

## STRENGTH AND POWER TRAINING FOR THE HIGH PERFORMANCE ATHLETE

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I would like to begin the presentation today with several definitions and a brief discussion of the relevance of strength and power to the high performance athlete.

### [a] Definitions

**Strength:** the peak force or torque developed during a single maximal voluntary contraction (MVC).

**Power:** the rate ( $t$ ) at which mechanical work is performed or  $W/t$ . Thus power refers to the velocity at which a movement occurs.

To illustrate the difference between strength and power, consider the force-time curve for an isometric contraction of the elbow extensors in 2 hypothetical athletes. In Figure 2 it can be seen that athlete A can generate more force than athlete B, while the rate of force development by athlete B is more rapid than that by athlete A. Thus athlete A possesses more strength than B but over 0.3 seconds athlete B displays greater power.

One would normally expect athlete A to be superior in an event such as weight lifting while B would be more effective in an event such as

throwing, where an external object must be accelerated over a short duration (e.g. 0.3 sec).

### [b] Relevance of strength and power to various sports

**In general, the shorter the duration of the effort, the greater will be the relative importance of strength and power to sport performance.**

Thus, in events such as lifting, jumping or throwing it is obvious that strength and/or power (in conjunction with the technique) are the major determining factors. Conversely in long duration endurance events, such as marathon running or distance swimming, strength and power would be relatively unimportant.

Activities such as racquet sports and most team sports, which require intense bursts of energy release, separated by periods of lower intensity recovery, would also be dependent upon high levels of strength and power.

