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The Obtuse Nature of Muscular Strength: The Contribution of Rest to its Development and Expression

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ABSTRACT

Weiss, L.W. The obtuse nature of muscular strength: the contribution of rest to its development and expression. *J. Appl. Sport Sci. Res.* 5(4):219-227. 1991.—*Various resistance activities are used today to increase the force-generating capacity of specific skeletal muscles. Many interdependent factors influence the magnitude of improvement, but great muscular tension during training appears necessary to elicit the desired changes in muscle function. If adequate tension is to be manifested in specific muscles, they must not be excessively fatigued. Consequently, sufficient rest should be provided during and between strength-training sessions in order for recovery to occur. In addition, when other components of motor or physical fitness are concurrently being developed, precautions should be taken so that fatigue does not adversely affect strength development. In many cases, this requires the conduction of strength training and other conditioning activities during dedicated times within a session or at different times of the day.*

Rest may be categorized as occurring during a training session (intratraining-session rest), between training sessions (intertraining session rest) and just before a performance or test (pre-performance rest). In order to enhance muscular tension during strength training, the phosphagen system should serve as the primary catabolic vehicle for the resynthesis of adenosine triphosphate (ATP). Five or fewer repetitions of each lift should be completed per set, and exercises involving some of the same muscle groups should be separated by about three or four minutes, depending on the trainee's recovery capacity. Specific guidelines currently are unavailable concerning intertraining-session rest due to methodological dilemmas in experiments designed to test them. The primary problems to be resolved are to identify a physiological marker indicating the point of maximal overcompensation consequent to each training session, and whether training volume should be standardized per session or per week. Evidence relating strength to pre-performance rest is meager at best. However, some preliminary work appears to indicate that 96 hours of rest may enhance strength performance as measured against a constant external load, while 48, 72 and 120 hours of rest appear to have no significant effect on moderately trained men. Although these findings are preliminary, they do seem to coincide with the effects of tapering during training for competitive swimmers.

KEY WORDS: isokinetic contraction, dynamic concentric/eccentric contractions, muscular fatigue, recovery, tapering, training frequency.

INTRODUCTION

An increase in muscular strength can enhance an average person's ability to perform activities that require great force output, and can improve a weak person's performance of daily activities. Consequently, people participate in strength-training programs for diverse reasons, ranging from rehabilitation to preparation for fire fighting, law enforcement, military duties, or competitive and recreational sports. Another reason for weight training is to reduce the likelihood or severity of injuries that may occur during vigorous physical activities (10, 27, 53, 59).

The magnitude of strength gains depends on many interacting elements, including the genetic potential for increasing strength, the specific muscles used during a sequence of training exercises, the short- and long-term variability of the exercise routine, the overall intensity of training sessions and the quantity and locus of rest (9, 17, 34, 55, 61). This review primarily focuses on the role of rest on the development and expression of muscular strength.

Rest will be considered as recovery time after participation in heavy-resistance activities, and may or may not involve sleep. There are three subcategories: intratraining-session rest, intertraining-session rest and pre-performance rest. Intratraining-session rest is the interval of inactivity between multiple sets of a single exercise or a series of exercises. Intertraining-session rest is the period of inactivity between exercise sessions (often referred to as training frequency). Pre-performance rest is the interval between the final training session and testing or competition.

Unfortunately, few experimental studies have directly addressed the role of the subcategories of rest on strength performance or development. In addition, any consensus is hindered by an overall absence of standardization of semantics, experimental treatments and testing protocols in strength-related research. An attempt follows to establish some common ground for subsequent specific discussions on the role of rest in developing and expressing strength. The next two sections include discussions of some ambiguities in measuring strength and the primary factors underlying training-elicited strength gains.

AMBIGUITIES IN MEASURING STRENGTH

Distinctly different measurements of strength frequently are lumped together into one broad category. This may once have been appropriate, but technological advances in recent years have made it possible to evaluate strength in more complex ways. Phenomena that appear to affect one measurement of strength do not necessarily have a similar influence on alternative measurements. Therefore, a critical need appears to exist for specifying how strength is measured; otherwise, a misapplication of results may occur.

Strength testing historically has involved two general types of skeletal muscle contractions: isometric (static) and dynamic (constant external load and isokinetic). An increase in isometric strength generally is regarded as having little relationship with improvements in athletic performance that requires the generation of an appreciable amount of dynamic force. This appears to be due, in part, to an absence of common movement; therefore, an assessment of isometric strength seems to have limited potential for application to most sports and recreational activities (3, 12, 15, 18). On the other hand, dynamic strength is considered more highly related to activities that require a great deal of dynamic force, especially when movement patterns used in testing are similar to those used in the actual activity (17, 18, 51). Unfortunately, even dynamic strength has specific limitations in practical applicability.

