Training Principles: Evaluation of Modes and Methods of Resistance Training – A Coaching Perspective

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ABSTRACT

Current information and evidence indicate that for most activities free weight training can produce superior results compared to training with machines, particularly when the free weight training involves complex, multi-joint exercises. A number of reasons can account for the superiority of free weights; the major factor deals with mechanical specificity. Mechanical specificity is concerned with appropriate movement patterns, force application and velocity of movement. Considering the available evidence that adherence to the concept of specificity of exercise and training can result in a greater transfer of training effect then free weights should produce a more effective training transfer. Therefore, the majority of resistance exercises making up a training programme should include of free weight exercises with emphasis on mechanical specificity (i.e. large muscle mass exercises, appropriate velocity, contraction type etc.). Generally, machines should be used as an adjunct to free weight training and, depending upon the sport, can be used to a greater or lesser extent during various phases of the training period (preparation, pre-competition, competition).

INTRODUCTION

Resistance training is a general term used to describe a number of different training goals such as training for improved performance, hypertrophy (i.e. body building), increased fitness and health for a variety of populations, injury prevention or rehabilitation (Stone, et al., 1991). Health-associated 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 (Conroy et al., 1993; Johnson et al., 1983; Johnson

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et al., 1982; McMillan et al., 1993; Poehlman et al., 1992; Stone, 1991; Stone et al., 1983). However, improved physical performance is the parameter most often associated with resistance training. Programmes incorporating strength training as an integral part of physical conditioning have been shown to improve performance in ergonomic tasks, such as lifting weighted boxes to different heights (Asfour et al., 1984; Genaidy et al., 1994) and have been associated with improved athletic performance. For most sports, resistance exercise is an integral part of training for improve performance.

Improvements in performance can include increased muscular strength, power and both low and high intensity exercise endurance (McGee et al., 1992; Paavolainen et al., 1999; Robinson et al., 1995). Changes in these variables (strength, power, endurance factors), as a result of resistance training, can be related to improved measures of athletic performance such as the vertical jump, sprint times, distance running times, and measures of agility (Harris et al., 1999; Paavolainen et al., 1999; Wilson and Murphy 1996). These types of observation indicate that resistance training can have a transfer of training effect that results in a change in specific functional abilities and capacities. Appropriately choosing a training method (reps and sets, velocity of movement, periodisation etc.) can make a considerable difference in the outcome of a resistance training programme (Fleck and Kraemer, 1997; Garhammer, 1981; Harris et al., 1999; Stone and O’Byrant, 1987; Stone et al., 1999a; Stone et al., 1999b).

For example: high volume resistance training programmes likely have a greater influence on body composition and endurance factors compared to low volume programmes (McGee et al., 1992). It is also very likely that the choice of training mode (type of equipment) can influence training adaptations.

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

**Free weight**: Applies resistance by use of a freely moving body. This includes barbells, dumbbells, associated benches and racks, medicine balls, throwing implements, body mass, and augmented body mass (i.e. weighted vests, limb weights). Allows for resistance/force production accommodation. Challenges the lifter to control, stabilise, and direct the movement.

**Machine**: Applies resistance in a guided or restricted manner. Includes plate loaded and selectoriser devices, electronically braked devices, hydraulic devices, springs, and rubber-band devices. These devices offer a smaller challenge for control, stabilisation, and direction of movement than free weights.

The following discussion will examine the relative usefulness of various types of machines and free weights for sports performance enhancement in relation: (1) to basic training principles, (2) comparison research and (3) practical aspects based on 1 and 2.

**BASIC TRAINING PRINCIPLES**

There are three basic training principles: overload, variation, and specificity.
Overload

Overload is concerned with providing a proper stimulus for eliciting a desired physical, physiological or performance adaptation. Fundamentally, overload is exercise and training which 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 (% 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. The volume of training is related to the number 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, etc. these exercises are repeated. Volume load (repetitions x the mass lifted) is the best estimate of the amount of work accomplished during training (Stone and O’Bryant, 1987; Stone et al., 1999a; Stone et al., 1999b). 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 selection of exercises and equipment. While programming (i.e. sets and reps) for a specific exercise is independent of exercise mode, the resulting overall 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 post-exercise) and therefore the volume of training. With a few exceptions, such as leg press devices, most machines are devised to use single joint or small muscle mass exercises. Furthermore, most training programmes using machines are centre on several small muscle mass exercises and, therefore, 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 using free weights (see ‘Practical Considerations’, no. 3, below).

