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Training Principles: Evaluation of Modes and Methods of Resistance Training

Michael H. Stone, PhD
Department Of Physical Education, Sport & Leisure Studies
University Of Edinburgh
Edinburgh, Scotland

David Collins
Department Of Physical Education, Sport & Leisure Studies
University Of Edinburgh
Edinburgh, Scotland

Steven Plisk, MS, CSCS
Department Of Athletics
Yale University

Greg Haff, PhD, CSCS
Exercise Science
Appalachian State University

Margaret E. Stone, BA, CSCS
Scottish Institute Of Sport
Edinburgh, Scotland

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RESISTANCE TRAINING HAS been shown to improve a variety of performance- and health-related variables (63). Improvements in performance can include increased muscular strength, power, and both low- and high-intensity exercise endurance (36, 44, 50). Changes in these variables (strength, power, and endurance factors) as a result of resistance training are related to improved measures of athletic performance, such as the vertical jump, sprint times, distance-running times, and agility (27, 44, 74). Programs incorporating strength training as an integral part of physical conditioning have also been shown to improve performance in ergonomic tasks, such as lifting weighted boxes to different heights (2, 23). These types of observations indicate that resistance training can have a transfer-of-training effect that results in a change in functional ability and capacity. Health-related changes resulting from resistance training can include improved cardiovascular parameters; beneficial endocrine and serum lipid adaptations; increased lean body mass and decreased fat; increased tissue tensile strength, including bone; and decreased physiological stress (16, 29, 30, 37, 47, 63, 69).

Choosing an appropriate training method (repetitions and sets, velocity of movement, periodization, etc.) can make a considerable difference in the outcome of a resistance-training program (19, 22, 27, 66, 67, 68). For example, high-volume programs have a greater influence on body composition and endurance factors than do low-volume programs (36). It is also probable that the choice of training mode (type of equipment) can influence the adaptations to a training program.

The following definitions will be used to discuss the usefulness of various devices:

- Free weight–application of resistance by a freely moving body. Includes barbells, dumbbells, associated benches and racks, medicine balls,

throwing implements, and body mass. Allows for accommodation of resistance and force production. Challenges the lifter to control, stabilize, and direct the movement.
- Machine–application of resistance in a guided or restricted manner. Includes plate-loaded and selectorized devices, electronically braked devices, springs and rubber band devices. Lesser challenge for control, stabilization, and direction of movement

The following discussion will examine the relative usefulness of various types of machines and free weights for performance enhancement in relation to the following: (a) basic training principles, (b) comparison research, and (c) practical aspects based on the first 2 issues.

Basic Training Principles

There are 3 basic training principles: overload, variation, and specificity. We shall discuss each of these.

Overload is concerned with providing a proper stimulus for eliciting a desired physical, physiological, or performance adaptation. Overload is exercise and training that goes beyond normal levels of physical performance. An overload stimulus will have some level of strength (intensity), frequency, and duration of application. Thus, all stimuli will have a level of intensity, relative intensity (percentage of maximum), frequency, and duration (volume). The intensity of training is associated with the rate of performing work and the rate at which energy is expended; the volume of training is a measure or estimate of how much total work is performed and the total amount of energy expended. Intensity (and relative intensity) is provided by the amount of weight lifted, and the volume of training is related to the number of repetitions and sets per exercise; the number and types of exercises used (large- versus small-muscle mass); and the number of times per day, week, month, and so on that these exercises are repeated. Volume load (repetitions × the mass lifted) is the best estimate of the amount of work accomplished during training (66–68). The application of training intensity and volume can be considered both in terms of the overall workout (i.e., all exercises performed during a specified period) or in terms of individual exercises. An understanding of overload factors can aid in the choice of exercises and equipment. Although programming (i.e., sets and repetitions) for a specific exercise is independent of exercise mode, the resulting total work (accomplished per session, week, month, etc.) is not independent. For example, in general, changes in body composition, particularly decreases in body fat, are related to the total energy expenditure (during and after exercise) and therefore to the volume of training. With some exceptions, most machines use single-joint, small–muscle mass exercises; furthermore, most training programs using machines are centered on several small–muscle mass exercises and would result in a smaller energy expenditure than if larger muscle mass exercises were used. Thus, we make the argument that large–muscle mass exercises and therefore larger energy expenditures are much more readily accomplished by using free weights (see third bulleted point in Practical Considerations section).