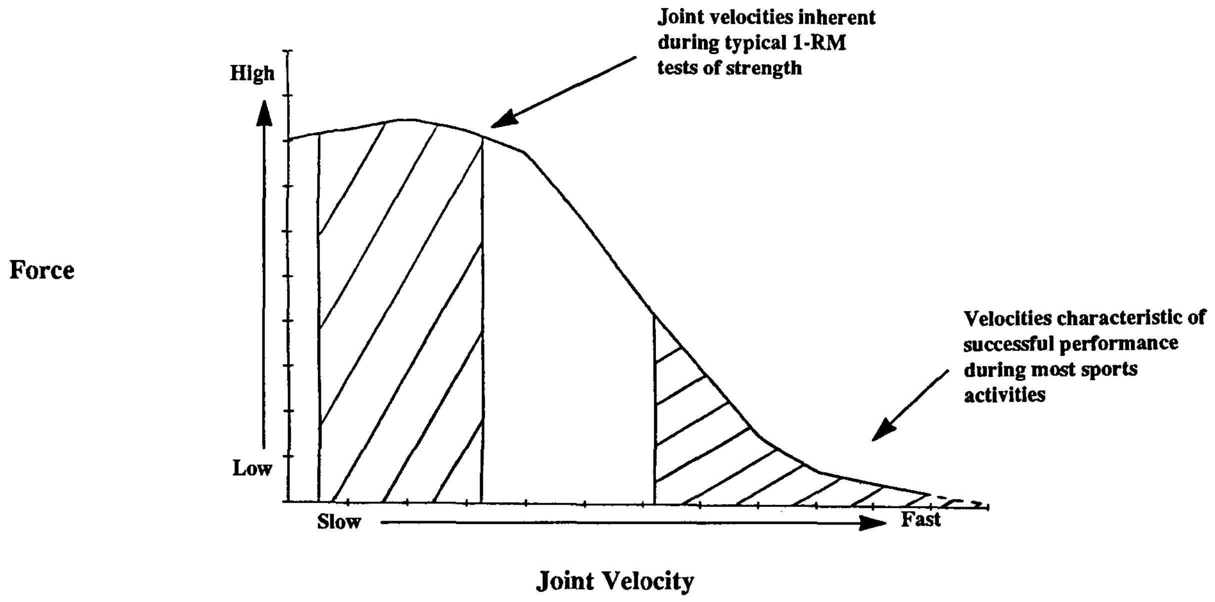
There are two major expressions of dynamic strength, which incorporate what are commonly referred to as either concentric/eccentric constant exernal load or isokinetic contractions (44). The term isotonic is inappropriate because no dynamic contraction can maintain a constant force through the range of motion. Typically, maximum strength involves the movement of the heaviest possible constant external load through a specified range of motion at a variable speed for one repetition (1 RM). In this situation, strength is limited by that portion of the lift in which the trainee is weakest. Also, skeletal muscles have a tendancy to contract at progressively slower rates of speed as the load against which they are used is increased. This force-velocity relationship has been described as a hyperbolic curve for isolated muscles (29), whereas slight variants to this have been reported for some in vivo assessments (8, 26, 48, 60). These reports indicate that when humans are tested under slow-speed conditions, slightly less force is sometimes generated compared to what would be predicted from the in vitro model (see Figure 1).

Because many traditional 1 RM tests of dynamic strength (parallel squat, bench press, shoulder press, arm curl) involve relatively slow-speed motions (olympic-style lifts are notable exceptions), and the speeds inherent in many physical activities that involve the generation of an appreciable amount of force are relatively fast, the relation of the two is questionable (61) (see Figure 1). Therefore, the use of 1 RM tests, other than those similar to olympic-style lifts, would seem to apply directly to only a small, select group of sports and recreational activites that involve great force output at relatively slow speeds. The olympic-style lifts may be more useful in this regard, but a great deal of technical skill is required to safely perform them on a 1 RM basis.

An alternative test of maximal strength may be administered if isokinetic equipment is available. In this case, movement takes place at a controlled, constant speed, thereby allowing force output during selected motions to vary with changes in musculoskeletal leverage. The dynamic contractions involved under these circumstances have been termed isokinetic. Force output during isokinetic contractions typically is monitored throughout a designated range of motion, and the completion of two or three consecutive repetitions normally is required for maximal force to be achieved (47).

When expressing force output or strength derived from isokinetic tests, several factors should be considered. First, because force output may be tested at many velocities, the velocity used may substantially influence the outcomes of various experimental treatments. Second, because the effects of various training programs on the force-velocity relationship are currently unclear, isokinetic tests of muscular strength would be more meaningful if

Figure 1. Typical force-velocity relationship for skeletal muscles operating against a variety of loads. For many lifts, a problem may arise in the use of the traditional 1 RM strength test. When a maximum force is exerted against a constant external load, as in the bench press or squat, the velocity at which the force is exerted may be substantially slower than the speeds used in most sports. When viewed in this manner, the typical 1 RM strength test may not reflect an athlete's ability to exert force during a particular motion in a sports setting.



administered using a wide variety of speeds. Third, access to instantaneous measurements of force gives investigators the opportunity to express strength in several ways. For example, strength may be expressed as the force exerted at a designated bar angle, as the peak within the full range of motion, as the average force over a specified range of motion, or as an average value for multiple repetitions. These four expressions of isokinetic strength are not necessarily related, so the interpretation of strength data could vary profoundly as a result of choosing one expression over another. Therefore, the particular expression used for isokinetic strength should be clearly identified.

