

Applying Biomechanics in Strength and Conditioning

Strength and conditioning is a profession in which a great deal of biomechanical research has been conducted recently. The National Strength and Conditioning Association (NSCA) is the leading professional strength and conditioning association in the world, and their journals—*Strength and Conditioning Journal* and *Journal of Strength and Conditioning Research*—have been receptive to articles on the biomechanics of exercise. Traditionally, strength and conditioning careers were limited to coaching the physically gifted in intercollegiate athletics. However, more and more opportunities exist for personal training with a wide variety of clients in the private sector.

Strength coaches and personal trainers are responsible for prescribing exercises that benefit their clients. On the surface this may seem a simple task, but in reality it is quite complicated. Exercises must be selected and exercise technique monitored. Exercises must be relevant, and the intensity must be sufficient for a training response but not too great as to cause overtraining or a high risk of injury. Biomechanics helps strength and conditioning professionals to assess these risk:benefit ratios, determine the most appropriate (sport-specific) exercises, and evaluate technique during training. As in teaching and coaching, biomechanical knowledge is important for the strength and conditioning professional so they can coordinate their efforts with sports medicine professionals.

QUALITATIVE ANALYSIS OF SQUAT TECHNIQUE

One of the most common and important exercises in athletic conditioning is the parallel squat. The squat is a functional exercise used for a wide variety of sports and other fitness objectives. The squat is usually performed as a free-weight exercise, making movement technique critical to overloading the target muscle groups and minimizing the risk of injury. Exacting technique in free-weight exercises is necessary because small variations allow other muscles to contribute to the lift, diminishing overload of the muscles or movements of interest. What are the main technique points of the squat often emphasized by strength and conditioning experts? Which biomechanical principles are most strongly related to those technique points?

Table 11.1 presents some of the typical technique points and cues for the parallel or front squat. Evaluate the strengths and weaknesses in the biomechanical principles related to the eccentric phase of the squat illustrated in Figure 11.1. Again, assume the lifter has performed a couple of repetitions this way and you are confident you can identify stable strengths and weaknesses in application of the principles.

The lifter depicted in Figure 11.1 has very good squat technique, so there are virtually no weaknesses in application of biomechanical principles. His stance width

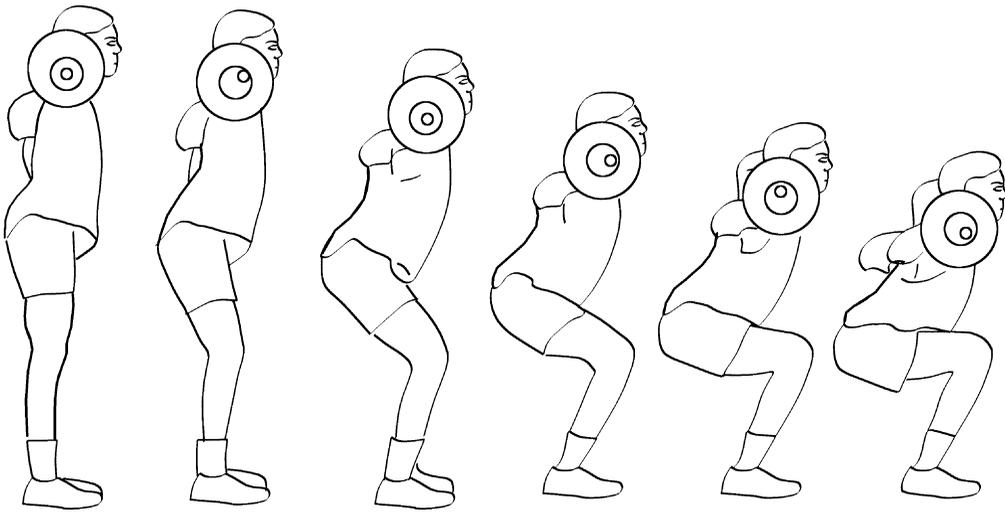


Figure 11.1. The eccentric phase of a person doing a squat. Time between images is 0.2 seconds.

