an undulating (nonlinear) periodization of a strength-power phase using upper- and lower-body complex training

Day	Exercise	Sets	Repetitions	Intensity
Week 1				
Monday	Clean pull	4	4, 3, 3, 2	72, 75, 77, 80%
	Single-leg exercise and lower-body plyos	3	5 each leg	
	Pull-ups	3	8	
	Push-ups	3	8	
	Military press	3	6	
Tuesday	Off			
Wednesday	Squat	4	4, 3, 3, 2	80, 85, 85, 87%
	Hamstring exercise	3	5	
	Bench press and upper-body plyos	4	4, 3, 3, 2	80, 85, 85, 87%
	Renegade row	3	6	
	Biceps and triceps	3	6	
Thursday	Off			
Friday	Power clean and lower-body plyos	4	4, 3, 3, 2	72, 75, 77, 80%
	Single-leg exercise	3	5 each leg	
	Inverted row	3	8	
	Incline dumbbell press	3	8	
	Shoulder combination	3	8 each exercise	
Week 2				
Monday	Clean pull	4	4, 3, 2, 2	75, 77, 80, 82%
	Single-leg exercise and lower-body plyos	3	5 each leg	
	Pull-ups	3	8	
	Push-ups	3	8	
	Military press	3	6	
Tuesday	Off			
Wednesday	Squat	4	4, 3, 2, 2	85, 87, 90, 90%
	Hamstring exercise	3	5	
	Bench press and upper-body plyos	4	4, 3, 2, 2	85, 87, 90, 92%
	Renegade row	3	6	
	Biceps and triceps	3	6	
Thursday	Off			
Friday	Power clean and lower-body plyos	4	4, 3, 2, 2	75, 77, 80, 82%
	Single-leg exercise	3	5 each leg	

(continued)

Table 4
(continued)

Day	Exercise	Sets	Repetitions	Intensity
	Inverted row	3	8	
	Incline dumbbell press	3	8	
	Shoulder combination	3	8 each exercise	
Week 3				
Monday	Clean pull	3	4, 3, 3	80, 82, 85%
	Single-leg exercise and lower-body plyos	3	5 each leg	
	Pull-ups	3	8	
	Push-ups	3	8	
	Military press	3	6	
Tuesday	Off			
Wednesday	Squat	3	4, 3, 3	87, 90, 92%
	Hamstring exercise	3	5	
	Bench press and upper-body plyos	3	4, 3, 3	87, 90, 92%
	Renegade row	3	6	
	Biceps and triceps	3	6	
Thursday	Off			
Friday	Power clean and lower-body plyos	3	4, 3, 3	80, 82, 85%
	Single-leg exercise	3	5	
	Inverted row	3	8	
	Incline dumbbell press	3	8	
	Shoulder combination	3	8 each exercise	
Week 4				
Monday	Clean pull	3	3, 3, 2	85, 87, 90%
	Single-leg exercise and lower-body plyos	3	5 each leg	
	Pull-ups	3	8	
	Push-ups	3	8	
	Military press	3	6	
Tuesday	Off			
Wednesday	Squat	3	3, 3, 2	90, 92, 95%
	Hamstring exercise	3	5	
	Bench press and upper-body plyos	3	3, 3, 2	90, 92, 95%
	Renegade row	3	6	
	Biceps and Triceps	3	6	
Thursday	Off			

Table 4 (continued)				
Day	**Exercise**	**Sets**	**Repetitions**	**Intensity**
Friday	Power clean and lower-body plyos	3	3, 3, 2	85, 87, 90%
	Single-leg exercise	3	5	
	Inverted row	3	8	
	Incline dumbbell press	3	8	
	Shoulder combination	3	8 each exercise	
Week 5				
Monday	Clean pull	4	4, 4, 3, 3	75, 75, 77, 80%
	Single-leg exercise and lower-body plyos	3	5 each leg	
	Pull-ups	3	8	
	Push-ups	3	8	
	Military press	3	6	
Tuesday	Off			
Wednesday	Squat	4	4, 4, 3, 3	77, 77, 80, 82%
	Hamstring exercise	3	5	
	Bench press and upper-body plyos	4	4, 4, 3, 3	77, 77, 80, 82%
	Renegade row	3	6	
	Biceps and triceps	3	6	
Thursday	Off			
Friday	Power clean and lower-body plyos	4	4, 4, 3, 3	75, 75, 77, 80%
	Single-leg exercise	3	5 each leg	
	Inverted row	3	8	
	Incline dumbbell press	3	8	
	Shoulder combination	3	8	

Plyos = plyometrics; shoulder combination = front raise, side raise, and bent raise in succession.