Typical physical activities do not involve the constant-velocity motions characteristic of isokinetic tests. Furthermore, because most isokinetic devices can measure only concentric contractions, access to data on eccentric actions frequently is unavailable. Eccentric strength plays a critical role in many athletic or recreational activities. For example, gymnasts use eccentric actions to block or convert horizontally oriented linear velocity into vertical distance during floor-exercise and vaulting routines. Therefore, specific circumstances exist in which the omission of eccentric measurements may contribute to a misapplication of various research findings on muscular strength. Furthermore, testing/training modality transfers must be considered as a carryover of strength training. Gains may not be observed with isokinetic testing when training is performed on conventional equipment (e.g., barbell, weight machines).

A collective consideration of the limitations associated with strength assessment clearly indicates a need for additional technological advances. Although dynamic constant external load and isokinetic measurements of dynamic strength have specific limitations, they currently appear to be the best representations of strength in many activities (61).

For this review, strength is used in a broad sense. It is defined as the maximum quantity of force exerted either against a specified mode of resistance or at a specific speed of motion at any point in a designated range. No distinctions will be made for inter-individual leverage variability, for the use of complex machines versus free weights, between single- and multiple-joint movements, or between fast- and slow-speed movements. Obviously, this broad treatment of strength may compromise the exernal validity (increase the probability of inappropriate generalizations being made). This should be considered as subsequent sections concerning the role of rest on strength performance and development are presented.

PRIMARY FACTORS UNDERLYING TRAINING-ELICITED STRENGTH GAINS

Two primary factors are fundamental to any program designed to enhance muscular strength, especially if the gains are intended to improve physical performance in selected activities or to prevent injuries. These factors are muscular tension and training specificity.

Adequate Muscular Tension

Exercise-induced gains in muscular strength appear to be roughly related to the amount of tension produced in dynamically contracting skeletal muscles, with progressively more pronounced improvements taking place consequent to increasing tension (2, 16, 22, 23). This tension/strength-enhancement relationship appears to be nonlinear when two or fewer maximal repetitions are completed. The additional muscular tension associated with completing 1 RM or 2 RM appears to elicit no greater strength gains in previously untrained individuals than performing multiple sets of 5 RM or 6 RM (5, 46). Also, sets including large numbers of repetitions involve substantially less tension per repetition and consequently elicit minimal gains in strength (2). Atha noted that "tension, not fatigue, is the strengthening stimulus, although the additional effects of stretch induced by the tension also contribute and a fatigued muscle cannot generate enough tension to reap the benefits of a maximum adaptive response" (3). Although advanced trainees likely will respond differently to various sets and loads, empirical evidence indicates a continued necessity for high skeletal-muscle tension for subsequent gains in strength.

The factor of tension duration needs some mention at this point. Not only is high muscular tension a requirement for appreciable strength improvements, but an undefined minimum per-contraction duration of this tension also appears to exist (3). For example, ballistic activities characteristically involving short bursts of muscular activity do not appear to appreciably enhance strength even though muscular tension is near maximal.

If these assumptions are generally correct, and maximal strength gains are a high priority, then training should involve near-maximal tension of essentially non-fatigued skeletal muscles for some currently unspecified duration per contraction.

Training Specificity

A second concept critical to strength development is training specificity. Physiological systems tend to adapt primarily to the specific stresses placed upon them (19, 43, 50). Wallis and Logan called this the SAID (specific adaptations to imposed demands) principle (57). As related to strength training, the SAID principle indicates that only those muscles exposed to a training stimulus will increase in strength. The specific movement pattern used in training is where most strength improvement will occur, even when different exercises involve identical muscle groups.

As noted previously, maximum strength development appears to result from high tension as opposed to muscle fatigue. However, it is unclear how this principle applies during initial involvement in strength training, when specific neurological adaptations or learning are the primary bases for strength increases (35, 41, 49). It seems reasonable that with learning playing a pivotal role in early strength development, training programs for novices should be designed to initally maximize learning. Unfortunately, studies of the effects of fatigue and rest on motor learning provide little clarification because no consensus exists (1, 36, 38, 42, 52). A conservative approach in addressing this situation would be for novices or trainees learning a new lift to minimize fatigue at the beginning of each set. It also would seem prudent to use a submaximal resistance for a higher than typical number of repetitions until the new lift has been thoroughly learned.

Another factor germane to the specificity of strength development is the use of energy systems. One interpretation of the SAID principle suggests that trainees stress the same energy systems during conditioning that will be used during performance. This will be addressed in the discussion of intratraining-session rest.

The primary factors of adequate muscular tension and training specificity will be used as bases for the following discussion on appropriate intra- and intertraining-session rest intervals for maximal strength development.

INTRATRAINING-SESSION REST

As noted earlier, heavy-resistance programs designed to maximize strength development should involve great muscular tension. Fatigue reduces the potential of skeletal muscles to exert force due to a concomitant reduction in tension development. Therefore, fatigue appears to compromise the training stimulus for strength development. In that regard, energy-system use during weight training plays an important role in the fatigue process.

