A Review: Factors in exercise prescription of resistance training

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With the increased popularity of resistance training over the past 10 years, questions regarding the development and exercise prescription of a resistance training program are becoming more numerous. A wide range of individuals with diverse needs and goals utilize resistance exercise as a part of their athletic conditioning programs. Thus, the strength and conditioning specialist must become more sensitive to the subtle differences in the programs prescribed. Furthermore, the challenge of the strength and conditioning professional is to better individualize conditioning programs.

Design of the Exercise Session

Development of a resistance training program starts with the design of an exercise session. Specific choices need to be made for the following program variables:

1. the choice of the exercises to be used
2. the load, resistance or intensity of the exercise
3. the order of the exercises
4. the length of the rest periods between sets
5. the number of sets to be performed for each exercise

Exercise sessions need to be developed and modified for each individual's needs. The biggest challenge in resistance training today involves the individualization of exercise programs based on exercise capacity, genetic predisposition and sport requirements. The use of these variables can be very helpful in analyzing, modifying and evaluating any resistance exercise program.

Exercise Selection and Loading Factors

The adaptive changes observed will be specific to the muscles used in an exercise program (4). Furthermore, every time the angle of an exercise is changed, the exercise functionally changes (22). Thus, the number of possible exercises and angles used is almost as limitless as the body's functional movements. This requires specific exercise selection based upon an analysis of the muscles and joint angles desired to be trained.

The greater the need for transfer of the training effects to a specific sport skill, the greater the need for the exercise selection to closely mimic the angles, speed and type of contraction utilized in the sport skill (22). In many sports, this would require a wide variety of exercises for various muscle groups which contribute in different ways to the sport performance (12). Beginner, or "base" programs, would utilize exercises that use each of the major muscle groups of the body for the shoulders, back, chest, abdomen and legs. Exercise selection will also indicate the type of muscular contraction to be utilized. Typically this would mean either isometric, dynamic constant resistance (isotonic) or isokinetic contractions. The type of
equipment used dictates what mode of contraction would be utilized. (For extensive reviews of these contraction modes, readers are referred to references 4, 8, 12, 13, 29, 33.)

**Isometrics**

Isometric, or static resistance exercise, refers to a muscular contraction where no change in the length of the muscle takes place (29). The muscle does not generate enough force against the mass to cause movement. These exercises are typically performed against immovable objects (e.g., wall, a barbell or weight machine loaded beyond maximal concentric strength). Also, self (e.g., maximal tension production in straight leg quad exercise) or partner programs can be employed to perform isometric exercise programs.

Isometrics came to the attention of the American public in the early 1950s when Steinhaus (39) introduced the work of two Germans, Hettinger and Muller (23). Hettinger and Muller (23) demonstrated unbelievable gains in strength of five percent a week with the use of a daily two-thirds of maximal isometric contraction performed for six seconds. Subsequent studies demonstrated that isometric training leads to static strength gains but that the gains are substantially less than five percent per week. The majority of research suggests that maximal isometric contractions are superior to submaximal ones (12, 33, 38, 44). Also, gains in isometric strength result from either a small number of long duration contractions or a higher number of short duration contractions (33). The total contraction time has been determined to be an important factor (should be 30 seconds greater). It has become evident that daily training using isometrics is superior to other isometric training frequencies (12).

It must be remembered that strength increases due to isometric training effects are joint angle specific (14, 35). This joint angle specificity appears to have a carryover of 20 degrees of the training joint angle (28). In addition, a higher number of contractions leads to greater carryover of strength to joint angles other than the training angle (35). Isometric training at four different angles throughout the elbow flexor's range of motion has been shown to increase the strength at all four angles and significantly increase dynamic power of the elbow flexors (27). Thus, these studies indicate that if isometric training is to be used to increase strength throughout a joint range of motion, training should take place at several joint angles and utilize total contraction time of greater than 30 seconds (e.g., 20 five-second contractions).