#### (1) The importance of strength or power.

**Since power reflects the rate at which force can be exerted, it is normally of greater importance to**

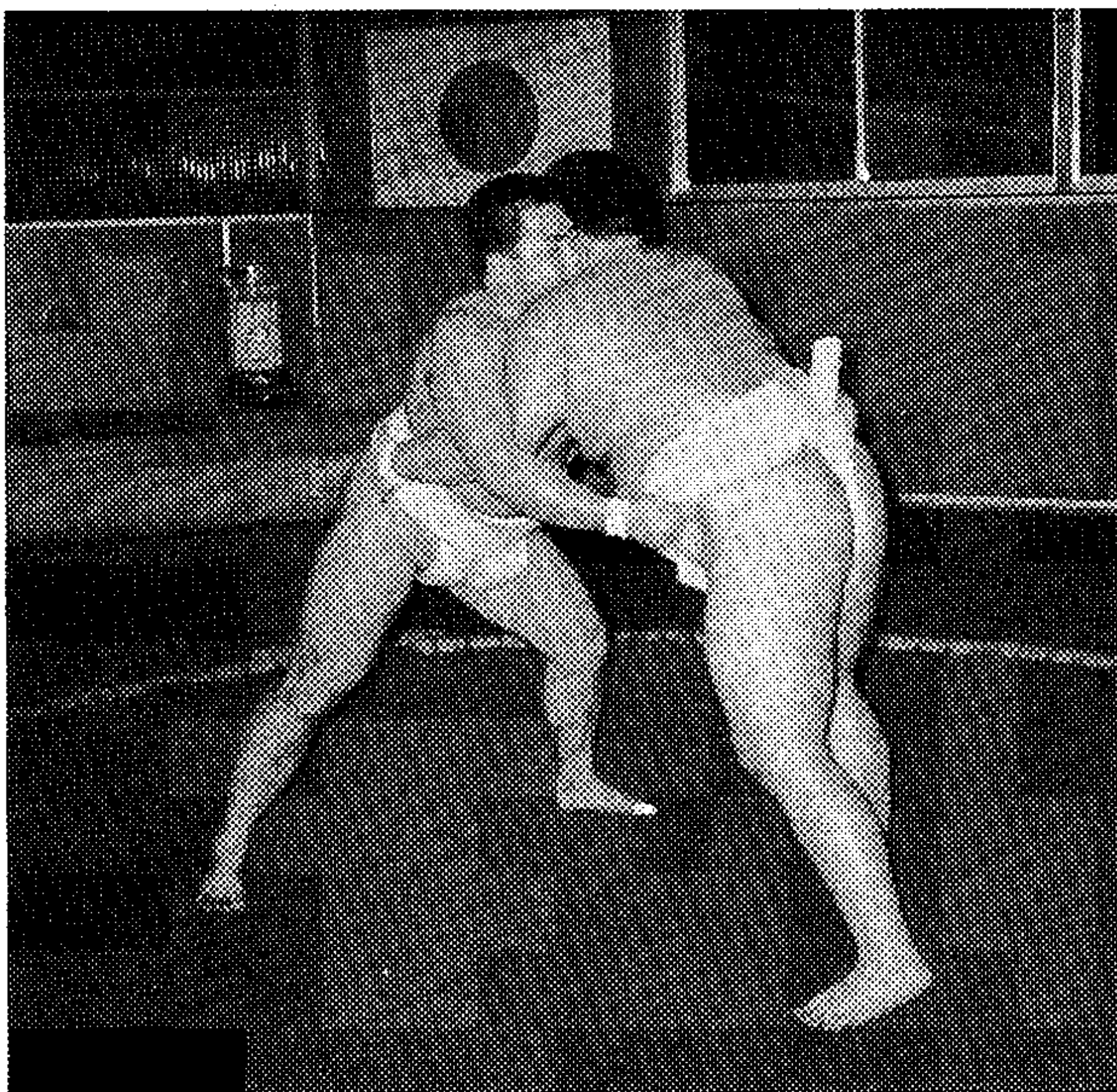


Fig. 1

**sport performance than strength.**

In "explosive" events where a segment of the body, the whole body or an external object must be accelerated – as in kicking, jumping or throwing, the time for contraction is usually too brief to allow the muscle group to develop maximal strength. Thus, success will be determined by the power of the muscle group.

Conversely in relatively slow movements such as weight lifting and some wrestling or gymnastics movements,

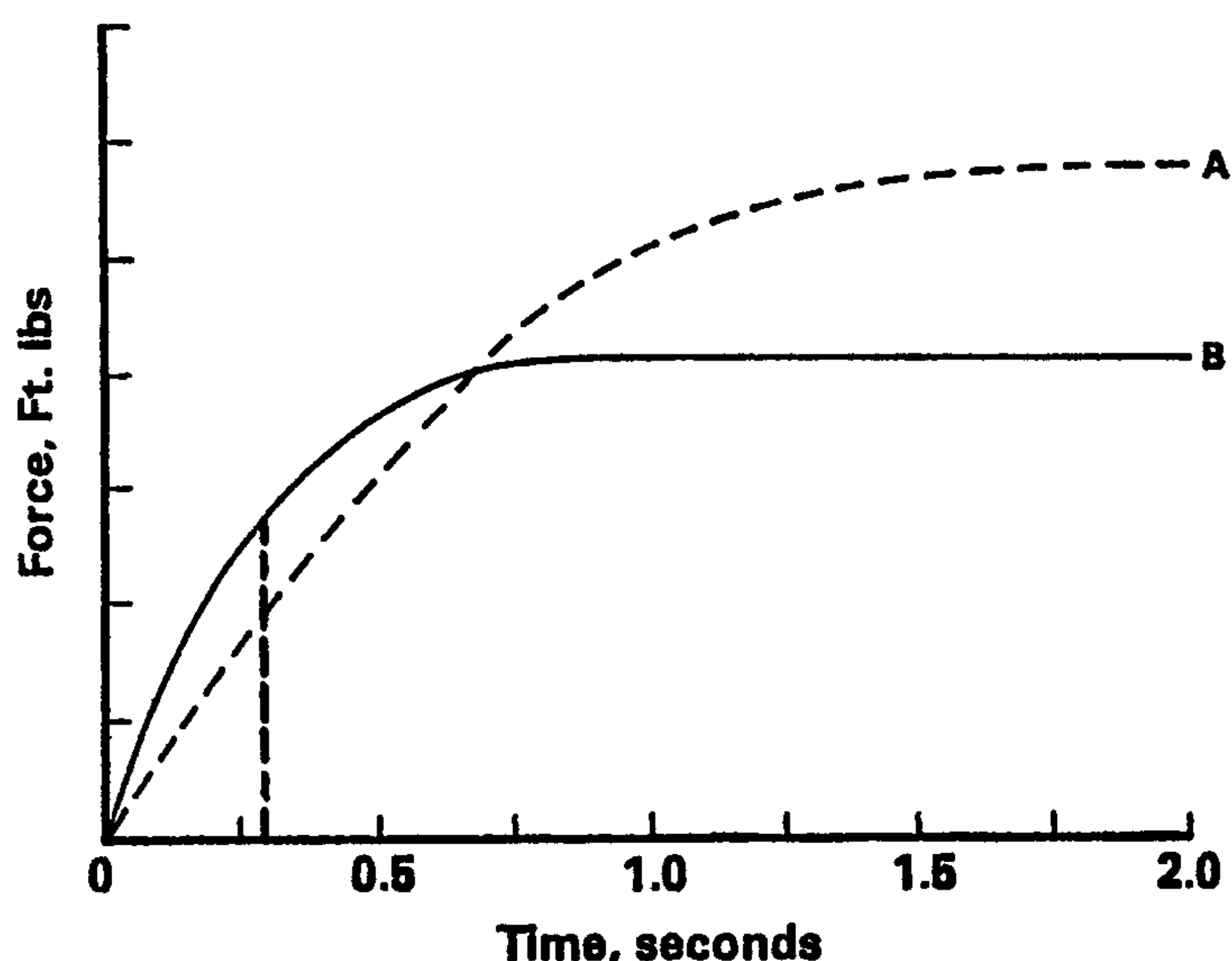


Fig. 2 Peak force and rate of force development in 2 different athletes.

strength may be of greater importance than power. While there is usually a good correlation between a muscle's strength and power, this is not always true and each is most effectively trained by different methods.