The energy for all skeletal muscle contractions is provided by the hydrolysis (breakdown) of the high-energy phosphate compound known as adenosine triphosphate (ATP). This energy is released when a phosphate molecule is chemically cleaved from ATP. Unfortunately, ATP quantity is somewhat limited and must be restored in order for high-tension muscular contractions to continue. Another high-energy phosphate compound known as phosphocreatine (PCr) can be used to help replace ATP. This process apparently involves the splitting of PCr into a creatine molecule and an inorganic phosphate, resulting in the release of sufficient energy to reform ATP. PCr hydrolysis for ATP resynthesis consequent to muscular contractions is known as the phosphogen system. This process is quite powerful in terms of ATP resynthesis per unit of time. Unfortunately, the supply of PCr is quite limited. It may be nearly depleted in a maximally worked skeletal muscle in less than 15 seconds, after which adequate ATP resynthesis may occur only if the intensity of the exercise is reduced (25, 40, 61).

Heavy-resistance programs involving the completion of five or fewer repetitions (usually 12 to 15 seconds) to a point approximating failure primarily rely on the phosphagen system for energy needs. If rest is provided after this short-term intensive exercise, the body will primarily use aerobic catabolism, a more efficient but less powerful process involving the consumption of oxygen for resynthesizing ATP. Aerobic catabolism not only provides for the body's energy needs during rest, but also for the restoration of ATP and PCr within three or four minutes of actual rest (30, 32). ATP and PCr resynthesis likely will be delayed if strenuous exercise involving the same muscles is resumed before full recovery.

If the weight-training program involves the completion of substantially more than five repetitions, or if a set is repeated before three minutes of recovery, an alternative source of ATP resynthesis will be increasingly relied upon. Under these circumstances, the working muscles tend to use an energy system known as anaerobic glycolysis to reform ATP. Anaerobic glycolysis is nearly as powerful as the phosphagen system, but results in both the production and accumulation of lactic acid (lactate) in the active tissues. It has been reported that maximal isometric force-generating capacity following sustained (average = 52 seconds) submaximal contractions (60 percent MVC) in humans is restored within two minutes, even though intracellular pH remains at a very low level (56). Although lactate accumulation is reduced somewhat during this short recovery period, the authors speculated that hydrogen ion concentration correspondingly increases due to PCr resynthesis. This combination of actions would result in the maintenance of a low intramuscular pH. Unfortunately, it is unclear whether recovery from dynamic contractions operates in a manner similar to what Sahlin and Ren reported for isometric contractions (56). Based on this report, however, there is reason to suspect that at least some near-maximal contractions can take place after as little as two minutes of rest, particularly if the number of repetitions per set is no more than five.

On the other hand, if multiple sets are completed using a two-minute rest interval, intramuscular PCr supply would be progressively reduced because only a portion of the normal resting level is restored in that time period. The obvious question, then, is whether an increasing reliance on anaerobic glycolysis during dynamic resistance training will impair tension development and subsequent gains in muscular strength. Because the answer is currently unclear, a conservative approach to establishing an intratraining-session rest interval would be prudent. This would mean allowing three to four minutes for full recovery of intramuscular PCr levels. This might be accomplished by completing all sets desired for a given exercise with three to four minutes rest between sets, or more efficiently by setting up a circuit of exercises, each of which involves different muscle groups. In this way, the rest interval provided between different exercises could be very short (one to two minutes is suggested) as long as the involvement of each muscle group is separated by four or five minutes. This longer rest interval is preferred because each of the involved muscle groups will require a portion of the aerobically generated ATP for restoration of its own intramuscular stores of ATP and PCr, which may result in the need for a larger than normal recovery time. During heavy squats, cardiac output may be temporarily compromised due to very high intra-abdominal and intra-thoracic pressures.

If a reduction in the intratraining-session rest interval is necessary and results in some lactate accumulation, recovery might be facilitated by very light muscular activity between sets, including the fatigued body parts. Because aerobic catabolism is primarily responsible for recovery, easy rhythmical movements tend to facilitate it by enhancing circulation via the muscular pump. The enhanced circulation associated with light muscular activity facilitates the movement of lactate to the heart, where it can be used directly as a source of fuel for ATP resynthesis, and to the liver, where it can be converted to glycogen through gluconeogenesis (6, 7). Much of the excess lactate can be oxidized by the slow-twitch oxidative fibers involved in the light muscular activity (14, 28).

Circuit weight training has been used for years to develop sport-specific strength and for general conditioning. Recently, some investigators have suggested manipulating the number of sets and repetitions as well as the duration of rest intervals, so that the particular energy system primarily used during competition is also used during training (33, 39, 45). One rationale for involving the same energy system that would be used in the actual physical activity is to fully apply the SAID principle. For example, if a sport or physical activity primarily uses anaerobic glycolysis to provide energy for muscular contractions, a heavy-resistance program would be designed to do likewise. A training program following this rationale might be used to set up a program involving as many as 20 to 25 repetitions of a particular exercise per set, with short rest intervals (usually less than one minute) between multiple exercises. Although circuit weight-training programs may significantly increase strength (20, 21, 62), the large number of repetitions and the short rest intervals are designed to incompletely restore intramuscular ATP and PCr levels and substantially increase lactate levels (13, 19). Because this type of program is designed to fatigue the trainee, it is unlikely that maximal muscular tension-development will be possible. Therefore, even though strength may be enhanced, it is highly improbable that the increase will be maximal.