Table 11.1
TECHNIQUE POINTS AND CUES FOR THE SQUAT

Technique points	Possible intervention cues
Stance	Athletic position
Extended/neural spine	Slight arch
Slow, smooth movement	Slow and smooth
Keep thighs above horizontal	Thighs parallel to the ground

is appropriate, and there is no indication of difficulties in terms of control of the body or the bar (Balance). The images suggest that the motion was smooth, with simultaneous coordination. The timing information in the caption indicates the squat was slow, maximizing the time the muscles were stressed (Force–Time Principle). This lifter also keeps his spine straight with normal lordosis, so the spinal loads are primarily compression and are evenly applied across the disks. This more axial loading be-

tween the spinal segments is safest for the spine. Recent research has shown that spinal flexion reduces the extensor muscle component of force resisting anterior shear in the spine (McGill, Hughson, & Parks, 2000), making it more difficult for the muscles to stabilize the spine. Strength and conditioning coaches would also need to be familiar with research on the effect of weight belts in squats and other heavy lifting exercises.

Our lifter completed this exercise with the appropriate full Range of Motion, while not hyperflexing the knee. There is good trunk lean, which distributes the load on both the hip and knee extensors. The amount of trunk lean (hip flexion) in a squat is the primary factor in determining the distribution of joint moments that contribute to the exercise (Escamilla, 2001; Hay, Andrews, Vaughan, & Ueya, 1983; McLaughlin, Lardner, & Dillman, 1978). The more upright posture in the front squat decreases the hip and lumbar extensor torques, while increasing the knee extensor torques required in the exercise.

A large part of the strength and conditioning professional's job is motivating and monitoring athletes. The coach needs to look for clues to the athlete's effort or a change in their ability to continue training. Some of these judgments involve application of biomechanical principles. How an athlete's Balance changes over a practice or several sets of an exercise could give a strength coach clues about fatigue. Since the figure and introduction give no clues to this aspect of performance, the best intervention in this situation is to praise the good technique of the athlete and possibly provide encouragement to motivate them.

Strength and conditioning professionals also must integrate sport-specific training with other practice and competition. The next example will focus on the sport-specificity of a plyometric training exercise.

QUALITATIVE ANALYSIS OF DROP JUMPS

Plyometrics are common exercises for improving speed and muscular power movements in athletes. Plyometric exercises use weights, medicine balls, and falls to exaggerate stretch-shortening-cycle muscle actions. Considerable research has focused on drop jumps as a lower-body plyometric exercise for improving jumping ability (Bobbert, 1990). Recent research has shown that drop jump exercise programs can increase bone density in children (Fuchs, Bauer, & Snow, 2001). Qualitative analysis of drop jumps is important in reducing the risk of injury in these exercises and monitoring technique that has been observed to vary between subjects (Bobbert *et al.*, 1986). Qualitative analysis is also important because drop jumping and resistance training can affect the technique used in various jumping movements (Hunter & Marshall, 2002). Table 11.2 presents important technique points and cues for drop jumps.

Table 11.2
TECHNIQUE POINTS AND CUES FOR DROP JUMPS

Technique points	Possible intervention cues
Landing position	Toe-heel landing
Rapid rebound	Quick bounce
Minimize counter-movement	Range of motion
Arm integration	Arms down and up

What are the strengths and weaknesses in the drop jump performance illustrated in Figure 11.2?

The athlete doing the drop jump illustrated in Figure 11.2 has several good technique points, and possibly one weakness. The strong points of her technique are good lower-extremity positioning before touchdown, moderate countermovement, and a nearly vertical takeoff. This indicates good Balance during the exercise. It is difficult to evaluate the speed or quickness of the performance from the drawings with no temporal information in the caption. This athlete did have a short eccentric phase with a quick reversal into the concentric phase. Occasionally subjects will have a longer eccentric phase that minimizes the stretch-shortening-cycle effect of drop jumps (Bobbert *et al.*, 1986). The Force-Time Principle applied to plyometric exercises explains why large forces and high rates of force development are created over the short time of force application in plyometrics.