- (2) **Strength vs. strength-to-mass ratio.** Strength can be expressed in absolute units or relative to body mass.

**Generally, when an external object must be resisted or moved, absolute strength is more important. When the body mass itself must be supported or projected the strength-to-mass ratio will be of most importance.**

Thus, in a throwing event such as shot put, it is the absolute strength and power of the athlete which will determine his success. In events such as high jumping or gymnastics, it is the strength or power ratio which is most crucial.

Since there is generally a positive correlation between body size and absolute strength, this explains why shot putters tend to be large athletes while gymnasts tend to have small body sizes.

For many sports, both are important. For example, in soccer, strength and power are important for kicking the ball, while a high strength-to-mass ratio is important for accelerating and changing direction.

#### [c] Factors affecting strength and power

- (1) **Muscle area.** Since muscle area is largely determined by the cross sectional area of its fibers and fiber area is largely determined by the amount of



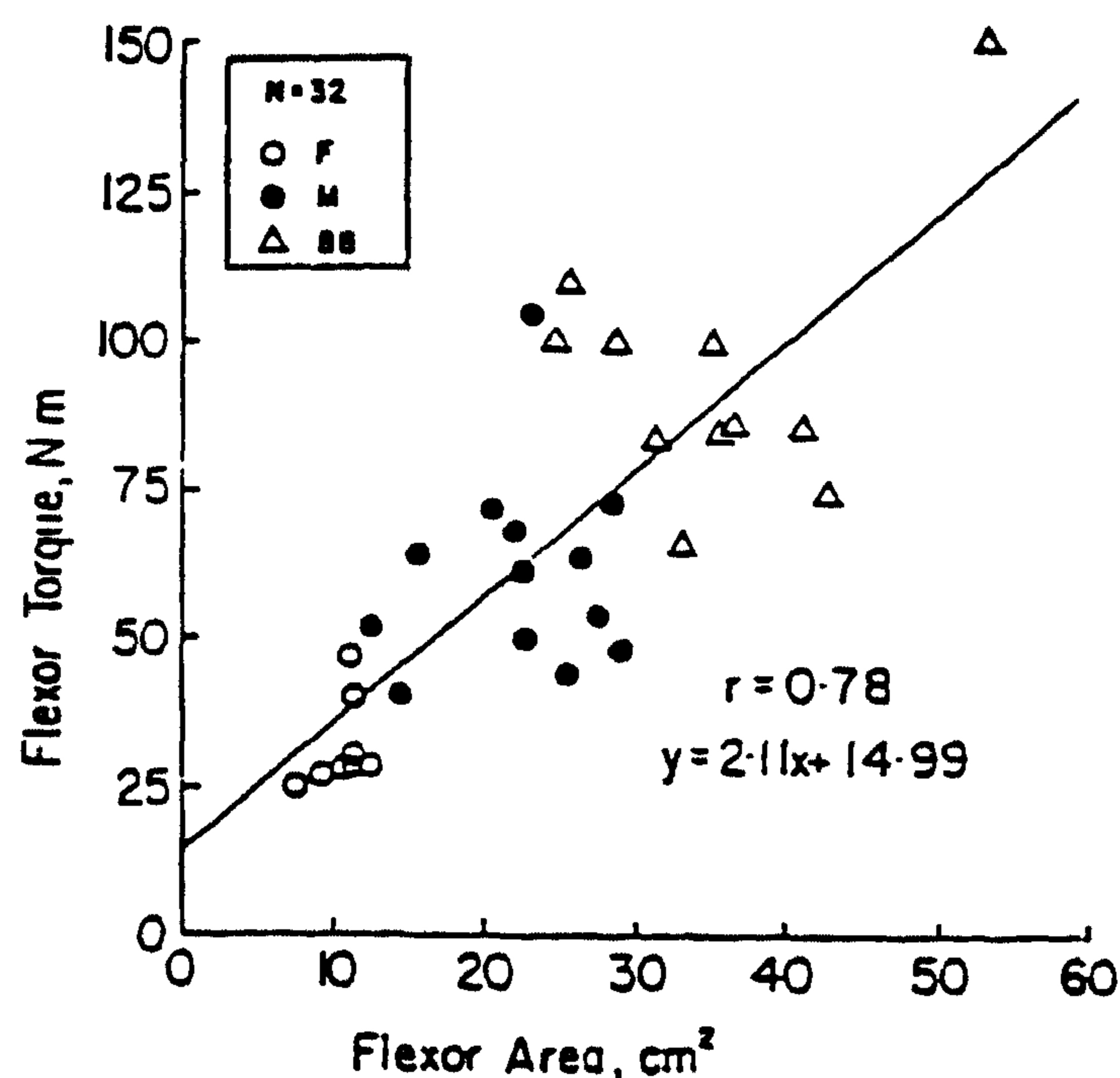


Fig. 3 The correlation between maximal voluntary strength (elbow flexion at  $30^\circ$ ,  $\text{sec}^{-1}$  on a Cybex Dynamometer) and total cross sectional area of the elbow flexors (biceps brachii plus brachialis). The subjects were 8 females, 13 untrained males and 11 trained bodybuilders. Muscle areas were calculated from CT Scans. [Courtesy of D.G. Sale and J.D. MacDougall]

contractile protein (number of cross bridges), one would expect strength to be greatly affected by muscle area.