If muscular tension and not fatigue is the primary strengthening stimulus (2, 16, 23, 24), then strength training for specific muscles should be avoided when they are fatigued. When a lifter primarily depends on anaerobic glycolysis for energy requirements during training by interspersing short rest intervals between multiple sets or by doing many repetitions per set, strength development may be compromised. For example, bodybuilders typically depend on anaerobic glycolysis for energy requirements during training. Although experienced bodybuilders are undeniably strong and have undergone a great deal of muscular hypertrophy, they are usually not as strong as comparably sized powerlifters (squat, bench press, deadlift). The link between short rest protocols using heavy resistance (eight to 10 RM) and muscular hypertrophy remains to be clarified. Powerlifters, on the other hand, typically train with sets involving few repetitions interspersed with relatively long rest or recovery periods. Consequently, they rely primarily on the phosphagen system for their energy needs during training. Lamb suggested that in order for maximum strength development to occur, the lifter should rest for five to 10 minutes between sets that primarily involve the same muscle group (34). He reasoned that a fully recovered muscle is best able to respond to the training stimulus. This rest interval is substantially longer than the three to four minutes suggested by others (32, 37) but, as alluded to previously, might be appropriate during sets that involve a particular muscle group during circuit weight training. It is currently unknown whether excessive rest between sets has positive, negative or no effects on strength development.

Trainees who need a great deal of strength in a particular physical activity should use intratraining-session rest intervals of sufficient duration to allow the lifter to primarily use the phosphagen system during actual lifting. If maximal strength gains are unnecessary or unsafe, as for young children or the elderly, a less strenuous program using lighter loads and more repetitions would be more appropriate. Furthermore, because recovery rates vary between individuals, intratraining-session rest intervals should be individualized. If successful performance depends on great muscular strength as well as anaerobic glycolysis for ATP restoration, a separate activity-specific training session should follow strength training to address that need.

INTERTRAINING-SESSION REST

It is generally accepted that a period of rest is needed after each heavy-resistance training session in order for the skeletal muscles involved to fully recover from the stress placed on them (59). What is lacking, however, is either a physiological marker or a definitive time frame indicating when the lifter should repeat the exercise training session to obtain optimal results.

As previously discussed, a lack of standardization of such factors as semantics, experimental treatments and testing protocols has made it difficult to generalize results of strength training studies. Variations in the training routines and conditioning status potentially confound the effects of various intertraining-session rest intervals on strength improvement (4). In addition, the short time frame for most studies, and whether to control for total training volume, have been controversial issues plaguing efforts to advance our understanding of this phenomenon.

The time-frame issue continues to be a problem, primarily because it is difficult to successfully retain enough subjects for a long-term training study. Most investigators are constrained by the length of an off-season or school term, or by the motivation of the subjects to continue a specific training program over an extended period of time. In general, this means that most training studies have been short in duration, making it difficult to determine the long-range effects of various training routines.

The controversy concerning whether to equate volume when comparing training programs is particularly troublesome for studies that address intertraining-session rest. As it is commonly used in dynamic constant external resistance strength training studies, volume is the sum of all weight lifted within a training session, regardless of the range of motion. For example, a trainee completes four sets of bench presses including 10 repetitions x 60 kilograms, 8 reps x 80 kilograms, 6 reps x 90 kilograms and 5 reps x 95 kilograms. Volume for the bench press in this training session would be 2,255 kilograms.

If a study is conducted involving various intertraining-session rest intervals, and an attempt is made to equate volume over the period of a week, then sets and repetitions would be adjusted so that a trainee using a short intertraining-session rest interval would complete no more total volume per week than a person using longer rest intervals. In the above example, a person training three days a week would be able to complete only one set of bench presses per exercise session instead of three, and might use 9 repetitions x 85 kilograms (volume = 2,295 kilograms).

The basis for equating weekly volume for groups with different intertraining-session rest intervals is the assumption that the total volume completed (i.e., work) is a major factor affecting strength gains (17). However, the magnitude of its importance remains to be demonstrated. Until this issue has been satisfactorily resolved, controversy and confusion will continue over the establishment of an optimal intertraining-session rest interval. With this in mind, two studies are presented in which volume was constant either per training session or per week.

Gillam addressed the problem of determining the most appropriate intertraining-session rest interval by maintaining a constant training-session volume (22). Subjects were untrained male high school students who volunteered to train for nine weeks. All subjects used the same training routine but completed it either one, two, three, four or five days per week. Significantly greater muscular strength, measured with a 1 RM protocol against a constant external load, was found in subjects who trained five days per week as compared to all other training frequencies. In addition to the volume controversy, a question could be raised about the lack of a control group. For some youngsters involved in the study, a significant amount of physical maturation might have occurred, which may have confounded the results.