Variation is concerned with appropriate manipulation in training intensity, speed of movement, volume, and exercise selection. Appropriate variation is an important consideration for the prolongation of adaptations over continuous training programs (32, 33). Furthermore, appropriate sequencing of volume; intensity; and exercise selection, including speed–strength exercises, in a periodized manner can lead to superior enhancement of a variety of performance abilities (27). Although changes in volume and intensity are possible with machines, proper application, sequencing, and variation of movement patterns and speed–strength and speed-oriented exercises are limited at best. This is due to the limitations in the movement pattern and movement characteristics of the machines themselves.

Specificity of exercise and training is the most important consideration when selecting appropriate equipment for resistance training, especially if performance enhancement is a primary goal. Specificity includes both bioenergetics and mechanics of training (68, 73). This discussion will be concerned with mechanical specificity.

The transfer-of-training effect deals with the degree of performance adaptation that can result from a training exercise and is strongly related to specificity. Mechanical specificity refers to the kinetic and kinematic associations between a training exercise and a physical performance. This includes movement patterns, peak force, rate of force development, acceleration, and velocity parameters. The more similar a training exercise is to the actual physical performance, the greater the probability of transfer (5, 53, 55).

Siff and Verkhoshansky (56) refer to transfer-of-training effect as “dynamic correspondence”; that is, the basic mechanics, but not necessarily the outward appearance, of training movements should be similar to those of the athlete's sport performance. They (56) suggest a number of considerations and performance criteria that can be used in selecting training modes (and methods) that can maximize the transfer-of-training effect.

In terms of performance, the criteria are as follows:

- accentuated regions of force production
- amplitude and direction of movement
- dynamics of effort (i.e., static versus dynamic characteristics of the movement and appropriate power output)
- rate and time of maximum force production
- regime of muscular work (eccentric versus concentric muscle actions)

The fourth criteria, dealing with rate of force production, is especially important in selecting exercises for the training of explosive athletic movements. Mechanical specificity has been extensively studied as it affects strength-training exercise.

Explosive Strength and Power

In untrained subjects, heavy weight training can produce a rightward shift and beneficial effects in the entire force–velocity curve (25, 68). However, considerable evidence suggests that in trained subjects, high-velocity training is necessary to make marked alterations in the high-velocity end of the force–velocity curve (25, 27, 68).

Although training isometrically can result in increases in peak rate of force development and velocity of movement, especially in untrained subjects (5), the isometric-training effect on dynamic explosive-force production is relatively minor (25). Indeed, examination of the relative peak rates of force development (RFD) of isometric movement compared with fast ballistic movement supports the use of high-velocity, high-RFD movements in order to enhance dynamic explosiveness (24). Studies and reviews of the scientific literature indicate that the primary effect of ballistic training is an increased rate of force production and velocity of movement, whereas traditional heavy-weight training primarily increases maximum strength (25, 27, 35, 52). Additionally, high-power training beneficially alters a wide range of athletic performance variables to a greater extent than does traditional heavy-weight training, especially in subjects with a reasonable initial level of maximum strength (74). However, improvements in strength, power, and measures of athletic performance resulting from combination and sequenced training (strength ≥ power ≥ speed) may be superior to those from either heavy resistance training or high-speed resistance training alone (25, 39, 61). A recent longitudinal study of American collegiate football players (27) indicated that a combination (heavy training followed by combination training) produces superior results in measures of maximum strength and measures of athletic performance, such as the vertical jump, standing long jump, and 10-yd shuttle run, compared with continuous high-velocity or heavy-weight training.

These data strongly indicate that power and speed of movement specificity (as well as appropriate variation) are necessary considerations in the formulation of training programs leading to increased power and speed of movement. Even a cursory examination of most machines indicate that access to high-speed and high-power training may be limited because of limitations on acceleration patterns (particularly in variable-resistance and semi-isokinetic devices), friction, inappropriate movement patterns, and limited ranges of motion.