**There is, in fact, a significant correlation between muscle cross sectional area and voluntary strength (Figure 3).**

Inspection of Figure 3 indicates that the relationship, although statistically significant, still displays considerable scatter. The reason for this scatter probably relates to differences between subjects' abilities to maximally activate and synchronize all of their motor units when performing an MVC.

## (2) Muscle length.

It is known that muscles contract more forcefully when they are at

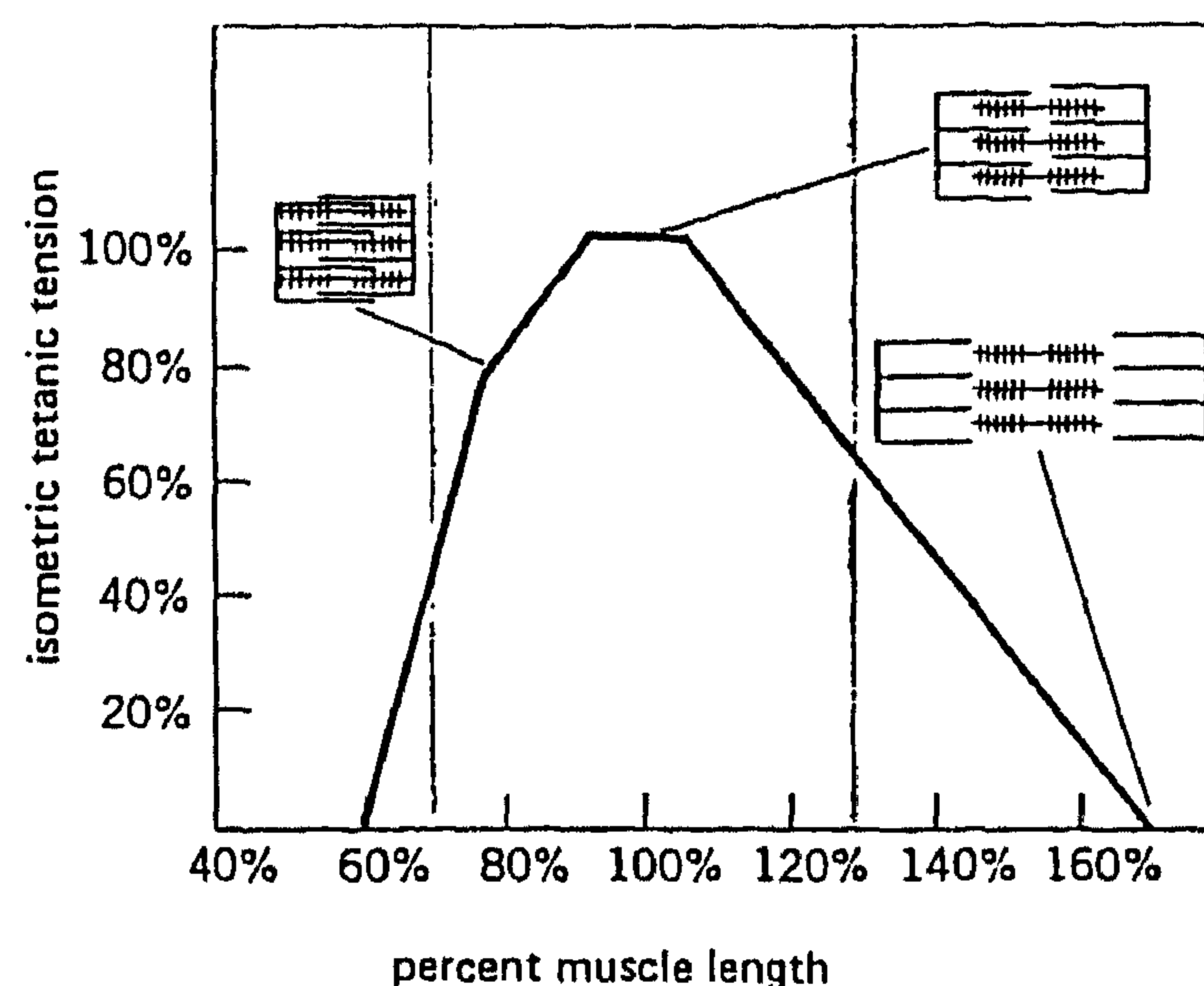


Fig. 4 Variation in isometric tetanus tension with muscle fiber length. The shaded band represents the range of length changes (from 70 to 130 percent) that can occur in the body while the muscles are attached to bones. (Adapted from Gordon, Huxley, and Julian.)