Isometric training has been typically utilized when the joint movement is limited in injury rehabilitation and to improve strength at specific angles in the dynamic range of motion (12). Some sports utilize isometric contractions. For example, wrestling utilizes isometric contractions in certain holds and would benefit from inclusion of specific isometric exercises in the exercise program to address these needs. Isometric resistance exercise programs are typically used as a supplemental part of most resistance training programs.

**Dynamic Constant External Resistance**

The most popular form of resistance exercise involves the use of some form of dynamic resistance exercise. Isotonic is traditionally defined as a muscular contraction in which the muscle exerts a constant force throughout the entire movement. Performance of free-weight exercises and exercises on various weight training machines, though usually called isotonic, are not true isotonic exercises. The force exerted by the muscle is not constant but varies with the mechanical advantage of the joint involved in the movement. Thus, isotonic is not a good term to use and is starting to find disfavor in scientific literature (29). Dynamic constant external resistance will be the term used in this manuscript.

The last 40 years of research have had a strong focus on the optimum number of sets and repetitions necessary to achieve optimal gains in strength. This line of research has made a few assumptions: 1) an optimum number of sets and repetitions exists; 2) once found it will work for all individuals and exercises; and 3) it will promote increases in strength for an indefinite period of time. In drawing conclusions from a large number of studies it should be kept in mind that the majority of studies utilized novice subjects, college-aged individuals and a short period of training time (six to 12 weeks). Hakkinen (20) has discussed the effect of a higher pretraining status on subsequent strength gains. The strength-trained athlete takes about twice the training time to make half the improvement made by the novice lifter. Thus, an individual's pretraining level of strength will dictate the rate of improvement.

The amount of resistance (load) used for a specific exercise is probably one of the most important variables in resistance training. When designing a resistance exercise program, a load for each exercise must be chosen. The use of either a repetition maximum (i.e. load that will allow only listed number of repetitions) or some percentage of the one repetition maximum (1 RM) is typically the way that load is determined. The RM method of prescribing the load is easier as it eliminates the need for repeated 1 RM testing to keep the exercise stimulus effective. The research has supported a strong basis for a repetition continuum. The continuum simply relates RM loads to strength gains made. No magic number exists but RM loads around 6 RM appear to result in the largest strength improvements (2, 4, 8, 12). The effective range appears to be from 2 to 10 RM. As the load decreases and the RMs increase, the return on strength is diminished. It appears beyond 20 to 25 RM strength gains are more related to enhanced motor performance (2, 4). Conversely, as training RMs are increased above 20 RM, gains are primarily made in muscular endurance (2).
Variable Resistance

Many equipment companies have produced machines which alter the resistance throughout the range of motion in an attempt to match the increases and decreases in strength (strength curve) throughout the range of motion. Theoretically, this causes the muscle to contract maximally throughout the range of motion and results in greater gains in strength. Due to variations in limb length, point of attachment of the muscle’s tendon to the bones and body size, it is hard to conceive of one mechanical configuration that would match the strength curve of all individuals for each exercise. Biomechanical research has shown that for at least one type of variable resistance equipment, considerable modification of the five exercise machines is required to approximate the strength curves of the exercise movement (21). Changes in strength using variable resistance exercise are similar to free weight and non-variable resistance exercise equipment (12). Any superiority has yet to be clearly established. Thus, loading and prescription follow that of dynamic constant external resistance exercise.

Eccentric Training

Each resistance training exercise typically has a concentric (shortening) and eccentric (lengthening) phase. Thus, the weight is lifted up and returned to its starting position using these two directional contractions. Eccentric training, where this lengthening phase of the movement is loaded, gained attention in the 1970s. It was discovered that muscle tension is higher during eccentric contractions than it is during either isometric or concentric contractions (36). Short-term eccentric training has been shown to cause significant increases in resistance and isometric contractions (48). The importance of the eccentric contractions in resistance training was noted by Kom and Buskirk (30), who demonstrated that eccentric training caused greater increases in maximal eccentric, concentric and isometric force than the same program using only concentric contractions. However, subsequent studies reviewed elsewhere (4, 8, 13) have been unable to demonstrate any clear superiority of eccentric training. Present scientific investigations are now focusing on the role of eccentric contractions in physiological adaptations to resistance exercise.