Joint Angle Specificity

Isometric strength training typically produces gains that are greatest at the joint angle trained. Progressively smaller gains in isometric maximum strength are found as measurements are taken farther away from the training angle (2, 34). It is also known that the use of variable-resistance devices result in strength gains that are the greatest at the joint angle at which the greatest resistance is applied and may be reduced at other angles (2, 34), a problem not inherent in free-swinging or freely moving devices (31, 43). Although variable-resistance devices attempt to match resistance to human strength curves, there has been little evidence of success (12, 26).

Movement Pattern Specificity

Studies and reviews of the literature have consistently noted that the magnitude of measured maximum strength gains depends on the similarity between the strength test and the actual training exercise (1, 5, 20, 48, 51–53).

Several investigations indicate that free weights can have strong mechanical relationships to a number of designated activities, such as the vertical jump (13, 21), and produce greater increases in measures of strength and power than do machines (31). Because of these relationships, there is a strong probability that training with free weights may have a greater transfer of training to athletic and ergonomic tasks than machines (43, 60, 62, 64). This primarily results from the ability to perform movements with free weights that mechanically mimic athletic and ergonomic tasks more effectively than machines. However, there are few studies that actually compare alterations in performance using various devices for training. These are discussed below.

Machines Versus Free Weights

Transfer-of-Training Effects: Maximum Strength Gains

Short-term studies (10, 28, 65, 71) using specific strength tests (strength was measured on the different types of apparatus used in training) have consistently indicated that free weights produce superior strength gains. These studies (10, 28, 65, 71) indicate that when measuring 1RMs, free-weight training transfers to machine testing better than machine training transfers to free-weight testing. Recently, in our laboratory (unpublished data), we have also shown that this effect occurs in women (11). Studies in which the strength testing has not been specific (strength was measured on an apparatus different from that used in training) have not shown strength-gain differences (40, 54, 57). In the studies by Saunders (54) and Silvester et al. (57), training was dynamic and strength testing was isometric, which likely masked or reduced any maximum-strength gains or differences. Furthermore, dynamic tests of strength in which the testing device is supposedly nonspecific can in fact favor either free-weight or machine training. This is because the dynamic-testing device has to be either free weights or a machine. In the study by Messier and Dill (40) comparing Nautilus and free-weight training, tests of leg strength were performed on a Cybex II semi-isokinetic leg extension device, an open–kinetic chain exercise (OKCE). The Nautilus group used leg extensions as 1 of the training exercises. Free-weight training was carried out using the squat, a closed–kinetic chain exercise (CKCE), and no leg extensions were performed. Thus, the Nautilus group likely had an advantage in testing because part of their training was biomechanically similar to the operation of the testing device. (See Movement pattern specificity section in *Problems Associated With Comparing Adaptations of Various Modes of Resistance Training* section) Although training differences may be masked or muted by using a "nonspecific" device to measure strength, these studies do demonstrate a transfer-of-training effect for strength gains.

Isokinetic Devices

Many clinicians and some exercise scientists believe that isokinetic training and testing offer advantages over other modes and methods. However, there is considerable scientific evidence that demonstrates that isokinetic training and testing not only do not offer advantages over other forms of testing and resistance training but in fact, in many instances, may be inferior to other modes and methods (25, 31, 46). Isokinetic refers to exercise using a constant angular velocity of a machine lever arm against which a body segment applies force. Theoretically, an isokinetic device will accommodate force production and maintain a constant velocity; thus, a maximum force effort can be made through the complete range of motion. However, there are no commercially available devices that produce an isokinetic movement throughout a complete range of motion, especially at fast speeds (14). This lack of complete isokinetic range of motion is due to acceleration at the beginning and to deceleration at the end of the range of motion (14, 42). Thus, these devices are more properly termed "semi-isokinetic". Proponents of semi-isokinetic testing and training suggest that these devices offer a degree of velocity specificity not found in other devices, including free weights (72). However, available semi-isokinetic devices can use maximum testing (or training) speeds of only 500°/s or less. These angular velocities that typically are far less than either the single- or multiple- (summated) joint peak velocities that occur in many athletic activities (15). Furthermore, moments (forces) produced during isokinetic contractions of the same muscles at the same velocities can be different compared with the forces produced as a result of different movement patterns. For example, Bobbert and van Ingen Schenau (9) compared the moments produced during plantar flexion and found substantially higher moments during vertical jumping compared with isokinetic movement. Furthermore, they (9) found marked differences in the timing of muscle activation between the 2 conditions. Thus, it is doubtful that semi-isokinetic devices can adequately provide a velocity- or force-specific stimulus compared with free movement. Studies and reviews comparing semi-isokinetic and other resistance-training modes indicate a high degree of strength specificity (25, 41). Additionally, strength and power gains as a result of free-weight training or variable-resistance training are not always demonstrable when measured on semi-isokinetic devices (1, 20).