**resting length and that contractile force decreases as the muscle becomes shorter, or if it is stretched beyond resting length.**

This is known as the "length-tension effect" and can be explained in terms of the sliding filament model. When the muscle is stretched beyond resting length, the amount of overlap between actin and myosin filaments is changed as indicated in Figure 4. As the muscle shortens past resting length, the actin filaments begin to overlap each other, interfering with cross-bridge binding and reducing the number of active cross bridges.

## (3) Muscle length and power.

**Although strength is primarily determined by the cross-sectional area of a muscle, the velocity of shortening (power) is also affected by the length of the muscle.**

Since sarcomere length is quite constant between individuals, the athlete with the longer muscles has more sarcomeres arranged end to end. Thus when all sarcomeres shorten, the athlete having the longer muscle will achieve the greatest shortening per unit time.

(4) **Angle of pull.**

Since muscle contraction causes rotational movements at joints, the magnitude of the torque produced depends upon the force of contraction and the magnitude of the perpendicular distance between the "line of pull" of the muscle and the axis of the joint.

For example, it can be seen from Figure 5 that the optimal angle of pull is position B, where the elbow joint is at 90°. In position C some of the contractile force is dissipated in the form of a compression at the elbow joint, while in position A it is being dissipated in the form of a separation force between the forearm and upper arm.

- (5) **The strength curve.** The force of a maximal contraction will vary widely throughout the full range of movement. This is due to the combined effects of the angle of pull and the length-tension effect.

**The resultant variations in**

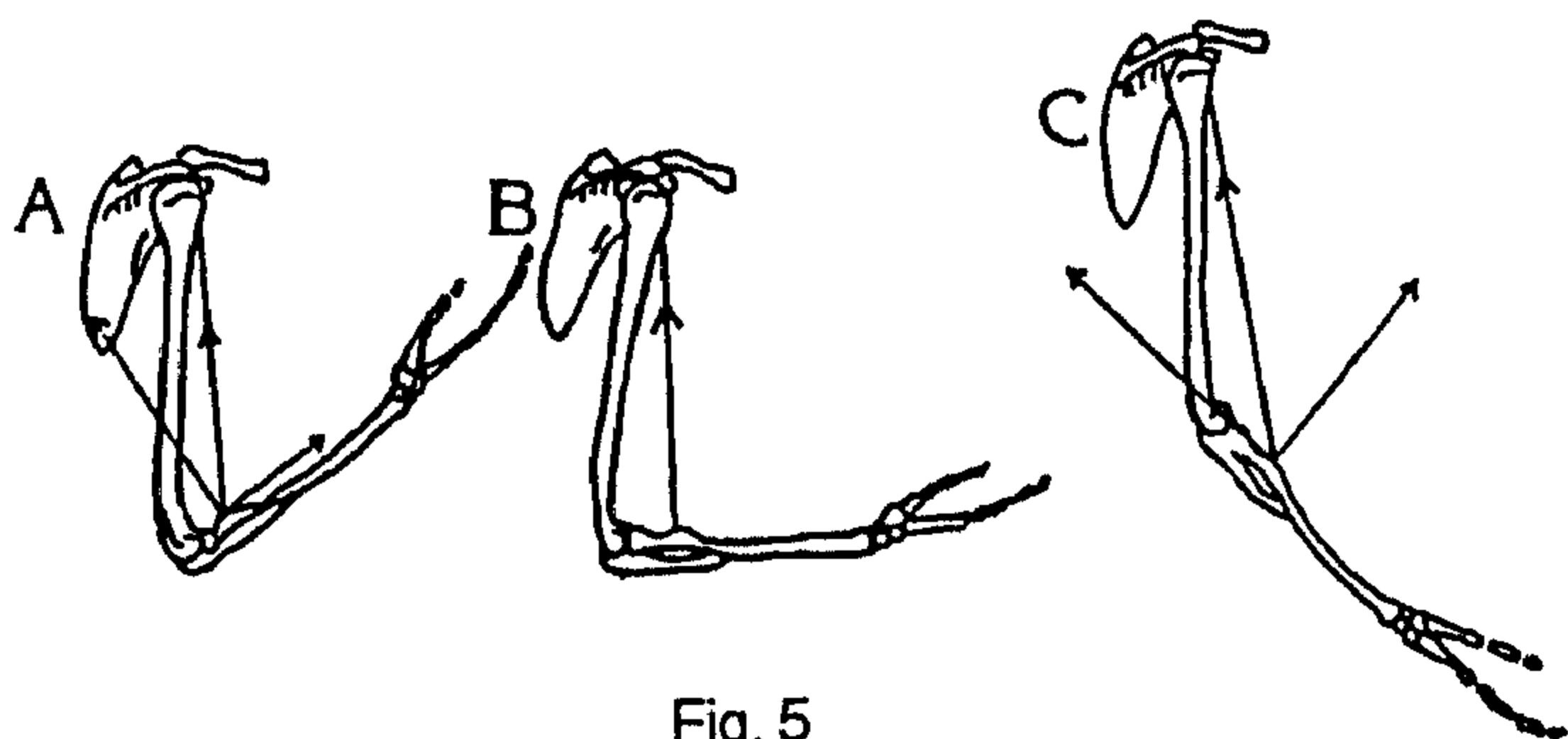


Fig. 5

**strength at different joint angles is known as the strength curve for that movement.**

- (6) **Muscle fiber composition.** Since Type II fibers normally have larger cross-sectional areas than Type I fibers, they contract more forcefully than Type I fibers when activated. Since Type II fibers develop force more rapidly than Type I fibers, they exhibit