In contrast, Hunter conducted an investigation on the effectiveness of two intertraining-session rest intervals on strength development, in which he equated training volume per week (31). Young adult men and women were used to compare the effects of a standardized series of weight-training exercises for four consecutive days per week versus three alternate days per week for seven weeks. Total sets per week were held constant for the two training groups. Results indicated that strength, measured by 1 RM against a constant external load, was improved significantly more in the group training four days per week. In addition to the volume controversy, the impact of the two-day versus three-day weekends used in the investigation is unclear. As in the previous example, these factors may have confounded the results of the study.

With the plethora of complications associated with evaluating the efficacy of different intertraining-session rest intervals, it is difficult to make any firm recommendations. At the very least, the identification of a physiological marker indicating the point of maximal overcompensation consequent to heavy-resistance training is a prerequisite for understanding this phenomenon. A series of well-controlled studies using each approach might best address the problem of volume equality per training session versus per week. In the meantime, practitioners should deal with each trainee individually in terms of intertraining-session rest. Changes in the makeup of singular training sessions may necessitate a reduction or increase in the recovery interval between workouts. A lack of progress may indicate the trainee is taking too much or too little rest.

PRE-PERFORMANCE REST

Athletes frequently reduce training volume or abstain from exercise before performance. The training routine may be altered because of transit time or a lack of appropriate facilities during travel to contests. The change may also be a conscious effort to taper or reduce training volume before performance. Regardless of the rationale, an understanding of the effects of short-term layoffs on strength performance could be useful. Investigators experimenting with various strength-training programs should be aware of the effects of pre-performance rest in order to know when best to test their subjects. Unfortunately, limited scientific data is available on the effect of reduced training schedules (tapering) and short-term abstinence on muscular strength.

Tapering

Costill et al. reported on the effects on swimmers of a two-thirds reduction in training yardage over a 15-day period (11). A noteworthy change during the taper period was a marked increase in muscular strength. As a consequence of reduced training, the swimmers demonstrated an increase in arm strength and power from 17.7 percent to 24.6 percent. Although it would be inappropriate to directly apply the effects of a reduced training schedule for swimmers to a reduced schedule for weight trainers, it does provide an interesting basis for experimental questions. In fact, the taper used in swimming might be considered analogous to the progressively increased load and decreased training volume over a period of months typical of periodization models (54, 55).

Training Abstinence

Weiss et al. reported on the effects of 48, 72, 96 and 120 hours of rest on isokinetic and isotonic plantar flexion strength in young men who had just completed eight weeks of isotonic training on a seated heel-raise apparatus (58). Both slow- and fast-speed isokinetic tests, as well as the 1 RM strength test, were unaffected by rest. However, a subsequent and more appropriate statistical analysis of the data altered the present study's results on the dynamic constant external (1 RM) tests. It appears that strength was increased significantly at 96 hours as compared to 48 and 120 hours of rest. Both training and testing were done with the knees flexed at 90 degrees, a position that minimizes the contribution of the gastrocnemius and maximizes the contribution of the soleus muscle during plantar flexion. Furthermore, because the soleus muscle is primarily comprised of slow-twitch-oxidative motor units and the gastrocnemius of a more heterogeneous mixture, the motor-unit type primarily used for training and testing may have influenced the effects of the various rest intervals. These results should be verified and expanded by testing both highly trained subjects and more heterogeneous muscle groups.

CONCLUSIONS

There are at least three phases of rest that should be considered in any strength-training program: the period between sets of the same exercise (intratraining-session rest); the time between exercise sessions (intertraining-session rest); and the interval between the last training session and the performance of a maximal test of strength for competition or research (pre-performance rest).

An apparent key to strength development is a systematic repetition of near-maximal muscular tension, an unlikely occurrence in fatigued muscles. For intratraining-session rest, a three- to four-minute interval, between multiple sets of five or fewer repetitions, is recommended. The appropriate quantity of intertraining-session rest is unclear because of the lack of a definitive physiological marker indicating when recovery is complete, and because of the unresolved issue of whether training volume should be equated per session or per week. Consequently, it should be dealt with on an individual basis, with trainers who can recognize signs of under- or overtraining. For pre-performance rest, there is some indication that no strength is lost after five days of rest and that it might actually be at its highest level after four days without exercise in young, moderately trained men. Recommendations for intertraining-session and pre-performance rest are tentative at best, and much experimentation remains to be done to gain insight into these phenomena.