Because movement is rarely performed at a constant velocity through a full range of motion, it may be argued that a freely moving object or device will allow muscle contractions to occur that are more similar to natural motions (68). A recent comparison of isotonic (freely moving leg extension device) versus semi-isokinetic leg extension training indicated that isotonic training is superior in producing both strength and power gains (31).

Transfer-of-Training Effect: Functional Effects

Few studies (MEDLINE and SPORTDiscus, 1978–1999) dealing with modes of training have investigated carryover to aspects of performance other than strength, such as sprinting or jumping, and none have investigated effects on ergonomic tasks. As of this writing, only a few studies have compared free weights and resistance machines (4, 28, 57, 65, 70, 71) and semi-isokinetic devices (3) as to their effects on the vertical jump and vertical-jump power indices. Five studies (3, 4, 57, 65, 70) found that free weights produce superior results, and 2 studies (28, 71) found statistically equal results, although percentage gains favored the free-weight groups. No studies could be located that indicated that machine training produces superior results in gains in vertical jump compared with free weights. Although these studies generally indicate the superiority of free weights in producing a transfer-of-training effect, they are not definitive. More investigation is needed to fully understand the training adaptations associated with both machines and free weights.

Problems Associated With Comparing Adaptations of Various Modes of Resistance Training

Comparing training adaptations of various modes of resistance exercise is difficult at best. Several confounding factors become evident, which we will discuss.

Study Length and Trained State. The subject number in many of the comparative studies is relatively small. For example, in the study by Wathen and Shutes (71), the authors indicated that significance favoring free weights in the vertical jump would have been reached provided the subject number had been higher (n = 8 per group). Regardless of the purpose, a significant problem with the majority of training studies is their length. No study making comparisons of training modes has lasted longer than 12 weeks.

An important consideration is the training status of the subjects. It has been known for over 30 years that initially untrained subjects can markedly increase maximum strength using almost any reasonable training program or device. However, such improvements may well be due more to neurogenic changes such as skill learning rather than to myogenic effects. In the early stage of learning for any movement, gains will be rapid, with subsequent improvements ongoing but asymptotic (17, 55). It is extremely likely that early gains in performance in any exercise regime will be due to the improved central representation of the skill rather than to muscle changes per se. Indeed, because substantial strength gains have been shown to occur through the use of mental practice alone (i.e., no physical training, only imagining an execution of the movement), it is likely that both central representation (learning the skill) and peripheral nerve transmission and efficiency of fiber recruitment account for more variance in the early strength gains that may occur through training (58, 75). Thus, in short-term studies, although some specificity can be demonstrated over a relatively short term (1), comparisons between devices lasting a few weeks are likely measuring only initial changes in learning, many of which are of a more general nature, particularly intramuscular adaptations. Additionally, these initial changes are quite large in magnitude compared with adaptations occurring later in the training program. Although these initial changes can lead to an increased ability to exert maximum force, many training-specific effects may require longer periods to become evident or may be masked by the large initial changes in the nervous system. Consequently, longer observation periods (>0.5 years) are likely required to completely elucidate long-term intra- and intermuscular task specificity or specific alterations in hypertrophy/muscle physiology as a result of training with different modes.