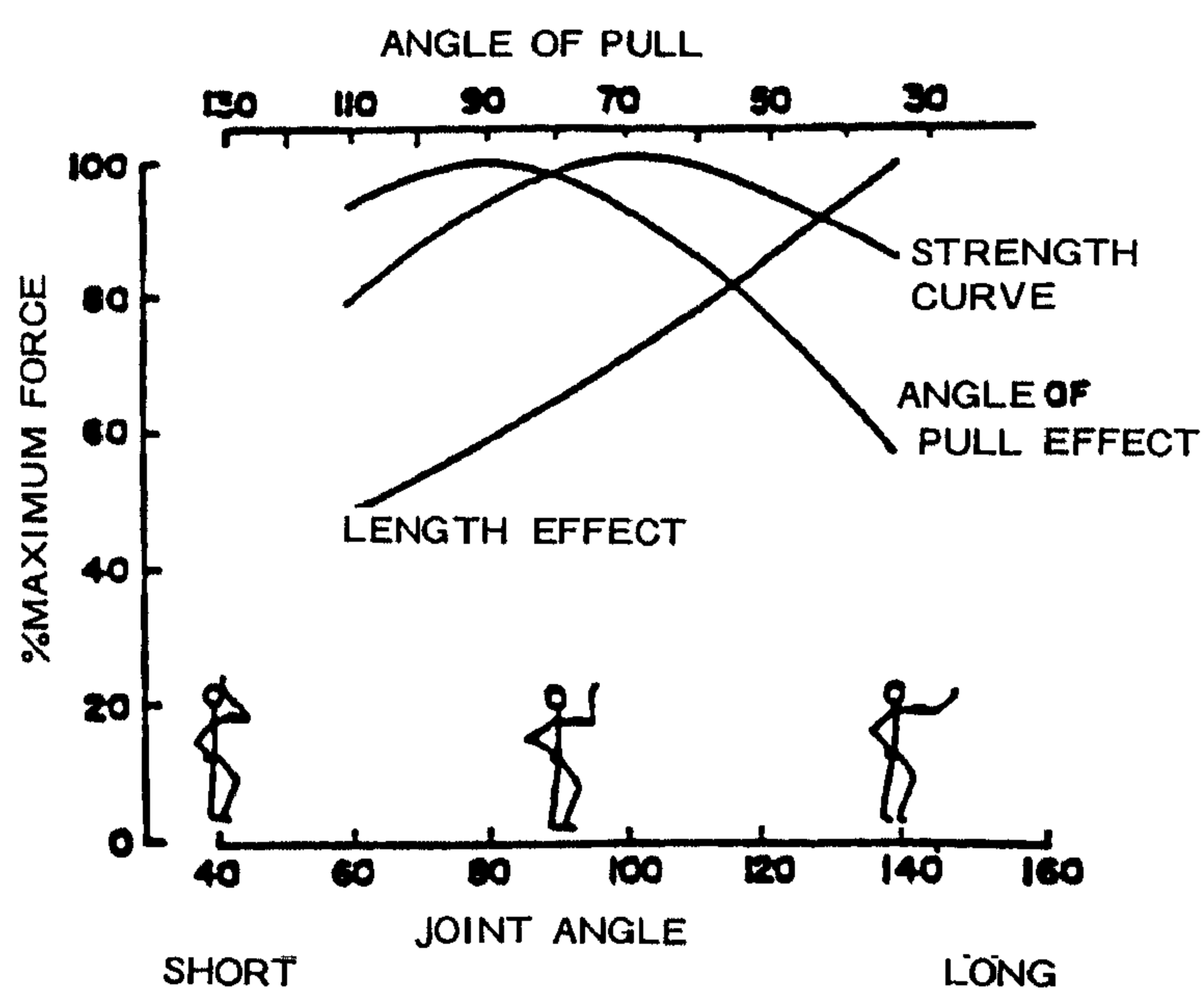


Fig. 6 Effect of muscle length and angle of pull upon elbow flexion strength. The length-tension effect and the angle of pull effect interact to produce the strength curve for elbow flexion. Through the range of movement depicted, the length effect acts to increase muscle tension from the shortest to longest muscle lengths. The longest length corresponds to an elbow joint angle (bottom horizontal axis) of 140°. In contrast the optimum angle of pull (90°, see top horizontal axis) occurs at a joint angle of about 80°. Thus, the peak of the resultant strength curve would be expected to occur somewhat between joint angles of 80° and 140°; in fact, it occurs at a joint angle of about 100°.