The obvious weakness is not using her arms in the exercise. Most athletes should strive to utilize an arm swing with coordination similar to jumping or the specific event for which they are training. If the arms are accelerated downward as the athlete lands, this will decrease eccentric loading of the lower extremities. For jump-specific training, cue the athletes to swing their arms downward in the drop so the arms are

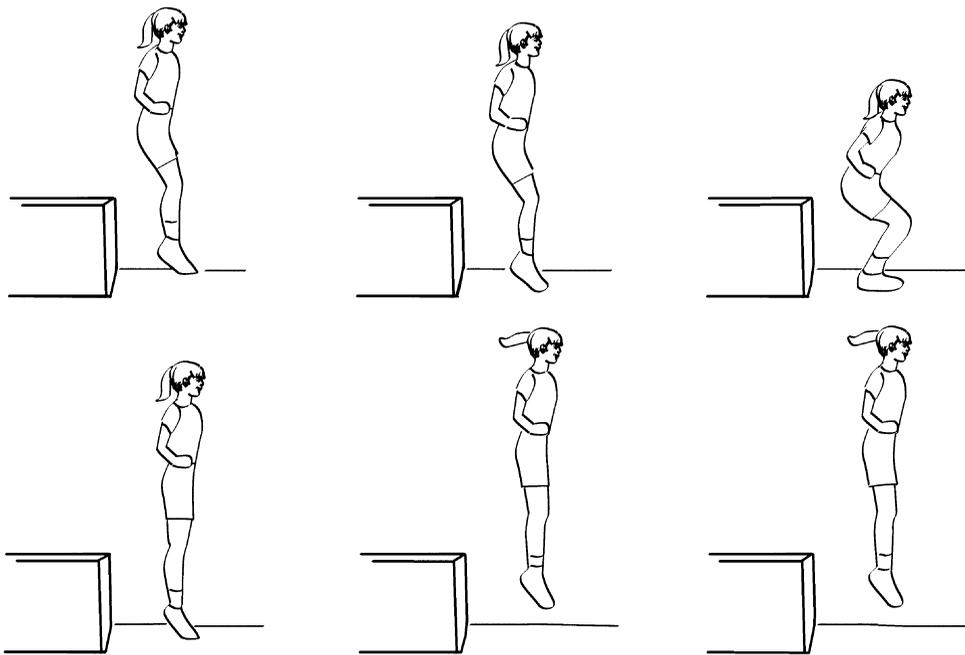


Figure 11.2. An athlete doing a drop jump exercise.

swinging behind them during the loading phase, increasing the intensity of eccentric loading of the lower extremities. The vigorous forward and upward swing of the arms from this position increases the vertical ground-reaction force through segmental interaction (Feltner *et al.*, 1999). The cue “arms down and up” could be used to remind an athlete of the technique points she should be focusing on in the following repetitions. A key conditioning principle is that the exercises selected for training should closely match the training objectives or movement that is to be improved. This matching of the exercise conditions to performance conditions is the conditioning principle of specificity. Exercise specificity will also be examined in the next example.

EXERCISE SPECIFICITY

In the past, exercise specificity was often based on a functional anatomical analysis

(chapter 3) of the movement of interest. Exercises were selected that supposedly trained the muscles hypothesized to contribute to the movement. We saw in chapters 3 and 4 that biomechanics research has demonstrated that this approach to identifying muscle actions often results in incorrect assumptions. This makes biomechanical research on exercise critical to the strength and conditioning field. The strength and conditioning professional can also subjectively compare the principles of biomechanics in the exercise and the movement of interest to examine the potential specificity of training.

Suppose you are a strength and conditioning coach working with the track and field coach at your university to develop a training program for javelin throwers. You search SportDiscus for biomechanical research on the javelin throw and the conditioning literature related to overarm throwing patterns. What biomechanical princi-

ples are most relevant to helping you qualitatively analyze the javelin throw? The technique of a javelin throwing drill is illustrated in Figure 11.3. These principles would then be useful for examining potential exercises that would provide specificity for javelin throwers. Let's see how the principles of biomechanics can help you decide which exercise to emphasize more in the conditioning program: the bench press or pullovers. We will be limiting our discussion to technique specificity.