When eccentric training is used as the primary training style for a particular exercise, limited data suggest that optimal loading is 120 percent of the concentric 1 RM (26). Future studies need to evaluate other loading strategies. Other considerations are also important. A disadvantage of eccentric training is the development of greater post-exercise soreness than that which accompanies isometric, concentric and dynamic constant external resistance exercise (13, 42). Soreness usually peaks at 48 hours after exercise and lessens after each subsequent training session for a period of two weeks (13, 30). After this time, soreness is no worse than that which follows isometric training (30). To lift such heavy loads, training partners and/or special equipment are used to perform exercises using this style of lifting. Eccentric training is not the primary mode of most resistance training programs and is typically used to provide variation in the exercise program.

Isokinetic Training

Isokinetic typically refers to a muscular contraction performed at a constant angular limb velocity (29). A machine is needed to exercise in this fashion. This form of training has gained popularity in injury rehabilitation/evaluation and specialized training settings. Isokinetic training allows the individual to exert maximal force continuously throughout the range of motion and allows for training to occur at various speeds of contractions. Recently, a new generation of isokinetic machines allows for both eccentric and concentric isokinetic contractions. Previous research to date has examined concentric isokinetic training.

Isokinetic training increases isokinetic strength. A wide variety of exercise protocols has been utilized and reviewed elsewhere (4, 12, 13). Studies to date suggest a number of general guidelines for exercise prescription concerning short-term (six to 20 weeks) training responses: 1) the number of repetitions performed appears to have little to do with increases in peak torque (Note: minimum of 3); 2) the velocity of training is dictated by the velocity of the desired peak torque increases (i.e. if an individual wants peak torque increases at slow speeds, slow speed training is prescribed; conversely, if the goal is peak torque increases at fast speeds, fast speed training is prescribed); and 3) if only one velocity is used, an intermediate training velocity is recommended for greatest strength carryover to other velocities.

A summary of various studies and the effects of various resistance training programs on strength improvement can be seen in Table 1.

Other program variables also need to be considered prior to planning the resistance training exercise session.

Order of Exercise

Typically, large muscle group exercises (e.g. squat) are performed before smaller muscle group exercises (e.g. leg curls) for the same body part. It has been theorized that exercising larger muscle groups first provides a greater stimulus to the muscles involved. East European lifters have utilized “pre-exhaustion” orders where the reverse order is utilized. This pre-exhaustion technique has been typically used by elite lifter groups, and its efficacy remains to be determined. The empirical evidence still indicates that large muscle group priority results in better training responses. Again, efficacy of “pre-exhaustion” techniques and order effects require further direct study.

Order considerations must also be made if one develops a circuit training program where the individual moves from one exercise to another. Beginners are many
times less physically tolerant of performing arm-arm or leg-leg exercise sequences, but trained individuals may benefit from the added exercise stress in this type of exercise protocol. This again points to the need for individualizing the configuration of the exercise stress.

Length of Rest Periods
Many times the length of the rest periods taken between sets and exercises is overlooked when designing a resistance training program. The amount of rest allowed will determine the metabolic reliance upon glycolytic energy.