[From D.G. Sale and R.W. Norman in *Physiological Testing of the Elite Athlete*, J.D. MacDougall, H.A. Wenger and H.J. Green, (Eds.) 1983.]

greater power than Type I fibers. **Although all fiber types are recruited during an MVC, it would be advantageous for the athlete in a strength and power sport to possess a high percentage of type II fibers.**

It is thus not surprising that successful strength and power athletes tend to have a higher proportion of Type II fibers and a lower proportion of Type I fibers than normal.

(7) **Neural factors.**

**The force output during a maximal contraction is dependent upon the number (and cross-sectional area) of the motor units recruited and the firing frequency of those units.**

Force of contraction will thus be maximal when all available motor units have been recruited and when they are all firing at their optimal rate. Strength and power are thus not only dependent upon the size of the muscle (total number of cross bridges) but also upon the capacity of the central nervous system to "drive" that muscle.

It has been shown that these neural factors are trainable and largely explain why individuals at the start of a strength training program often make large gains despite no increase in muscle size.

(8) **Age and gender.**

**Peak absolute strength occurs in both males and females at approximately age 25 years and declines thereafter.**

In males, strength-to-mass ratio peaks in the early 20's, while in females it is highest just before puberty.

In general, females possess approximately 60% of the absolute strength of males, but this varies according to muscle group — i.e. upper body strength of females is closer to 50% that of males while leg strength approaches 75% that of males.

Chronic overloading (resistance training) of a muscle group will result in an increase in size and strength throughout all ages, however the greatest gains occur between the ages of 15-25 for both males and females.

- (9) **Training.** It is well known that heavy resistance training will result in an increase in muscle size and strength. With progressive overload training muscles undergo hypertrophy and improve their strength in order to accommodate the increased load. If a muscle receives less loading than it is accustomed to, its function deteriorates.

If the loading is too great for the muscle to adapt to, then injury or over-training results.

**In order for the athlete to improve his/her performance in strength and power sports, adaptation must occur in both the muscle (amount of contractile protein) and the nervous system (ability to drive the muscle).**

3. **Adaptations with Strength and Power Training**

[a] **Adaptations within skeletal muscle.**

- (1) **Muscle size.** When training is intense enough and frequent enough, there is an increase in muscle size (hypertrophy).

**The increase in muscle size which**

occurs with training is caused by an increase in the cross-sectional area of both Type I and Type II fibers and a proportional increase in connective (between fiber) tissue. The degree of hypertrophy is greater in Type II than Type I fibers.

The increase in fiber area is directly related to an increase in both the size and number of myofibrils within each fiber. The change in myofibril size is the result of additional actin and myosin filaments, and the increase in number is probably due to a longitudinal splitting of myofibrils. Muscle hypertrophy thus results in a greater amount of contractile protein and a greater number of potential cross-bridges for contraction.

(2) Fiber numbers.