The principles most relevant to the javelin throw are Optimal Projection, Inertia, Range of Motion, Force–Motion, Force–Time, Segmental Interaction, and Coordination Continuum. Athletes throw the javelin by generating linear momentum (using Inertia) with an approach that is transferred up the body in a sequential

overarm throwing pattern. These principles can be used in the qualitative analysis of the throwing performances of the athletes by coaches, while the strength and conditioning professional is interested in training to improve performance and prevent injury. The fast approach (Range of Motion) and foul line rules make the event very hard on the support limb, which must stop and transfer the forward momentum to the trunk (Morriss, Bartlett, & Navarro, 2001). This Segmental Interaction using energy from the whole body focuses large forces (Force–Motion) in the upper extremity. The size and weight of the javelin also contribute to the high stresses on the shoulder and elbow joints. While some elastic cord exercises could be designed to train the athlete to push in the direction of the throw (Optimal Projection), this section will focus

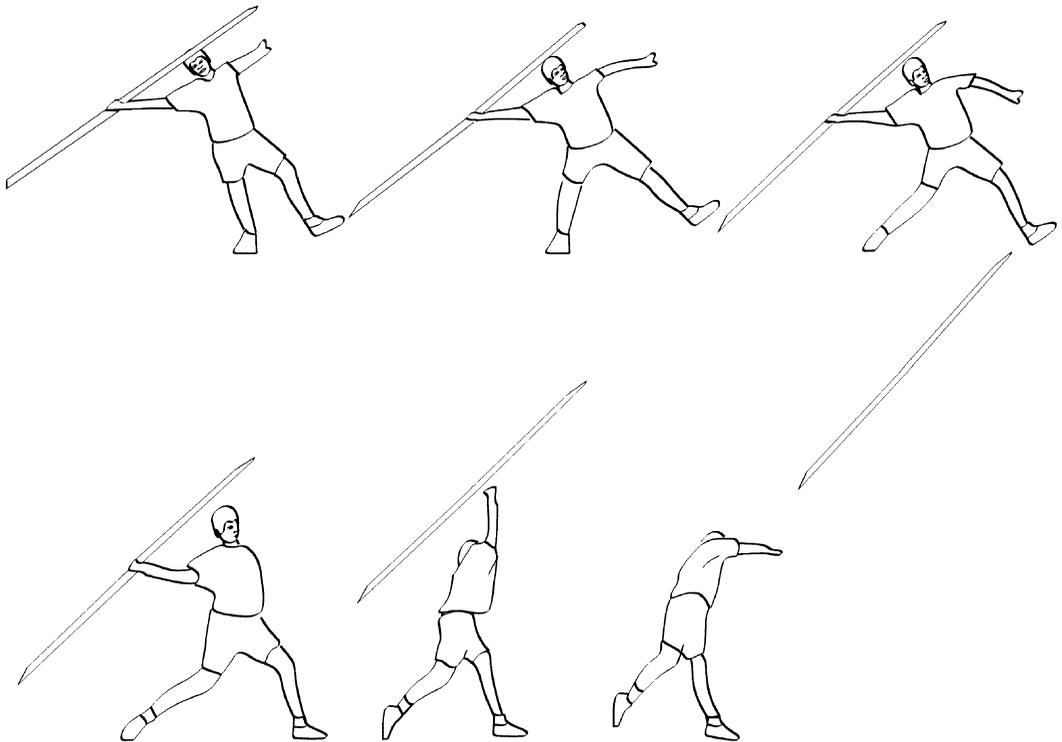


Figure 11.3. Typical technique for the javelin throw drill.

on the specificity of two exercises: the bench press and pullovers. Space does not permit a discussion of other specificity issues, like eccentric training for the plant foot or training for trunk stability.

For specificity of training, the exercises prescribed should match these principles and focus on muscles that contribute (Force–Motion) to the joint motions (Range of Motion), and those which might help stabilize the body to prevent injury. While much of the energy to throw a javelin is transferred up the trunk and upper arm, a major contributor to shoulder horizontal adduction in overarm patterns is likely to be the pectoralis major of the throwing arm. The question then becomes: which exercises most closely match Range of Motion and Coordination in the javelin throw? Matching the speed of movement and determining appropriate resistances are also specificity issues that biomechanics would help inform.

Biomechanical research on the javelin can then help select the exercise and customize it to match pectoralis major function during the event. EMG and kinetic studies can be used to document the temporal location and size of muscular demands. Kinematic research help identify the shoulder range and speed of shoulder motion in the javelin throw. A good strength and conditioning coach would review this research on the javelin throw with the track coach (Bartlett & Best, 1988; Bartlett *et al.*, 1996).