Variation

Variation is concerned with appropriate manipulation in training volume and intensity, speed of movement and exercise selection. Appropriate variation is an important consideration for the prolongation of adaptations over continuous training programmes (Kramer et al., 1997; Kraemer et al., 1997; Stone et al., 2000a; Stone et al., 2000b). Furthermore, appropriate sequencing of volume, intensity, exercise selection including speed-strength exercises in a periodised manner can lead to superior enhancement of a variety of performance abilities (Harris et al., 1999). While changes in volume and intensity are possible with machines, proper application, sequencing and variation of movement patterns, speed-strength and speed-oriented exercises are limited at best. Thus training limitations are largely due to the limitations in the movement pattern and movement characteristics imposed by the mode of training.
Specificity

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 (Stone and O'Bryant, 1987; Wilmore and Costill, 1994). This discussion will be concerned with mechanical specificity.

Transfer of training effect deals with the degree of performance adaptation, which 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 probabilities of transfer (Behm, 1995; Sale, 1992; Schmidt, 1991).

Siff and Verkoshanski (1998) suggested that the degree of transfer of training effect depends upon the degree of dynamic correspondence. They argued that the basic mechanics, but not necessarily the outward appearance, of training movements must be similar to those of performance in order to achieve maximum transfer. In selecting training modes they present a number of considerations and performance criteria which can be applied to maximise transfer of training effect.

These basic criteria are appropriate application of:

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

The fourth criterion dealing with rate of force production is especially important in selecting exercises for the training of explosive athletic movements.

Mechanical specificity has been studied extensively as it affects strength training exercise.

EXPLOSIVE STRENGTH AND POWER

Strength can be defined as the ability to produce force (Stone, 1993). Explosive strength deals with the ability to produce high peak rates of force development (PRFD) and is related to the ability to accelerate objects including body mass (Schmidtbleicher, 1992; Stone, 1993). Therefore, explosive strength can be produced dynamically and isometrically (Stone, 1993). Dynamic explosive strength exercises which result in high power outputs and high PRFDs (speed-strength exercises) are crucial in training athletes from a variety of sports (Schmidtbleicher, 1992; Stone, 1993). Thus, an understanding of the components of dynamic explosive exercises is an important consideration in the selection of training modes.
Work is the product of force and the distance that the object moves in the direction of the force (force x distance). Power (P) is the rate of doing work (P = force x distance/time) and can be expressed as the product of force and velocity (P = force x velocity). Power can be calculated as an average over a range of motion or as an instantaneous value occurring at a particular instant during the displacement of an object. Peak power (PP) is the highest instantaneous power value found over a range of motion. Maximum power (MP) is the highest peak power output one is capable of generating under a given set of conditions (i.e. state of training, type of exercise etc.). Typically, the highest concentric power outputs occur at approximately 30–50% of maximum isometric force capabilities.

Power output is likely to be the most important factor in separating sports performances (i.e. who wins and who loses). While average power output may be more associated with performance in endurance events, for activities such as jumping, sprinting, and weightlifting movements, PP is typically strongly related to success (Garhammer, 1993; Kauhanen et al., 2000; McBride et al., 1999; Thomas et al., 1996).

In previously untrained subjects, heavy weight training can produce a rightward shift and beneficial effects across the entire force velocity curve (Hakkinen, 1994; Stone and O’Bryant, 1987). However, considerable evidence suggests that in well-trained subjects, high velocity training is necessary to make further alterations in the high velocity end of the force velocity curve (Hakkinen, 1994; Harris et al., 1999; Stone and O’Bryant, 1987).

Isometric training can result in an increased peak rate of force development (PRFD) and velocity of movement, especially in untrained subjects (Behm, 1995), the isometric training effect on dynamic explosive force production is relatively minor (Hakkinen, 1994). Indeed, examination of the relative peak rates of force development of isometric movement compared to fast ballistic movement supports the use of high velocity/high RFD movements in order to enhance dynamic explosiveness (Haff et al., 1997). 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, while traditional heavy weight training primarily increases maximum strength (Hakkinen, 1994; Harris et al., 1999; McBride et al., 1999; Sale, 1988). Furthermore, some evidence indicates that high power training can beneficially alter a wider range of athletic performance variables than traditional heavy weight training, especially in subjects with a reasonable initial level of maximum strength (Wilson et al., 1996). However, improvements in strength, power and measures of athletic performance resulting from combination and sequenced training (strength >> power >> speed) may be superior to either heavy resistance training or high-speed resistance training alone (Hakkinen, 1994; Medvedev et al., 1981; Stone, 1993). A recent longitudinal study using American collegiate football players (Harris et al., 1999) indicates that a combination (heavy training followed by combination training) produces superior results, in that a greater number of variables encompassing a wide range of performance measures showed significant improvements. These variables included measures of maximum strength
(1 RM) and other measures of athletic performance such as the vertical jump, standing long jump and 9.1 m shuttle run (Harris et al., 1999).