REFERENCES

1. Ammons, R. Distribution of practice in motor skill acquisition: a few questions and comments. **Res. Q. Exerc. Sport.** 59:288-290. 1988.
2. Anderson, T. and J. Kearney. Effects of three resistance training programs on muscular strength and absolute and relative endurance. **Res. Q. Exerc. Sport.** 53:1-7. 1982.
3. Atha, J. Strengthening muscle. **Exerc. Sport Sci. Rev.** 9:1-73. 1981.
4. Berger, R. Application of research findings in progressive resistance exercise to physical therapy. **J. Assoc. Phys. Mental Rehab.** 19:200-203. 1965.
5. Berger, R. Comparative effects of three weight training programs. **Res. Q.** 34:396-398. 1963.
6. Brooks, G. The lactate shuttle during exercise and recovery. **Med. Sci. Sports Exerc.** 18:360-368. 1986.
7. Brooks, G. Lactate: glycolytic end product and oxidative substrate during sustained exercise in mammals — the lactate shuttle. In: **Circulation, Respiration, and Metabolism**, R. Giles, ed. Berlin: Springer-Verlag. 1985.
8. Caiozzo, V., Perrine, J. and V. Edgerton. Training-induced alterations of the in vivo force-velocity relationship of human muscle. **J. Appl. Physiol: Respirat. Environ. Exerc. Physiol.** 51:750-754. 1981.
9. Clarke, D. Training for strength. In: **Women and Exercise**, M. Shangold and G. Mirkin, eds. Philadelphia, PA: F.A. Davis. 1988. pp. 55-64.
10. Clarke, H. Strength development and motor-sports improvement. **Physical Fitness Research Digest.** President's Council on Physical Fitness and Sports, U.S. Governmental Printing Office. 1974.
11. Costill, D., King, D., Thomas, R. and M. Hargreaves. Effects of reduced training on muscular power in swimmers. **Physician Sportsmed.** 13:94-101. 1985.
12. Cotten, D. Relationship of the duration of sustained voluntary isometric contraction to changes in endurance and strength. **Res. Quart.** 38:366-374. 1967.
13. deVries, H. **Physiology of Exercise for Physical Education and Athletics.** Dubuque, IA: W.C. Brown. 1986. pp. 220-223.
14. Dodd, S., Powers, S., Callender, T. and E. Brooks. Blood lactate disappearance at various intensities of recovery exercise. **J. Appl. Physiol.: Respirat. Environ. Exerc. Physiol.** 57:1462-1465. 1984.
15. Duchateau, J. and K. Hainaut. Isometric or dynamic training: differential effects on mechanical properties of a human muscle. **J. Appl. Physiol: Respirat. Environ. Exerc. Physiol.** 56:296-301. 1984.
16. Edgerton, V. Mammalian muscle fiber types and their adaptability. **Amer. Zool.** 18:113-125. 1978.
17. Fleck, S. and W. Kraemer. **Designing Resistance Training Programs.** Champaign, IL: Human Kinetics. 1987. pp. 3-46.
18. Fleck, S. and R. Schutt. Types of strength training. In: **Clinics in Sports Medicine**, G. Weiker, ed. 1985. pp. 159-168.
19. Fox, W., Bowers, R. and M. Foss. **The Physiological Basis of Physical Education and Athletics.** Philadelphia, PA: W.B. Saunders. 1988. pp. 39-60, 171-172.
20. Gettman, L. and M. Pollock. Circuit weight training: a critical review of its physiological benefits. **Physician Sportsmed.** 9:44-60. 1981.
21. Gettman, L., Ayres, J., Pollock, M. and A. Jackson. The effect of circuit weight training on strength, cardiorespiratory function, and body composition of adult men. **Med. Sci. Sports Exerc.** 10:171-176. 1978.
22. Gillam, G. Effects of frequency of weight training on muscle strength enhancement. **J. Sports Med. Physical Fitness.** 21:432-436. 1981.
23. Goldberg, A., Etlinger, J., Goldspink, D. and C. Jablecki. Mechanism of work-induced hypertrophy of skeletal muscle. **Med. Sci. Sports.** 7:185-198. 1975.
24. Gordon, E. Anatomical and biochemical adaptations of muscle to different exercises. **J. Am. Med. Assoc.** 201:129-132. 1967.
25. Gollnick, P. Energy metabolism and prolonged exercise. In: **Perspectives in Exercise Science and Sports Medicine, Vol. III: Prolonged Exercise**, D. Lamb and R. Murray, eds. Indianapolis, IN: Benchmark Press. 1988. pp. 1-42.
26. Gregor, R., Edgerton, V., Perrine, J., Campion, D. and C. deBus. Torque-velocity relationships and muscle fiber composition in elite female athletes. **J. Appl. Physiol.: Respirat. Environ. Exerc. Physiol.** 47:388-392. 1979.
27. Hage, P. Strength: one component of a winning team. **Physician Sportsmed.** 9:115-120. 1981.
28. Hermanson, L. and I. Stensvold. Production and removal of lactate during exercise in man. **Acta Physiol. Scand.** 86:191-201. 1972.
29. Hill, A.V. **First and Last Experiments in Muscle Mechanics.** London: Cambridge University Press. 1970. pp. 23-41.
30. Hultman, E., Bergstron, J. and N. McLeanan. Breakdown and resynthesis of phosphorylcreatine and adenosine triphosphate in connection with muscular work in man. **Scand. J. Clin. Lab. Invest.** 19:56-66. 1967.
31. Hunter, G. Changes in body composition, body build and performance associated with different weight training frequencies in males and females. **NSCA J.** 7:26-28. 1985.
32. Karlsson, J., Bonde-Petersen, F., Henriksson, J. and H. Knuttgen. Effects of previous exercise with arms or legs on metabolism

and performance in exhaustive exercise. **J. Appl. Physiol.** 38:208-211. 1975.