If the bench press and pullover exercise techniques remain in their traditional (supine) body position and joint ranges of motion, the bench press may provide the most activity-specific training for the javelin throw. The bench press typically has the shoulder in 90° of abduction, matching its position in the javelin throw. The bench press could be performed (assuming adequate spotting and safety equipment) with a fast speed to mimic the SSC of the javelin throw. This would also mimic the muscle

actions and rate of force development (Force–Time). Even greater sport specificity may be achieved by using plyometric bench presses with medicine balls. The plyometric power system (Wilson *et al.*, 1993) is a specialized piece of equipment that would also allow for dynamic bench press throws.

Pullovers often have greater shoulder abduction that is unlike the range of motion in the event. Pullovers also have a range of motion that requires greater scapular upward rotation and shoulder extension, which tends to compress the supraspinatus below the acromion process of the scapula. Athletes in repetitive overarm sports often suffer from this impingement syndrome, so pullovers may be a less safe training exercise than the bench press.

The other training goal that is also related to movement specificity is prevention of injury. What muscles appear to play more isometric roles in stabilizing the lower extremity, the shoulder, and elbow? What research aside from javelin studies could be used to prescribe exercises that stabilize vulnerable joints? What muscles are likely to have eccentric actions to “put on the brakes” after release? What exercises or movements are best for training to reduce the risk of injury? Why might training the latissimus dorsi potentially contribute to the performance and injury prevention goals of training for the javelin throw?

INJURY RISK

Imagine you are a strength coach at a junior college. You closely watch many of the young men in your preseason conditioning program because they have had little serious weight training in their high schools, and others may be pushing themselves too hard to meet team strength standards to qualify for competition. Suppose you see a player performing the bench press using

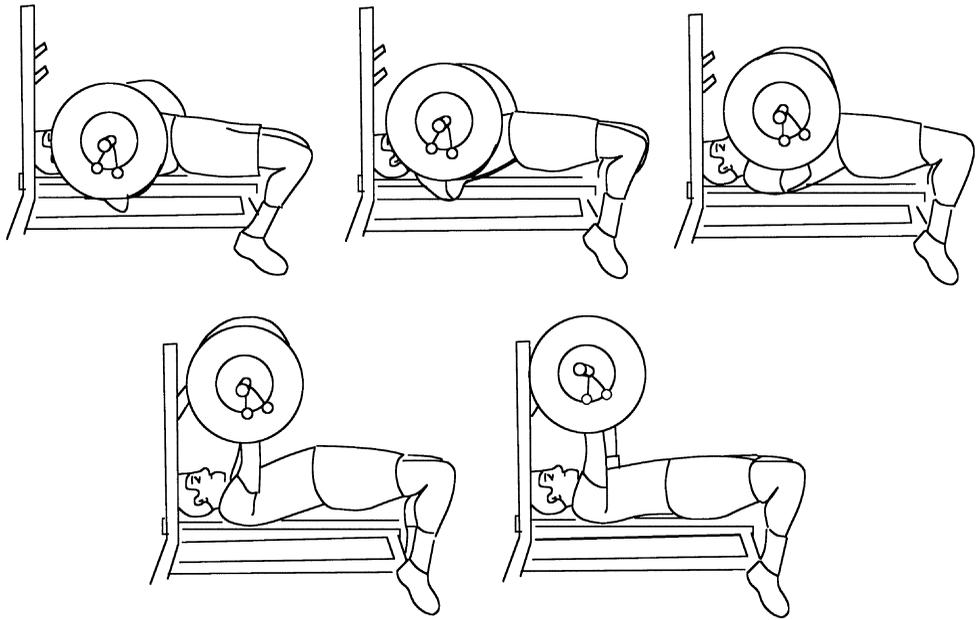


Figure 11.4. The concentric phase of a bench press from an athlete struggling to make a weight goal.

the technique illustrated in Figure 11.4. What are the strengths and weaknesses of performance? How would you diagnosis this performance and what intervention would you use?