| Table 1. Effects of selected resistance training programs on maximal strength |
|---------------------------------|------------------|-----------------|------------------|
| **A. Upper Body (Chest)**      |                  |                 |
| Type of Training               | Days/WK          | Length of Training | Program (Sets/Reps) | % Increase in mode specific strength (sex) | Ref |
| IM                              | -                | 100 days         | 3-10 sec contractions/day Elbow flexors | 92 | 25 |
| IM                              | -                | 36 days          | 10-5 sec contractions/day Elbow flexors | 20 | 6 |
| IM                              | -                | 36 days          | 1-5 sec contractions/day Elbow flexors | 0 | 6 |
| IM                              | -                | 35 days          | 42-3 sec contractions/day Triceps surae | 30 | 10 |
| IM                              | -                | 28 days          | 30-3 sec contractions/day Elbow flexors | 20 | 34 |
| IM                              | -                | 30 days          | 30-3 sec contractions/day Triceps | 32 | 19 |
| DCR                             | 3                | 24 wk            | 8 wk = 1x10, 8, 7, 6, 5, 4 | 38(F) | 7 |
| DCR                             | 3                | 9 wk             | 2x20 | 26(F) | 32 |
| DCR                             | 23               | 10 wk            | 2x7:16 | 29(F) | 45 |
| DCR                             | 3                | 10 wk            | 40-50%1RM for 30 sec | 16(M) | 46 |
| DCR                             | 3                | 20 wk            | 50%1RM, 6 wk = 2x10-20 | 20(F) | 8(M) |
| DCR                             | 3                | 10 wk            | 14 wk = 2x15 | 32(M) | 16 |
| IK                              | 3                | 8 wk             | 2x8-10 RM | 12(M) | 9 |
| IK                              | 3                | 8 wk             | 4 wk = 1x10 at 60° sec⁻¹ | 22(M) | 15 |
|                                 |                  |                  | 4 wk = 1x15 at 90° sec⁻¹ |                  |

|  |  |  |                  |                  |                  |
| **B. Lower Body (Legs)**       |                  |                 |
| DCR                             | 3                | 9 wk             | 2x10 | 48+(F) | 32 |
| DCR                             | 3                | 24 wk            | 8 wk = 1x10, 8, 7, 6, 5, 4 | 29(F) | 7 |
| DCR                             | 3                | 10 wk            | 16 wk = 1x10, 6, 5, 4, 3 | 27(F) | 46 |
| DCR                             | 3                | 12               | 40-50%1RM for 30 sec | 2x8 | 1 |
| DCR                             | 3                | 10               | 1 x to exhaustion | 71+(M) | 1 |
| DCR                             | 3                | 10               | 40-55%1RM for 30 sec | 3x8 | 1 |
| VR                              | 3                | 10               | 2x8-10 RM | 17(M) | 9 |
| VR                              | 3                | 10               | 3x8 | 27(M) | 37 |
| IK                              | 3                | 8                | 3x8 | 18*(M) | 16 |
| IK                              | 3                | 8                | 4 wk = 1x10 at 60° sec⁻¹ | 38(M) | 15 |
| IK                              | 3                | 20               | 4 wk = 1x15 at 90° sec⁻¹ | 2x12 at 60° sec⁻¹ | 42(M) | 17 |

IM = isometric
DCR = dynamic constant external resistance
VR = variable resistance
IK = isokinetic
+= values for 10 RM
++ = values for mean training weights
* = values for number of weight plates
RM = repetition maximum
sources. Even in circuit weight training where one minute rest periods and loads ranging from 40 to 60 percent of 1 RM are used, peak blood lactate concentrations exceed 13 mmol-L⁻¹ (18). When trained competitive athletes utilize heavier loads (70 to 80 percent 1 RM) peak blood lactate concentrations can exceed 23 mmol-L⁻¹ when short (30 to 60 second) rest periods are used (12). Thus, reduction of the rest period length may impair the maximal force production capability due to physiological alterations (e.g. decreased pHI) in the muscle and may not be desirable when typical strength training programs are utilized. If performance demands require the individual to tolerate high lactate concentrations for such sports as wrestling or middle distance sprints (e.g. 400 to 800m), this aspect of program design may provide a potent tool to utilize when designing a sport-specific resistance training program. Careful manipulation of rest periods is essential to avoid placing inappropriate or needless stresses on the individual during training.

Number of Sets
The number of sets utilized in an exercise session is directly related to training results. Typically three to six sets are used to achieve optimal gains in strength (4, 8, 12). Multiple set programs appear to improve the rate of strength gains compared to single set systems (12,33). Use of one or two sets may be more appropriate for beginners in the initial stages of a starter program or for circuit weight training. Once basic fitness has been achieved, a multiple presentation of the exercise stimulus (three to five sets) with proper rest periods between sets is superior to a single presentation of the exercise stimulus.