Only 3 studies in the scientific literature used previously trained subjects (65, 70, 71). Once again, however, skill acquisition effects may play a confounding role in such investigations. When individuals skilled in 1 set of movements (e.g., those for the bench press) change to another, albeit related, set of skills, the neurogenic and skill acquisition gains described earlier mean that those training on a novel skill will improve faster than those left in the old routine. Differences in the complexity of the exercises used (from a motor control perspective) will also serve to confound effects in short-term studies. Furthermore, prior skill level may also confound results through the test exercise itself. Depending on their previous practice levels, some subjects may have an inherent advantage over others. Consequently, only the results of investigations that have utilized repeated measures designs or used the preintervention performance on the test exercise as a covariate and that have allowed for the differential impact of learning effects can be really trusted. Finally, few studies have used women as subjects. Obviously, the only clear conclusion is that much more comprehensive studies need to be carried out over longer periods of time.

Work Equalization. Equalizing work is very difficult to achieve, even when set and repetition combinations are the same. This is partly because machines use a variety of methods to produce resistance and thus make it difficult to accurately calculate the amount of work accomplished (12). Furthermore, in practice, training protocols with equal workloads are rarely chosen. Training protocols are selected because they are believed to produce desired results. Often machine manufacturers or retailers recommend training protocols that can be different from those commonly used, particularly by serious athletes interested in improving performance (i.e., 1 set to failure versus multiple sets). Thus, many studies used different set-and-repetition combinations among comparison groups; for example, the study by Stone et al. (65), in which 1 set to failure was used with the Nautilus group and multiple sets were used with the free-weight group.

Mixed Protocols. Some studies have compared protocols using combinations (mixtures) of free weights and machines to machine-only training (38), making it difficult to separate out individual effects for different devices. Care must also be taken in properly describing the training devices. For example, in the study by Boyer (10), the "free-weight" lower-body training program was actually carried out with a leg sled. A leg sled is not a true free-weight device because its movement is in a single, fixed plane and results in guided and restricted movements and because the guiding apparatus can produce considerable friction not encountered in a freely moving object.

Movement Pattern Specificity: Closed Versus Open Kinetic Chain. Recently, the concept of OKCE and CKCE has received considerable attention in the scientific literature, particularly in terms of injury rehabilitation (6, 45). Although the exact definitions for various movement types have been debated and gray areas exist (7, 18), movements can generally be divided into exercises in which the peripheral segment can move freely and those in which the peripheral segment is fixed. For the purposes of this discussion, a CKCE is one in which the foot or hand is fixed, and force (in a weight-bearing manner) is transmitted directly through the foot or hand, such as in a squat or bench press. An OKCE is one in which the foot or hand is not fixed, such as in a leg extension, and the peripheral segment can move freely (45, 59). Typical CKCEs produce markedly different muscle recruitment and joint motions compared with OKCEs; for example, the isolated knee articulation of a leg extension versus the multiple articulations of the ankle, knee, and hip of a squatting movement. They also further complicate the learning and neurogenic effects outlined earlier. Although some human movements (such as walking) may contain a combination of open- and closed-chain aspects, it is the closed-chain aspects of movement that are crucial to performance and especially to improving performance (45, 59). Many machines are OKCE devices and likely do not provide complete specificity for training or for testing strength gained through CKCE training (1, 8, 45).

During studies comparing different devices, some differences likely occur because of movement pattern differences (i.e., OKCE versus CKCE) rather than because of differences in muscle contraction type, such as when comparing semi-isokinetic devices with free weights (1). If movement patterns could be made more similar, then results might be more readily comparable.

■ Practical Considerations: Advantages and Disadvantages Associated with Various Modes of Training

Available scientific evidence and logical arguments indicate that different modes of training can be associated with possible advantages or disadvantages, which include (43, 62, 63) the following:

1. A major advantage of free weights is the development of training protocols containing a high degree of mechanical specificity coupled with appropriate training variation. With free weights, the pattern of intra- and especially intermuscular activation that is used (as a result of exercise selection) can be more similar to the movement requirements of a specific task than can usually be obtained through machine exercise. Use of free weights allows proprioceptive and kinesthetic feedback to occur in a manner similar to that occurring in most athletic and daily performance movements. This is possible because with free weights, movement can take place in all 3 planes and is not being guided or otherwise restricted by the device. It should be noted that machines can limit movement or exercise selection in several ways. For example,
   - Typically, only 1 or 2 exer-

cises can be performed on a machine; thus, many machines are necessary for a complete training session. Free weights can allow many different exercises to be performed with minimum equipment.