The biomechanical principles relevant to the bench press are Balance, Coordination Continuum, Force–Time, and Range of Motion. When training for strength, resistance is high, the athlete must have good control of the weight (Balance), and coordination during the lift will be simultaneous. The force–time profile of strength training attempts to maintain large forces applied to the bar through as much of the range of motion as possible. The SSC nature of the movement should be minimized. This keeps the movement slow and force output near the weight of the bar. High initial forces applied to the ball results in lower forces applied to the bar later in the range of motion (Elliott *et al.*, 1989). The principle of Range of Motion in strength training tends

toward one of two extremes. First, minimize the range of motion of joints that do not contribute to the movement and of those that allow other muscles to contribute to the movement. Second, the range of motion for joint movements or muscles that are targeted by the exercise should be maximized.

The two principles most strongly related to exercise safety in the bench press are Balance and Range of Motion. Athletes must control the weight of the bar at all times, and a lack of control will affect the range of motion used in the exercise. The athlete in Figure 11.3 shows weaknesses in both balance and range of motion. Since the athlete is struggling to “make weight,” the difference in strength between the sides of the body manifests as uneven motion of the bar and poor balance. The athlete also hyperextended his lumbar spine in straining to lift the weight.

Several aspects of this performance may have a strength coach thinking about a

risk of immediate and future injury: lateral strength imbalance, poor control of bar motion, and hyperextension of the lumbar spine. Since the athlete is “maxing-out,” some of these weaknesses can be expected, but safety is the greatest concern. Spotters can assist lifters with poor bar control, or who can complete the lift with only one side of their body. Hyperextension of the spine, however, is an immediate risk to the athlete's low-back health. Hyperextension of the lumbar spine under loading is dangerous because of uneven pressures on the intervertebral disks and greater load bearing on the facet joints. The best intervention here is to terminate the lift with assistance from a spotter and return to lifting only when the athlete maintains a neutral and supported spinal posture on the bench. Here the immediate risk of injury is more important than balance, skill in the exercise, or passing a screening test.

EQUIPMENT

Equipment can have quite a marked influence on the training effect of an exercise. Exercise machines, “preacher” benches, and “Smith” machines are all examples how equipment modifies the training stimulus of weight-training exercises. Strength and conditioning catalogues are full of specialized equipment and training aids; unfortunately, most of these devices have not been biomechanically studied to determine their safety and effectiveness. Garhammer (1989) provides a good summary of the major kinds of resistance exercise machines in his review of the biomechanics of weight training.

Let's revisit the squat exercise using one of these training devices. This device is a platform that stabilizes the feet and lower legs. A person performing the eccentric phase of a front squat with this device is depicted in Figure 11.5. Compare the squat

technique of this subject with the technique in the traditional squat (Figure 11.1). What biomechanical principles are affected most by the use of this device?

Inspection of Figure 11.5 shows that there are several Range-of-Motion differences between the two squat exercises. Squatting with the device results in less knee flexion and ankle dorsiflexion. Note how the lower leg remains nearly vertical, and how the center of mass of the athlete/bar is shifted farther backward in this squat. There does not appear to be any obvious differences in trunk lean between the two devices with these performers. What do you think are the training implications for these small differences? Which body position at the end of the eccentric phase seems to be more specific to football, skiing, or volleyball: this or the front squat?

Using the device makes balancing easier, although it puts the line of gravity of the body/bar well behind the feet. The larger base of support and Inertia (body and stand) stabilizes the exerciser in the squat. It is not possible to compare the kinetics of the two exercises from qualitative analysis of the movements, but it is likely there are differences in the loading of the legs and back (Segmental Interaction). What joints do you think are most affected (think about the moment arm for various body segment and shearing forces in the knee)? What kinds of biomechanical studies would you like to see if you were advising the company on improving the device?

SUMMARY

Strength and conditioning professionals use the principles of biomechanics to qualitatively analyze the technique of exercises, evaluate the appropriateness of exercises, and reduce the risk of injury from dangerous exercise technique. Qualitative analysis of several free weight exercises was pre-