Frequency of Workout
The amount of rest between training sessions depends on the recovery ability of the individual. Traditionally, three workouts per week (MWF) were found adequate for recovery. As one advances and is better able to tolerate resistance exercise sessions, the frequency may be increased. A recent report has gone so far as to propose that four days in succession may be superior to three alternate days in effecting increases in strength (24). This suggests that the interaction of stress and recovery may be more complex than previously thought. Training frequency is a function of the type of training session, and the individual’s training experience and physical condition. It is well known that competitive lifters train six days a week and some beginners can tolerate only three days a week. Excessive soreness and fatigue are just two symptoms that mean the exercise stress is too demanding and that the exercise program needs to be reduced in severity.

After initial decisions are made for each of the acute program variables, a program is written. It is recommended that the optimal program is written first and then altered for any administrative limitations, (e.g. equipment availability). Thus, the optimal exercise stimulus is consid-

ered first, before changes in the program are made.

The next challenge in program design that must be addressed is to alter the training stimulus over time. Empirical and scientific evidence have shown the importance of providing variation in the training program.

Variation in Training
If training is to remain effective over longer periods of time, there is a need for variation in the training stimulus. Over the past several years, studies have demonstrated superiority of “periodized” resistance training over programs which perform the same exercise protocol each training session (40, 41). Periodization gained popularity among Eastern European weightlifters (31, 43). Over the past 10 years many different empirical models for periodizing training have been proposed and are described in detail elsewhere (12, 31, 40, 43). Still, one of the underlying concepts is to start with higher volumes of exercise and lower exercise intensities. Then over the course of a training period (divided into different cycles) the volume is reduced as the intensity is increased in the attempt to maximize strength/power development and to avoid overtraining. For advanced athletes the same basic pattern is used, but the volume of exercise is not reduced as much as it is in a novice lifter.

The superiority of different periodization or training variation models remains to be determined. Some lifters just alternate heavy (e.g. 3 to 5 RM), moderate (e.g. 8 to 10 RM), and light (e.g. 12 to 15 RM) days through the week. Others perform light sets for two to three weeks, moderate sets for two to three weeks and heavy sets for two to three weeks. Thus, variation is achieved in many ways over a training period. Future research efforts will need to provide further clarification of the efficacy and optimal methods of varying the exercise stimulus for not only strength/power development but other performance measures (e.g. high intensity endurance lifting) as well.

When designing resistance training programs, it is important to have specific goals. To mention a few, common goals are muscular hypertrophy, increasing 1 RM strength in various lifts and improving performance in a particular sport. Do not make the mistake of just adapting a program because a successful athlete used it. Evaluate individual needs, goals, demands, and prescribe exercise which will bring about the realization of the individual’s potential in these areas. The ability to design a successful resistance training program still requires good judgment and an understanding of the scientific basis for the choices made in the exercise prescription process.

References


An Interview with Dietmar Schmidtleicher
On Strength Training for Children

The September issue of the NSCA Bulletin featured Part 1 of an interview with Dietmar Schmidtleicher, conducted by Laurie Woodman and previously published in Australia's Sport Coach newsletter, October, 1987. Dr. Schmidtleicher is affiliated with the Sports Science Institute at Frankfurt University in West Germany. Mr. Woodman is the Executive Director of the Australian Institute of Sport. Their topic in this segment of the interview is prepubescent strength training.

LW: What are the most common mistakes that coaches make in strength training?

DS: There are a lot, but I will tell only some of them. The first one is working with the lower and the upper extremities and forgetting to work with the back or with the abdominals. Javelin throwers or shot putters, for example, will fail because the impulse produced with the legs never will reach the arms because they are weak in between. The second mistake is training only those muscles which give the main power for the event, and not working with the synergistic muscles. The third is not using sophisticated enough planning; not knowing when to introduce the phase. Coaches know they should do some strength training, but they don't know exactly at what time during the preparation or the competition phases this should happen. And they don't know if it's better to train in the morning or in the afternoon. That comes from the common mistake of generalizing about strength training or weight training. In endurance type training, we don't speak about endurance training, we speak about anaerobic training, about anaerobic alactic training or about aerobic training, and we should do the same in strength training. We should speak about a type of strength training in which we use the nervous adaptation, or about the type of strength training that we use for hypertrophy or for plyometrics, etc. Then it becomes much more easy for the coach to put it at the right time in the preparation phase, and in the daily training unit.