These data strongly indicate that, during resistance training, power and speed of movement (as well as appropriate variation) are necessary considerations in the formulation of training programmes leading to increased power and speed of movement. Even cursory examination of most machines indicate that high speed and high power training may be limited, relative to that available through free weights, due to limitations on acceleration patterns (particularly in variable resistance and semi-isokinetic devices), friction, inappropriate movement patterns and limited ranges of motion (Cabell and Zebas, 1999; Chow et al., 1997; Harman, 1983). Thus, we argue that dynamic explosive exercises are more effectively performed using free weights and free body exercises than machines.

**JOINT ANGLE SPECIFICITY**

Although, in very sedentary subjects, isometric training may improve strength at a variety of angles (Marks, 1994), isometric strength training typically produces gains that are greatest at the joint angle trained. Progressively smaller gains in isometric maximum strength are found as measurement moves away from the training angle (Atha, 1983; Logan, 1960).

Variable resistance devices attempt to match the encountered resistance to human strength curves by the use of various cams and lever systems. Ideally, this would allow a maximum contraction throughout a range of motion by maintaining optimum length-tension/leverage characteristics. Although variable resistance devices have attempted to match resistance to human strength curves, there is little evidence of success (Cabell and Zebas, 1999; Harman, 1983; Harman 1994). There are two possible reasons as to why variable resistance devices have failed to match strength curves. First, there is a relatively high degree of variability among humans (i.e. differences in limb lengths, moment arms etc.). Thus, machines in which resistance only matches average strength curves would not appropriately match every individual’s strength curve (Cabell and Zebas, 1999; Harman, 1983; Harman, 1994). Even if the resistance could be matched to the strength curve of an individual, a compounding factor is the force-velocity relationship. The speed of movement would have to be constant in order for an individual to maximally load the involved muscles throughout the range of motion – an exercise pattern in which the neural control would be non-specific to most real-life movements. Second, there is no evidence that the variable resistance devices even match the average human strength curves (Cabell and Zebas, 1999; Harman, 1983; Harman, 1994). Additionally, it should be noted that for many movements, groups of muscles are actually involved rather than a single muscle. Because each of these muscles have a different moment arm, there may be no common force-velocity (or length-tension) relationship. Thus, a constant velocity of movement would not necessarily fit every muscle involved. As a result, variable resistance devices may apply resistance inappropriately, thus limiting adaptation. In this context it has been noted that the use of variable resistance devices results in strength gains that are the greatest
at the joint angle at which the greatest resistance is applied and gains may be reduced at other angles (Atha, 1983; Logan, 1960). This angle specific training adaptation is not apparent when using free-swinging or freely moving devices (Kovaleski et al., 1995, Nosse and Hunter, 1985).

**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 (Abernethy & Jurimae, 1996; Behm, 1995; Fry et al., 1992; Rasch and Morehouse, 1957; Rutherford and Jones, 1986; Sale, 1988; Sale, 1992; Stone and Kirksey, 2000).

Several investigations indicate that free weights can have strong mechanical relationships to a number of specific activities such as the vertical jump (Canavan et al., 1996, Garhammer, 1981). 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 compared to machines (Nosse and Hunter, 1985; Stone, 1982; Stone and Borden, 1997; Stone and Garhammer, 1981). This primarily results from the ability to perform movements with free weights that mechanically mimic athletic tasks more effectively than machines. However, few studies are available that actually compare changes in performance using various devices for training:

**MACHINES VERSUS FREE WEIGHTS**

*Transfer of Training Effects: Maximum Strength Gains*

Short-term studies (Boyer, 1990; Jesse et al., 1988; Stone et al., 1979; Wathen and Shutes, 1982) 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 (Boyer, 1990; Jesse et al., 1988; Stone et al., 1979; Wathen and Shutes, 1982) indicate that, when measuring 1 RMs, free weight training transfers to machine testing better than machine training transfers to free weight testing. Recently, in our laboratory (Brindell, 1999, unpublished data), we have shown this effect also occurs in women. However, studies in which the strength testing has not been specific (strength was measured on an apparatus different from that used in training) have not indicated strength gain differences (Messier and Dill, 1985; Saunders, 1980; Silvester et al., 1982). For example, studies by Saunders (1980) and Silvester et al. (1982) used dynamic exercise for training but strength testing was isometric which likely mutes, masks, and reduces any maximum strength gains or differences (Wilson and Murphy, 1996). Furthermore, dynamic tests of strength in which the testing device is supposedly non-specific, in fact, can favour 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 (1985) 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.** The Nautilus group used leg extensions as one of the training exercises. Free weight training was carried out using the squat, a *closed kinetic chain exercise*, 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 testing device. (See ‘Problems Associated with Free Weight vs Machine Comparison’, ‘Movement Pattern Specificity’ (p. 91). Interestingly, although training differences may be masked or muted by using a *non-specific device* to measure strength, these studies do demonstrate a degree of 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 isokinetic training and testing likely do not offer advantages over other forms of testing and resistance training and in many instances may be inferior to other modes and methods (Augustsson *et al.*, 1998; Hakkinen, 1994; Kovaleski *et al.*, 1995; Petsching *et al.*, 1998).

*Isokinetic* refers to exercise using a constant angular velocity of a machine lever arm on 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 can produce an isokinetic movement throughout a complete range of motion, especially at the faster available speeds (Chow *et al.*, 1997). This lack of complete isokinetic range of motion is due to acceleration at the beginning and deceleration at the end of the range of motion (Chow *et al.*, 1997; Murray and Harrison, 1986). Thus, these devices are more properly termed semi-isokinetic. Proponents of semi-isokinetic testing and training point out that the reliability for these devices is usually quite good (Abernethy *et al.*, 1996) and that movement is less technique dependent compared to many free weight exercises (Augustsson *et al.*, 1998). However, the external validity of *semi-isokinetic* devices is questionable (Abernethy and Jurimae, 1996; Augustsson *et al.*, 1998; Fry *et al.*, 1992; Kovaleski *et al.*, 1995).

Studies and reviews comparing semi-isokinetic and other resistance training modes indicate a high degree of strength specificity (Hakkinen, 1994; Morrissey *et al.*, 1995). For example, moments (forces) produced during isokinetic contractions of the same muscles at the same velocities can be different compared to the forces produced as a result of different movement patterns. Bobbert and van Ingen Schenau (1990) compared the moments produced during plantar flexion and found substantially higher moments as well as differences in the timing of muscle activation during vertical jumping compared to semi-isokinetic movement. 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 (Abernethy and Jurimae, 1996; Augustsson *et al.*, 1998; Fry *et al.*, 1992).

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 which are more similar to natural motions (Stone and O’Bryant, 1987). A recent comparison of isotonic (freely moving leg extension device) versus semi-isokinetic leg extension training indicates that dynamic non-isokinetic training is superior in producing both strength and power gains (Kovařek et al., 1995).

Proponents of semi-isokinetic devices further suggest that these devices offer a degree of velocity specificity not found in other devices including free weights, presumably as a result of the ability of the device to overload at fast speeds (Watkins and Harris, 1983). However, available semi-isokinetic devices can use maximum testing (or training) speeds of only 400–500°/s or less, angular velocities which are typically far less than either single or multiple (summed) joint peak velocities that occur in many athletic activities (Coleman et al., 1993). Movements with free weights, particularly those with multiple joints actions, such as weightlifting movements (snatch, clean, and jerk), unweighted or weighted jumps, can result in much higher angular velocities than possible when using the semi-isokinetic devices which are currently available. For example, even at maximum attempts, angular velocities at the hip and knee during the snatch can exceed 500° x s⁻¹ (Baumann et al., 1988); lifts with sub-maximal weights would likely produce even higher values. Furthermore, these peak angular velocities occurred at joint angles at which force was still being exerted on the bar – clearly illustrating the potential for a force overload stimulus at angular velocities which can exceed the limits of semi-isokinetic devices (Baumann et al., 1988).

Considering the relatively poor external validity provided by semi-isokinetic devices we would argue that it seems doubtful that these devices can adequately provide a velocity/force specific stimulus that is comparable to free movements, particularly as it pertains to multi-joint movements.