a 4-hour maximum is placed on athletic-related activities for each day and a 20-hour maximum for the week (bylaw 17.1.6.1) (20). When out of season, student-athletes are allowed to engage in "required weight training, conditioning, and skill-related instruction" with a maximum of 8 hours per week including 2 that are devoted to skill development (bylaw 17.1.6.2(a)) (20). Additionally, football players are permitted a maximum of 8 hours per week for the aforementioned activities; however, viewing film may not last more than 2 hours per week (bylaw 17.1.6.2(b,c)) (20). Given the guidelines of the NCAA, strength coaches have approximately 60–90 minutes to conduct a strength and conditioning workout depending on where the team is in relation to its competitive season. If a rest time of 4 minutes is used between the resisted movement and the plyometric movement of complex training, there may not be time for the auxiliary lifts. For example, if 3 sets of complex training involving 5 repetitions of squat jumps follow a 4-minute rest period after 5 repetitions of squats are completed, that takes approximately 14.5 minutes to complete the 3 sets (assuming a squat repetition requires 5 seconds, totaling 25 seconds per set, and the plyometric movement requires 5 seconds because of resetting to the proper position, totaling 25 seconds per set). If a strength coach has only 60 minutes to work with a team, 3 sets of complex training will require approximately 25% of the time allotted to the workout.

Simply stated, collegiate strength and conditioning coaches have a limited amount of time with student-athletes. Workouts must be precise and allow athletes to gain as much as he or she can from each exercise. In an interview with 9 current NCAA Division I collegiate strength and conditioning coaches, the corroborating focus of complex training is to increase force development rather than to obtain PPO. When the athlete works in a fatigued state, such as in complex training with little rest, it may assist in increasing the rate of force development where the end result may be an athlete with greater explosive strength. The coaches attributed this adaptation to recruitment of additional muscles fibers because of muscle fatigue and neural activation. The literature states that there may be a decrease in power output if ample rest is not provided between the strength movement and explosive movement (2,6,15,17). It has been conceded that the athletes may not gain the power output from a fatigued state that they would gain from a nonfatigued state; however, the athlete may experience strength gains, which may later facilitate greater power output because of the recruitment of subsequent muscle fibers. Additionally, working in a fatigued state may prepare the athlete for play during which he or she may be fatigued during the later stages of a game or match. Working in a fatigued state may help the athlete work on mental toughness as well. Furthermore, discussion with numerous strength and conditioning coaches reveals that complex training is usually used during specific points of the year. It is primarily used during the strength-power phase of training before the power training phase but can be implemented in a more time-restricted phase, such as in-season, for maintaining the gains from the strength-power phase. Table 5 provides a sample 45-minute in-season workout for a skill position football player (i.e., defensive back, wide receiver, running back) using complex training.

The focal point of the literature is based on PPO with an unlimited amount of time spent on each exercise. As previously mentioned a longer rest period may increase PPO, but it does not suggest increases in performance, which is the goal of a strength and conditioning program. Realistically, strength and conditioning coaches must create the most parsimonious program that will yield the greatest training effect. Unfortunately, an optimal training situation is not always feasible; therefore, a modified complex training program may increase an athlete's performance. A more conventional complex training regimen may be useful during a phase in the year when the coaches have more time in the weight room, such as the off-season, where a greater rest period can be used between the resisted movement and the explosive movement.

To the authors' knowledge, there are no studies examining the number of sets that will generate the greatest training effect. A suggestion for future research is to determine the number of sets needed to create optimal power production during a restricted amount of time.

CONCLUSION

Lower-body power is an important component of athletic performance, and there are multiple methods used for development, including plyometrics, resistance training, and complex training. The goal of these training methods is to increase power production through a decrease in the amortization phase and an increase in concentric contraction velocities. The scientific literature reports that the optimal rest time during complex training is 4 minutes between resistance and plyometric movements; however, this may not be practical because of limited training time. Therefore, practitioners are encouraged to experiment with rest periods, loading parameters, volume, and progressions

Table 5
Sample 45-minute workout for an in-season skill position (defensive back, wide receiver, running back) football

	Time	Exercise	Sets/Reps
Dynamic warm-up	8 min	Major muscle groups	
Abs	7 min		
Lift	25 min		
	5 s/rep, 120-s rest between sets	SQ and jump to box	3 × 5 × 5
	40 s/set, 60-s rest	Single-leg RDL	2 × 5 each leg
	5 s/rep, 120-s rest between sets	BP and seated MB chest pass	3 × 5 × 5
	40 s/set, 60-s rest	Shoulder combination	3 × 8 each
Static stretch	5 min	Major muscle groups	

SQ = squat; RDL = Romanian deadlift; BP = bench press; MB = medicine ball; shoulder combination = front raise, side raise, and bent raise in succession; reps = repetitions; sec = seconds.

in protocols that they feel are effective for optimal performance for their athletes.

Courtney A. May *is a research scientist at the Naval Health Research Center.*

Daniel Cipriani *is an associate professor in Biomechanics in the Department of Exercise and Nutritional Sciences at San Diego State University.*

Kent A. Lorenz *is an exercise physiologist in the Department of Exercise and Nutritional Sciences at San Diego State University.*

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