• Machines typically allow little mechanical exercise variation (i.e., changes in hand or foot spacing), whereas free weights allow unlimited variation

• Most machines typically permit movement to occur in a single plane; free weights require balance and therefore permit exercise in multiple planes, as typically occurs in athletic and ergonomic movements

• Some machines (variable-resistance and semi-isokinetic devices) restrict normal acceleration and velocity patterns, which can change normal proprioception and kinesthetic feedback. For example, the design of variable-resistance devices attempts to match human strength curves with the resistance supplied by the machine. However, because of both human mechanical differences and limitations in machine design, matching resistance and strength curves has not been accomplished.

From a very practical standpoint, it can be argued that a prime rationale for the use of multijoint exercises such as weightlifting movements and their derivatives is that muscles act—and must be targeted—in functional task groups rather than in an isolated manner. Power output is the most important aspect for athletic development. It can be argued that the greater the effort (i.e., force, power, or RFD) the greater the subsequent training effect on neuromuscular activation and development of force, impulse, and power output. Furthermore, in many sports, power transmission from the ground up, through the kinetic chain, is a prerequisite for the development of neuromuscular synergy, stabilization, kinesthesis and proprioception—in turn carrying over to athletic movements as well as daily tasks.

2. Because free-weight exercises can involve more joints, used in a more complex manner (i.e., the joints have greater degrees of freedom), they automatically confer neurogenic and skill acquisition benefits not shown with typical machines. Even if the exercises are not identically matched with the target movements, some transfer is likely to occur. However, because free-weight movement can be designed to more closely approximate sports skills than can machine movement, greater transfer and consequently better motor performance will result.

3. Metabolic considerations are also important. The metabolic consequences of large–muscle mass exercises include energy expenditure and endocrine responses that likely influence training adaptations to a greater degree than do small–muscle mass exercises. For example, large–muscle mass exercises require more energy than do small–muscle mass exercises (69). Because body mass and body composition are strongly influenced by energy expenditure, large–muscle mass exercises are likely to be more effective in causing body composition (and metabolic) changes (63). A variety of large–muscle mass exercises can be performed with free weights, and these exercises are much more easily accomplished than with machines.

4. Some free-weight exercises and occasionally some machine exercises require the use of spotters. Spotters are necessary to catch the weight if a repetition is missed, to provide feedback concerning proper technique, and to provide encouragement.

5. Large muscle mass–multijoint exercises can result in a more time-efficient training session. One large–muscle mass exercise (for example, power snatches) can exercise as many muscle groups as can 4–8 small–muscle mass exercises. Employing a few large–muscle mass exercises rather than many small– or isolated–muscle mass exercises can save time.

6. Time may be a major factor in some training situations. However, it is a common misconception that machines can always save time. If the rest period between sets is very short (<30 seconds), then the ease of moving a pin into a weight stack may be an advantage. In most training situations, especially priority training, the rest time between sets is typically a function of the volume load per set and usually lasts about 2–3.5 minutes. Because of the relatively long rest periods, changing weights is not a problem.

7. Moving a weight-stack pin is usually easier and faster than changing weights on a bar; typical weight stack machines offer increments of 7.5 to 12.5 kg. Although some machine manufacturers offer lighter additional weights that

can be added to the weight stack, many do not. Furthermore, most gyms, health clubs, and so on do not have these smaller add-on weights available. Additionally, devices that use springs and elastic bands to produce resistance do not typically provide bands offering small increments (typically, the increments would be approximately 5–10 kg). With typical free weights, the incremental jumps can be made from approximately 0.5 to 45 kg. This wider range of weight increments can allow easier progression and more accurate resistance loading, especially if percentages of maximum are used in planning training programs.

8. Learning the technique of some multijoint free-weight movements may require some additional time and effort. However, the cost-to-benefit ratio of learning a new skill can be worth the effort.