Transfer of Training Effect

Few studies (Medline and Sports Discus, 1978–2001) 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 (Augustsson et al., 1998; Bauer et al., 1990; Jesse et al., 1988; Silvester et al., 1982; Stone et al., 1979; Wathen, 1980; Wathen and Shutes, 1982) to their effects on performance (other than strength). All seven studies made comparisons using the vertical jump (VJ) and vertical jump power indices. The vertical jump is often chosen as an indicator of explosive athletic performance because:

1. it is easy to measure;
2. the vertical jump is a primary component of many sports (i.e. basketball, volleyball etc);
3. there are reasonable associations/correlations between the vertical jump and the performance capabilities of athletes excelling at other explosive exercises. For example, sprinters jump higher and sprint faster than distance runners (Hollings and Robson, 1991); and
4. the VJ (or its components including velocity and power output) have been associated with performance ability in numerous specific sports (Anderson et al., 1990; Barker et al., 1993; Stone et al., 1980; Thissen-Milder and Mayhew, 1991).

Five studies (Augustsson et al., 1998; Bauer et al., 1990; Silvester et al., 1982; Stone et al., 1979; Wathen, 1980) found that free weights produce superior VJ results, while two studies (Jesse et al., 1988; Wathen and Shutes, 1982) found statistically equal results, although percent gains favoured the free weight groups. No studies could be located that indicate that machine training produces superior results compared to free weights in gains in vertical jump (or any other performance variable). While 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.

As previously indicated, specificity dictates that a number of kinetic and kinematic parameters must be appropriately overloaded to stimulate gains in performance. One of the most studied and contemplated performance aspects of specificity is the vertical jump (VJ) and its relationship to weightlifting movements (snatch, clean and jerk and derivatives) and the training practices of weightlifters. Indeed, improved weightlifting performance as a result of training has been associated with increased vertical jump height and associated power output among novices (Stone et al., 1980), and the vertical jump is stratified by achievement level among weightlifters (i.e. better weightlifters jump higher) (Stone and Kirksey, 2000). Furthermore, weightlifters have been shown to have superior weighted and unweighted vertical jump heights and power outputs compared to other athletes (Stone, 1991; McBride et al., 1999). Part of the reason for these superior performance characteristics are likely related to the mode and methods used by weightlifters in training. Although adaptations to training are always multi-factorial, one likely contributing factor is the degree of associated mechanical specificity which has been observed between weightlifting movements (i.e. snatch, clean and jerk and derivatives) and the vertical jump (Canavan et al., 1996; Garhammer, 1981). These factors include a combination of high power output, high rates of force development and movement patterns, which cannot be easily duplicated by machine use.

Other assumptions have been made concerning the use of free weights and machines, which cannot be supported when examined closely. For example, it is often assumed that throwing motions requiring twisting (trunk rotation) cannot be made and trained appropriately with free weights and that machines are necessary. However, this idea may be more related to lack of experience with free weight training rather than the actual mechanics of free weights or machines. First it should be remembered that most throwing movements are made in a standing or upright position. For many years throwers have simulated these upright positions using weighted balls and implements. Additionally walking twists and weighted hammer thrower exercises have been used successfully to overload upright trunk rotation and throwing motions. Furthermore, with the use of benches or pommel horses a variety of positional exercises
using both weights and balls can stress trunk rotation from a variety of angles that cannot be attained with most machines.

While most physical activities can be simulated and appropriately trained using free weights, there are possible exceptions: for example, some aspects of swimming in which motion is generated in a supine or prone position largely through propulsion by the upper body may require specialised dry-land training. In this case it may be advantageous to use a 'swim bench' to simulate and overload stroke mechanics.

Problems Associated with Free Weight vs Machine Comparisons

Comparisons of training adaptations resulting from various modes of resistance exercise can be quite difficult. Several confounding factors become evident:

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 (1982) the authors concluded that there was no difference in vertical jump gains between free weights and a jumping device. However, the authors also indicated that significance favouring free weights 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. Study length (i.e. training time) is an important consideration as it impacts on the training status of the subjects. It is recognised that initially untrained subjects can markedly increase maximum strength using almost any reasonable training programme or device. Both neural and muscle adaptations impact maximum strength, however, initial strength improvements are more likely to involve neural changes associated with learning a skill rather than muscle adaptations. In the early stages of learning a new movement, gains are typically rapid with subsequent improvements continuing but asymptotic (Crossman, 1964; Schmidt, 1991). It is highly probable that initial gains in performance, in any exercise regime, would primarily be due to the improved central representation of the skill rather than to muscle adaptations. 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). Therefore, it is likely that both central representation (learning the skill) and peripheral nerve transmission/efficiency of fiber recruitment account for more variance in the early 'strength' gains which result from training (Smith et al., 1998; Yue and Cole, 1992). Although some specificity can be demonstrated over a relatively short-term (Abernethy and Jurimae, 1996), comparisons between devices lasting a few weeks are likely measuring only initial changes in learning, many of which are more general in nature, particularly intra-muscular adaptations. Additionally these initial changes are quite large in magnitude compared to adaptations occurring later in the training programme. While 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 to be required to completely elucidate long-term intra- and inter-muscular task specificity or specific alterations in hypertrophy/muscle physiology as a result of training with different modes.

Three studies in the scientific literature used previously trained subjects (Stone et al., 1979; Wathen, 1980; Wathen and Shutes, 1982). However, it is still possible that skill acquisition effects may play a confounding role in such investigations. When individuals skilled in one set of movements (e.g. bench press) change to another skilled movement (even though it may be related), the neural adaptations and skill acquisition gains previously described suggest that those switching to the novel skill will improve more rapidly than those still using the old training mode. Differences in the complexity of the exercises used (from a motor control perspective) can 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 which have utilised repeated measures designs or used the pre-intervention performance on the test exercise as a covariate, and which have allowed for the differential impact of learning effects, can be really trusted. Finally, few studies have used women as subjects. Obviously, the only really clear conclusion is that much more comprehensive study needs to be carried out over longer periods of time.

Work Equalisation

Equalising work is very difficult to achieve even when set and repetition combinations are the same. This difficulty is partly due to the variety of methods employed by machines to produce resistance (i.e. semi-isokinetic, variable resistance, friction, springs etc.) and it is difficult to accurately calculate the amount of work accomplished (Augustsson et al., 1998; Cabell and Zebas, 1999). Compounding this problem is the fact that, in practice, training protocols with equal workloads are rarely chosen. Training protocols are typically selected because they are believed to produce desired results. However, machine manufacturers or retailers often recommend training protocols which can be different from that commonly used, particularly protocols used by serious athletes interested in improving performance (i.e. one set to failure vs multiple sets, non-ballistic versus ballistic movements). Thus, many studies actually compared one mode and protocol versus a different mode and protocol. For example, in studying methods/modes of training and comparing a manufacturer’s recommendations Stone et al. (1979) used one set to failure with the Nautilus group and multiple sets with the free weight group. Obviously, this could preclude definitive conclusions as to the effectiveness of the mode of training independent from the training programme.

Mixed Protocols

Some studies have compared protocols using combinations (mixtures) of free
weights and machines to machine-only training (Meadors et al., 1983) 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 (1990) the free weight lower body training programme was actually carried out using 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 the guiding apparatus can produce considerable friction not encountered in a freely moving object.

Movement Pattern Specificity: Closed Versus Open Kinetic Chain

Recently the concepts of open (OKCE) and closed kinetic chain exercises (CKCE) have received considerable attention in the scientific literature, particularly in terms of injury rehabilitation (Beynon & Johnson, 1996; Palmitier et al., 1991). Although the exact definitions for various movement types have been debated and grey areas exist (Blackard et al., 1999; Dillman et al., 1994), 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 the present discussion a CKCE is a movement 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 a squat or bench press. An OKCE is a movement in which the foot or hand is not fixed, such as a leg extension, and the peripheral segment can move freely (Palmitier et al., 1991; Steindler, 1973). Typically CKCE produce markedly different muscle recruitment and joint motions compared to OKCE, 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 neural effects previously discussed. 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 improving performance (Palmitier et al., 1991; Steindler, 1973). Many machines are OKCE devices and likely do not provide complete specificity for training or for testing strength gained through CKCE training (Abermethy and Jurimae, 1996; Augustsson et al., 1998; Blackburn and Morrissey, 1998; Palmitier et al., 1991).