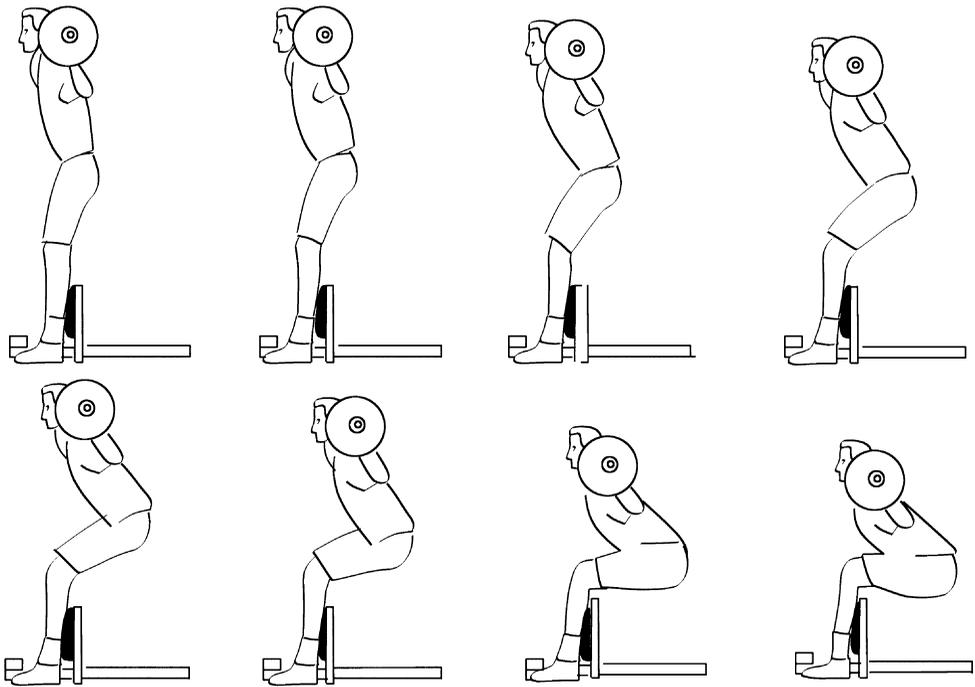


Figure 11.5. The eccentric phase of a person doing a squat using a foot and leg stabilizing stand.

sented, and we examined the biomechanical principles in the qualitative analysis of exercises machines. Strength and conditioning professionals also must integrate physiological and psychological knowledge with biomechanical principles to maximize client improvement. Since strength training utilizes loads closer to the ultimate mechanical strength of tissues, professionals need to keep safety and exacting exercise technique in mind.

DISCUSSION QUESTIONS

1. The squat and various leg-press exercise stations are often used interchangeably. What biomechanical principles are more important in the squat than in the leg press, and how would you educate lifters who think that the exercises do the same thing?

2. An athlete back in the weight room after initial rehabilitation from an injury is apprehensive about resuming their conditioning program. What biomechanical principles can be modified in adapting exercises for this athlete? Suggest specific exercises and modifications.

3. What aspect of exercise specificity (muscles activated or joint motions) do you think is most important in training for sports? Why? Does analysis of the biomechanical principles of exercises and sport movement help you with this judgment?

4. If an athlete uses unsafe technique in the weight room, should the coach's response be swift and negative for safety's sake, or should they take a positive (teachable moment) approach in teaching safer technique? Are there athlete (age, ability, etc.) or exercise factors that affect the best approach?

5. Athletes train vigorously, pushing their limits, treading a fine line between training safely and overtraining. Are there biomechanical indicators that could help the strength and conditioning professional recognize when training intensity has moved beyond overload to dangerous? Why?

6. For a specific sport movement, determine if conditioning exercises should emphasize Force-Time or Force-Motion to be more activity-specific.

7. What biomechanical principles are relevant to training overarm-throwing athletes with upper-body plyometric exercises? Be sure to integrate the muscle mechanics knowledge summarized in chapter 4 in your answer.

8. Strength training resistances are often expressed as percentages of maximum strength (1RM). If loads on the musculoskeletal system were also expressed as percentages of mechanical strength, what training loads do you think would be safe (acceptable risk) or unsafe (unacceptable risk)?

9. Which is most important in selecting weight training resistances: training studies or biomechanical tissue tolerances? Why?

SUGGESTED READING

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WEB LINKS

NSCA—National Strength and Conditioning Association.
<http://www.nasca-lift.org/menu.htm>

PCPFS Research Digest—research reviews published by the President's Council on Physical Fitness and Sports.
http://www.fitness.gov/pcpfs_research_digs.htm