33. Kraemer, W., Fleck, S. and M. Deschenes. A review: factors in exercise prescription of resistance training. **NSCA J.** 10:36-41. 1988.
34. Lamb, D. **Physiology of Exercise: Responses and Adaptations.** New York, NY: MacMillan. 1984, pp. 239-291; 1978, pp. 137-138.
35. Laycoe, R. and R. Marteniuk. Learning and tension as factors in strength gains produced by static and eccentric training. **Res. Quart.** 42:299-305. 1971.
36. Lee, T. and E. Genovese. Distribution of practice in motor skill acquisition: learning and performance effects reconsidered. **Res. Quart. Exerc. Sport.** 59:277-287. 1988.
37. Lemon, P. and J. Mullin. Effect of initial muscle glycogen levels on protein catabolism during exercise. **J. Appl. Physiol.: Respirat. Environ. Exercise Physiol.** 47:388-392. 1979.
38. Magill, R. The many faces of practice distribution in motor learning. **Res. Quart. Exerc. Sport.** 59:303-307. 1988.
39. McArdle, W., Katch, F. and V. Katch. **Exercise Physiology: Energy, Nutrition, and Human Performance.** Philadelphia, PA: Lea and Febiger. 1981. p. 300.
40. Meyer, R. and R. Terjung. Differences in ammonia and adenylate metabolism in contracting fast and slow muscle. **Am. J. Physiol.** 237:C11-C18. 1979.
41. Moritani, T. and H. deVries. Neural factors versus hypertrophy in the time course of muscle strength gains in young and old men. **J. Gerontol.** 36:294-297. 1981.
42. Newell, K., Antoniou, A. and L. Carlton. Massed and distributed practice effects: phenomena in search of a theory? **Res. Quart. Exerc. Sport.** 59:308-313. 1988.
43. Noble, B. **Physiology of Exercise and Sport**. St. Louis, MO: Times Mirror/Mosby. 1986. pp. 285-290.
44. Nordin, M. and V. Frankel. **Basic Biomechanics of the Musculoskeletal System.** Philadelphia, PA: Lea and Febiger. 1989. pp. 97-103.
45. O'Shea, P. Interval weight training — a scientific approach to cross-training for athletic strength fitness. **NSCA J.** 9:53-57. 1987.
46. O'Shea, P. Effects of selected weight training programs on the development of strength and muscle hypertrophy. **Res. Q.** 37:95-102. 1966.
47. Perrine, J. The biophysics of maximal muscle power outputs: methods and problems of measurement. In: **Human Muscle Power**, N. Jones, N. McCartney and A. McComas, eds. Champaign, IL: Human Kinetics. 1986. p. 19.
48. Perrine, J. and V. Edgerton. Muscle force-velocity and power-velocity relationships under isokinetic loading. **Med. Sci. Sports.** 10:159-166. 1978.
49. Sale, D. Neural adaptation to resistance training. **Med. Sci. Sports Exerc.** 20:S135-S145. 1988.
50. Sale, D. Neural adaptation in strength and power training. In: **Human Muscle Power**, N. Jones, N. McCartney and A. McComas, eds. Champaign, IL: Human Kinetics. 1986. pp. 289-307.
51. Schultz, R. Effect of direct practice and repetitive sprinting and weight training on selected motor performance tasks. **Res. Quart.** 38:108-118. 1967.
52. Smith, L. Strength increments following massed and distributed practice relative to motor learning. **Med. Sci. Sports.** 6:154-157. 1974.
53. Stone, M. Muscle conditioning and muscle injuries. **Med. Sci. Sports Exerc.** 22:457-462. 1990.
54. Stonem M., O'Bryant, H., Garhammer, J., McMillan J. and R. Rozanek. A theoretical model of strength training. **NSCA J.** 4:36-39. 1982
55. Stone, M., O'Bryant, H. and J. Garhammer. A hypothetical model for strength training. **J. Sports Med. Phys. Fitness.** 21:342-351. 1981.
56. Sahlin, K. and J. Ren. Relationship of contraction capacity to metabolic changes during recovery from a fatiguing contraction. **J. Appl. Physiol**. 67:648-654. 1989.
57. Wallis, E. and G. Logan. **Figure Improvement and Body Conditioning Through Exercise.** Englewood Cliffs, NJ: Prentice-Hall. 1964.
58. Weiss, L., Coney, H.and F. Clark. Optimal post-training rest interval for maximal strength performance. **Med. Sci. Sports Exerc.** 20:S86. 1988.
59. Westcott, W. **Strength Fitness.** Boston, MA: Allyn and Bacon. 1983. p. 56.
60. Wickiewicz, T., Roy, R., Powell, P., Perrine, J. and V. Edgerton. Muscle architecture and force-velocity relationships in humans. **J. Appl. Physiol.: Respirat. Environ. Exerc. Physiol.** 57:435-443. 1984.
61. Wilmore, J. and D. Costill. **Training for Sport and Activity: The Physiological Basis of the Conditioning Process.** Dubuque, IA: W.C. Brown. 1988. pp. 113-139.
62. Wilmore, J., Parr, R., Girandola, R., Ward, P., Vodak, P., Barstow, T., Pipes, T., Romero, G. and P. Leslie. Physiological alterations consequent to ciruit weight training. **Med. Sci. Sports.** 10:79-84. 1978.