Studies comparing different modes of training may produce some differences as a result of movement pattern differences (i.e. OKCE vs CKCE) rather than differences in muscle contraction type. It is also possible that mono-articular (single joint) or small muscle mass training programmes (or testing) may not provide adequate movement pattern specificity. Indeed, muscle action has been shown to be task dependent and muscle function during isolated movements may not be the same as during multi-joint movements (Zajac and Gordon, 1989). For example, it is possible that differences noted between semi-isokinetic devices vs free weights (1) may result from differences in the pattern of movement (OKCE vs CKCE or mono-articular vs multi-joint) rather than actual differences in the way the muscle contracts. If movement patterns could be made more similar then results may 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 (Nosse and Hunter, 1985; Stone and Borden, 1997; Stone et al., 1991a; Stone et al., 2000):

1. The development of training protocols containing a high degree of mechanical specificity coupled with appropriate training variation is a major advantage of free weights. With free weights the pattern of intra- and especially, inter-muscular 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 kinaesthetic feedback to occur in a manner more similar to that occurring in most athletic and daily performance movements. This is possible because, with free weights, movement can take place in all three planes and movement is not being guided or otherwise restricted by the device. It should be noted that machines can limit movement or exercise selection in various ways, for example:
   a) typically only one or two exercises 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;
   b) machines typically allow relatively little mechanical exercise variation (i.e. changes in hand or foot spacing), free weights allow unlimited variation;
   c) most machines typically permit movement to occur in a single plane, free weights require balance and therefore permit exercise in multiple planes as typically occur in athletic and ergonomic movements; and
   d) some machines (variable resistance and semi-isokinetic devices) restrict normal acceleration and velocity patterns which can change normal proprioception and kinaesthetic feedback. For example, the design of variable resistance devices attempts to match human strength curves with the resistance supplied by the machine. However, due both to human mechanical differences and to 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 multi-joint exercises such as weightlifting movements and their derivatives is that muscles act – and therefore must be targeted – as functional task groups rather than in isolated manners. Power output is the most important aspect for athletic development. It can be argued that the greater the effort (i.e. force/power/RFD) the greater the subsequent training effect on neuromuscular activation and force/impulse/power output development. Furthermore, in many sports power transmission from the ground up through the kinetic chain is a prerequisite for the development of neuromuscular synergy, stabilisation, kinaesthesia
and proprioception – in turn carrying over to athletic movements as well as daily tasks.

Since free weight exercises involve more joints, used in greater complexity (i.e., free weights 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, since free weights movements can be designed to more closely approximate sports skills than machines, greater transfer and consequently better motor performance can result.

2. Metabolic factors must also be considered. The metabolic consequences of large muscle mass exercises include energy expenditure and endocrine responses which likely influence training adaptations to a greater degree than small muscle mass exercises. For example, large muscle mass exercises require more energy than small muscle mass exercises (Scala et al., 1987; Stone et al., 1983). 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 (Stone et al., 1991b). A variety of large muscle mass exercises can be performed with free weights and these exercises are much more easily accomplished than with machines.

3. 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.

4. Large muscle mass – multi-joint-exercises can result in a more time efficient training session. One large muscle mass exercise can exercise as many muscle groups as 4–8 small muscle mass exercises. The relative advantages of a large muscle mass exercise compared to smaller muscle mass exercises and single joint exercises are indicated by metabolic considerations (Scala et al., 1987, see point number 3) as well as EMG findings (Wilk et al., 1996; Stuart et al., 1996). For example, a power snatch or squat press involve both upper and lower body musculature; in order to activate the same muscle mass several upper and lower body isolated exercises would be required. Similar arguments can be made when comparing movements, which seemingly exercise some or all of the same muscles such as squats versus a leg press or leg extension (Wilk et al., 1996). Thus, employing a few large muscle mass exercises rather than many small or isolated muscle mass exercises can be time efficient.

5. 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 s), 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 last about 2–3.5 min. Because of the relatively long rest periods changing weights is not a problem.
6. 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. While some machine manufacturers offer lighter additional weights, which can be added to the weight stack, many do not. Furthermore, most gyms, health clubs etc. do not have these smaller add-on weights available. Additionally, devices which 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 kg to 50 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 programmes.

7. Learning the technique of some multi-joint 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.

8. 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 with free weights. Training isolated muscle groups or single joints can be important in certain aspects of body building programmes, initial rehabilitation or as a part of injury prevention programmes.

9. Resistance training is a relatively safe method of training, and typically few injuries result (Hamill, 1994; Stone et al., 1994). It is commonly believed that machines are safer than free weights. However, there is little evidence to support this belief (Requa et al., 1993), particularly in supervised settings (Hamill, 1994). The authors have a combined weight room/strength training experience of well over 50 years. During this experience we have observed no more injuries among free weight users than among those using machines.