Strength training sometimes has to be done first and sometimes it should be last; it depends what type of strength training you do. And the fourth mistake, which is a common one, is that coaches don't really know at what age they can start children on weight training. So they wait for a very long time and normally start too late.

LW: What is the best time for children to start strength training?

DS: The medical doctors normally say around 14 to 16. The concentration of male hormones at that age is high enough to get a good increase in strength after a training period. The other point is that you will have an increase in maximum strength and the rate of force growth development. If you commence strength training at the age of 8, 9 or 10 there is not as big an increase as you will have later on, but you do have an increase, and in my opinion, from our experiences, it is much better to start between 8 and 10. It must be done very, very carefully, not too much, step by step, using a lot of forms in which you have weight training or strength training as games. Then increase the load step by step so that at the age of 13, 14, 15 or whatever it is, children know the skills which are necessary for safe, effective weight training. They have stronger muscles; not only those which they need for power, but also the supporting muscles, and their body is trained to take the high stresses of strength and regeneration. For those who start strength training at an early age there is a reduction in the incidence of injuries sustained during their whole high performance career, compared to those who start at the age of 14 to 16.

LW: If they start early, are they able to tolerate higher loads and more intensive training at an earlier stage as they begin to mature?

DS: Of course, because they are more experienced and their regeneration phases are shorter.

LW: The sports medicine specialists here say that you shouldn't have children doing weight training or particularly heavy weight training when they are young because of the dangers to the epiphyseal plates in the bones.

DS: Yes, I would agree with that, but the problem is not the load, the problem is how you organize the training
process. It's the same in West Germany. On the other hand, they say don’t use maximal contraction, but on the other hand they include jumps in all the training plans for the sports played at school. If you jump, you place about 10 times your body weight on each ankle, and if you jump down from a height of 80 cm your landing force is doubled. You can never get loads like that with a maximal voluntary contraction.

LW: What are the maximum voluntary loads that children can handle?

DS: As long as the maximal load is done under controlled conditions, that is, you support the back or the chest, there should be no danger. It is important that maximal contractions against maximal loads only be used under the control and direct supervision of the coach. As long as the coaches supervise and control it they can be sure they know what the kids are really doing. If they don’t control it, the kids will try by themselves, because everyone wants to know how strong he really is, and he has to use maximal loads to find out. Such unsupervised training can be very dangerous.

LW: In strength training, do we have anything to learn from the bodybuilders?

DS: Yes, I think so. The bodybuilders have developed a unique set of methods which produce the greatest hypertrophy in the shortest time span. I think you should use those bodybuilding methods because you can save time and you can use this time from other things.

LW: What are the main orthopaedic dangers of strength training?

DS: Orthopaedic problems can occur if it is not done in a sophisticated manner. For example, if you use training forms like “good mornings” with athletes who are not used to it or not strong enough, you can get into difficulties. Bodybuilders and weightlifters use good mornings, but they have muscles which are extremely strong, so nothing will happen. But normally with track and field athletes or with newcomers or juniors you can’t do this exercise. As long as you maintain the movement controls, and you include the appropriate regeneration phases, and these are long enough, you will have no difficulties with strength training. If someone has orthopaedic problems, he can go to an orthopaedic specialist who will diagnose strength training. So the best prevention against problems with strength training is strength training.

LW: If you are working with an athlete in strength training, do you have a preference for machines or free weights, or do you prefer to use them only in certain aspects of training?

DS: It depends a little bit on the habits and personality of the athlete. If he prefers a special type of machine and he works well on this machine, then he should use it. I think it is more important that he does weight training at all, and you shouldn’t force him to use a type of machine he does not like. I personally would prefer free weights, because normally with free weights more muscle groups are involved in one movement, and therefore, more muscle groups are trained. The disadvantage is that it takes a lot of time before the weight training skills are carried out correctly. Therefore, machines can be a big help for novices or newcomers because they reduce the technical element of effective free weight training.