9. Isolating specific small-muscle groups and the use of single-joint exercises can be accomplished quite easily using machines. Under some specific conditions, machines may isolate small muscle masses or stress specific parts of small muscle masses more efficiently or easier than free weights. Training isolated muscle groups or single joints can be important in certain aspects of bodybuilding programs, initial rehabilitation programs, or as part of injury prevention programs.

10. Resistance training is a relatively safe method of training, and typically few injuries result. It is commonly believed that machines are safer than free weights. However, there is no evidence to support this belief (49). The authors have over 100 years of combined weight room and strength-training experience. Over the course of our experience, we have observed as many or more injuries among machine users as among those using free weights.

11. Space is usually not a problem in most public gyms, such as the weight rooms at major American universities; however, it can be in some cases. For example, storage space in most private homes is limited. In the military, space is often at a premium, for example aboard ships. Transportation and storage of equipment occasionally dictates the type of equipment that can be used. In many cases, machines, especially those using springs and elastic bands, take up less space.

12. Equipment cost is often the determining factor in the selection of equipment. Machines, especially semi-isokinetic devices, are usually more expensive than free weights. Considering the cost of multistation and single exercise machines, free-weight equipment can be used to train the same number of people for less money. When equipping a typical training facility, free-weight equipment can also allow more people to be trained at the same time for the same monetary cost.

■ Conclusions

Although it is obvious that additional research is necessary to establish the effects of different modes of training on athletic and ergonomic performance, current information and evidence indicates that for most activities, training with complex, multijoint exercises using free weights can produce superior results compared with training with machines. Although there are a number of factors that can account for the superiority of free weights, a major factor deals with mechanical specificity. On the basis of the evidence that specificity of exercise and training result in a greater transfer-of-training effect, free weights should produce a more effective training transfer.

Therefore, the majority of resistance exercises making up a training program should be free-weight exercises with emphasis on mechanical specificity (i.e., large–muscle mass exercises). Machines can be used as an adjunct to training and, depending upon the sport, can be used to a greater or lesser extent during various phases of the training period (preparation, precompetition, and competition) or if there is a need to isolate specific muscle groups. ▲

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Stone

Michael H. Stone, PhD, is currently a professor of Sports Science at Edinburgh University, Edinburgh, Scotland. He was previously a professor of Exercise Science at Appalachian State Univer-


Collins


Plisk


Haff

sity. Since receiving his PhD from Florida State University, he has worked as a professor at Louisiana State University and at Auburn University. His primary research interests concern the physiological and performance adaptations to strength and power training.

David Collins is Chair of Physical Education and Sport Performance and also Head of Department, Physical Education, Sport and Leisure Studies, at the University of Edinburgh. He has worked as a Sport Psychologist in a variety of power sports and has also acted as a strength coach to elite level performers.

Steven S. Plisk, MS, CSCS, has been the Director of Sports Conditioning at Yale University since 1997. He received his BS in Sport and Exercise Science from the University of Colorado in 1990. He is a Certified Strength and Conditioning Specialist through the NSCA and a USAW Level I Coach. His professional activities include Associate Editor, Strength and Conditioning Journal Editorial Board; Vice President, NSCA Board of Directors; NSCA Coaches College Faculty; and NSCA Certification Commission Symposium Presenter.

G. Gregory Haff, PhD, CSCS, is an Assistant Professor in the Health, Leisure and Exercise Science Department at Appalachian State University. He currently coaches several national level Olympic weightlifters. He received his PhD from the University of Kansas. He is a nationally ranked weightlifter and serves as an athlete's representative on USA Weightlifting's Sports Medicine and Sport Science Committee. Greg is a column editor for the Roundtable Discussions Column in the *Strength and Conditioning Journal.*

Margaret Stone, BA, CSCS is currently the Performance and Excellence Manager for the Scottish Athletics Federation. Before beginning her coaching career, she had a successful career competing in track and field, especially the shot and discus, including competition in 2 Olympic Games. She is active in coaching and athletic education, is a regular speaker at USA Track and Field and USA Weightlifting educational clinics and seminars, and is a member of the USA Track and Field Development Committee.