10. Space for training equipment is usually not a problem in most public gyms, nor is it typically a problem for dedicated gyms such as the sports weight rooms at major American universities and many Sports Institutes (e.g. Australian Institute of Sport, Canberra). However, space can be a problem in some cases. For example, storage space in many 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.

11. Quite often, cost is the determining factor in the selection of equipment. Machines, especially semi-isokinetic devices, are usually more expensive than free weights. Considering the cost of multi-station 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.
USE OF FREE WEIGHTS WITH NON-ATHLETIC POPULATIONS

This review has been primarily concerned with strength power training adaptations for competitive athletes. However, the coach (and other fitness specialists) may be called upon to supervise, advise or assist with the training of recreational athletes or non-athletic groups. So, it is necessary to have some knowledge of the potential use of various modes of resistance training for these groups.

A commonly held belief is the assumption that certain non-athletic populations, particularly populations comprising the elderly or those afflicted with certain disease states, such as arthritis, cannot use free weights due to physical or psychological limitations. This assumption can be based on real or perceived limitations such as:

1. weight-bearing inability (either whole body or specific segments) as a result of pain or weakness and balance problems; and
2. psychological factors such as the free weights are intimidating; and
3. free weights require more technique training and supervision. However, in the authors' opinions this assumption has not been adequately tested.

In fact evidence suggests that using free weights can be a safe and effective method of enhancing performance in non-athletic populations, including aging populations in which the frequency and severity of degenerative diseases would be increasing. For example, among sedentary men ranging in age from approximately 30–60 years, training programmes employing primarily free weights have resulted in a number of beneficial alterations including increased maximum strength, power, and beneficial alterations in blood lipids (Johnson et al. 1982, Johnson et al. 1983, Blessing et al. 1987). More recently, Brill et al. (1998) successfully used a free weight programme with an elderly population (73–91 years) in promoting beneficial adaptations in several performance measures which affect daily living (such as balance, stair climbing, etc.). No adverse effects were noted in these investigations.

The important aspect to consider is primary exercises. Training exercises should be primarily carried out with free weights for the same reasons that athletic populations should use them. There is no reason to believe that the superior transfer of training effect which can be realised from free weights would not be effective in improving daily tasks such as lifting, carrying, shovelling, etc. In this respect it should be noted that free weights do not necessarily have to take the traditional form of barbells and dumbbells; rather, weighted vests and limb weights can be used to advantage among some groups, such as frail or elderly individuals. By using this form of free weights daily activities can be directly overloaded through augmented body or limb mass movements. For example, rising for a chair or stair climbing can be trained using a weighted vest. This type of free weight training may be less intimidating than traditional barbells and dumbbells. While a few machine exercises may be advantageous, most of the exercises should be performed with free weights for all populations. Exceptions are not usually population oriented but rather situation oriented, for example, where space may be at a premium (i.e. submarine crews have used
elastic bands which take up less space than either free weights or most machines). Indeed, the likelihood of not being able to perform a particular exercise may be more a function of individual physical and psychological characteristics, which may be coupled with specific disease states or injuries, rather than characteristics of a population. Competent strength training personnel can easily recognise these individual problems and programme adaptations can be made accordingly. In this context both authors have a background of training not only competitive athletes, but also of working with or supervising strength training programmes which have included recreational athletes, disabled athletes, middle aged, and elderly groups. While there are individuals with problems, which preclude the use of certain free weight exercises, it is our opinion, that most individuals can safely and effectively use training programmes primarily based around free weights.

**SUMMARY AND CONCLUSIONS**

It is obvious that additional research is necessary to establish the exact effects of different modes of training on athletic (and ergonomic performance). However, current information and empirical evidence indicate that for most activities training with complex, multi-joint exercises using free weights can produce superior results compared to training with machines. Future research should attempt to obviate several methodological problems associated with past comparison studies, particularly those associated with training state and length of study. Although there are a number of reasons which can account for the superiority of free weights a major factor deals with mechanical specificity. Considering 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 programme should include free weight exercises, particularly multi-joint exercises, with emphasis on mechanical specificity. Machines can be used as an adjunct to training and in sport can be used to a greater or lesser extent during various phases of the training period (preparation, pre-competition, competition), or if there is a need to isolate specific muscle groups.

**REFERENCES**


MODES AND METHODS OF RESISTANCE TRAINING