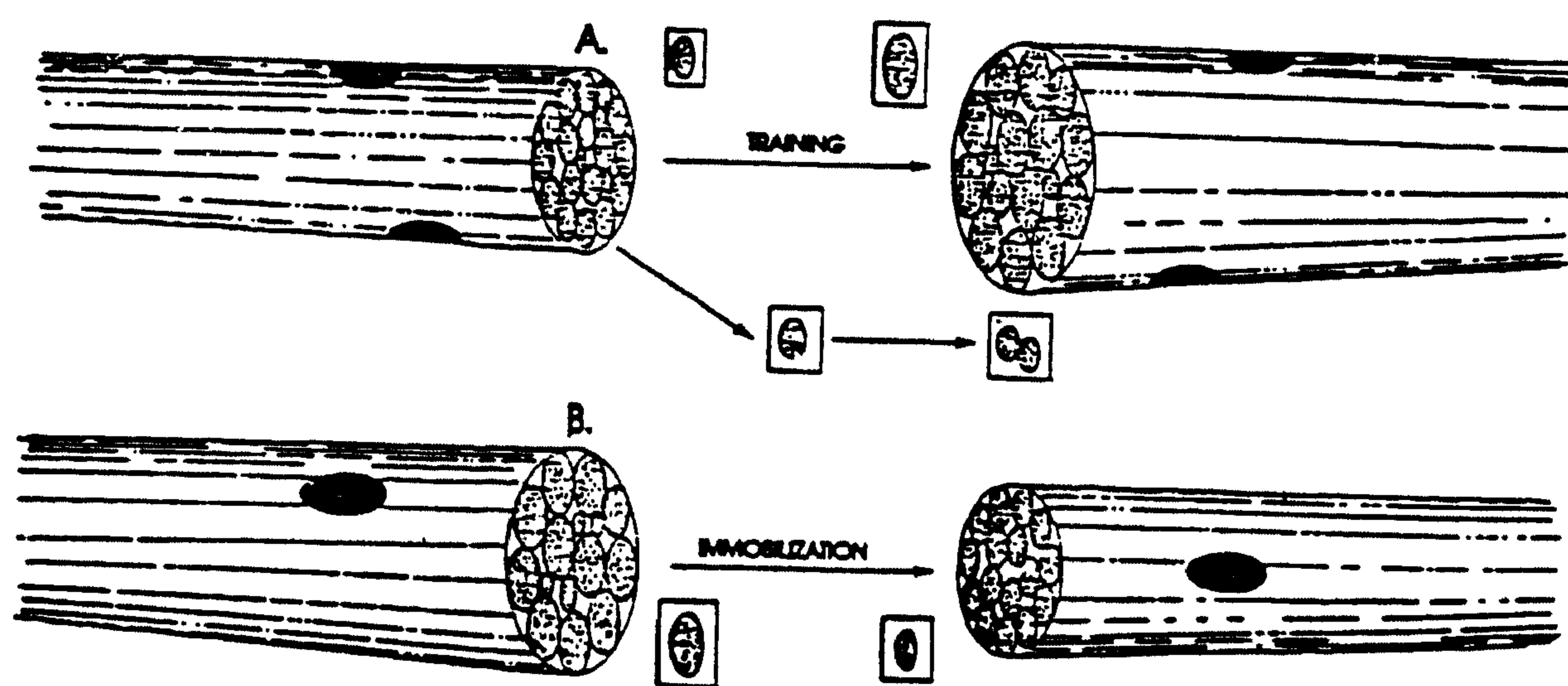
Although it has been demonstrated

that heavy resistance training may result in an increase in muscle fiber number in certain animal species, this does not occur in humans.

(3) Fiber types.

Although some researchers have shown that it may be possible to increase the proportion of Type I fibers with endurance training, conventional strength training does not have the opposite effect, that is, to increase the proportion of Type II fibers.

(4) Biochemical changes. Glycolytic and contractile enzyme levels do not increase with conventional strength training and have been shown to decrease slightly when training was intense enough to cause a significant muscle hypertrophy.



A. With training, cross sectional fibre area increases in direct proportion to the increases in myofibril size and number.

B. With immobilization, fibre area decreases in proportion to the decrease in myofibril size.

Fig. 7 [From J.D. MacDougall in Human Muscle Power, N.L. Jones, N. McCartney and A.J. McComas (Eds.) 1986].

Oxidative enzyme activities and the relative amount of mitochondria decrease with strength training due to a dilution effect of the added contractile protein. This is also true of muscle capillary density.

Muscle glycogen concentration increases and there is a slight increase in ATP and CP concentration with strength training.

**Thus, although there is an increase in the amount of short-term fuel sources following strength training, there is an actual decrease in the oxidative potential of the muscle per unit of mass.**

- (5) Connective tissue. Connective tissue (collagen) increases in proportion to the increase in fiber area, so that the proportion of connective tissue in hypertrophied muscle is similar to that in the non-hypertrophied state.

**[b] Adaptations within the central nervous system.**

- (1) Motor unit recruitment. A motor unit consists of a motor neuron and all of the muscle fibers which it innervates. When activated it contracts maximally.

The more units activated during a maximal voluntary contraction the greater will be the force output.

**Through mechanisms not yet understood, a program of strength-training can increase the number of motor units which can be activated during voluntary effort.**

Force can also be increased by increasing the firing rate of those motor units which are activated. Although as yet undocumented, such adaptations

are thought to occur with specific training.

- (2) Inhibition. Reflex inhibitor neurons, as well as inhibition from higher brain centres, are thought to affect an individual's ability to fully activate his motor units during maximal voluntary contractions. Such mechanisms may protect the muscle and its connective tissue from injury during extreme loading.

Such inhibition appears to exist in elite athletes, as well as untrained individuals, and is evidenced by the fact that greater activation occurs in a maximal unilateral (one limb only) contraction than can be achieved in that limb with a maximal bilateral contraction.

**There is evidence that, with specific training, the athlete is able to achieve greater excitation of his motor units but it is not known how much of this is due to a decrease in inhibition and how much is due to improved motor unit activation and firing rate.**

#### **4. How to Train Most Effectively**

**[a] Determining the proper muscle group.**

- (1) Prime movers. The prime movers are those muscles which are primarily responsible for causing a specific joint action.
- (2) Fixators. The fixators or stabilizers are the muscles which anchor or steady a bone, or body part, so that the prime movers have a firm base from which (or on which) to pull.

For example, in doing a push-up from the floor, the prime moves are the triceps and pectoralis muscles. Without



the static contraction of the abdominals and serratus anteriors, however, the trunk would sag and the shoulder joint would not be sufficiently stabilized for the prime movers to act.

**In strength training for a specific sport or activity, it is thus as important to train the fixator muscle group as it is to train the prime movers.**

- (3) Synergists. Synergists are muscles which contract statically in order to prevent an unwanted movement. Thus while not directly involved in causing the movement, they make it more effective by counteracting or neutralizing the undesired action of another contracting muscle.

- (4) Antagonists. Antagonists are muscles which produce movements opposite to that of the prime movers.

**Most coaches are able to easily identify and to design exercises for training the prime movers involved in their sport, but unless they also consider the fixators and synergistic muscles their training will be relatively ineffective.**

When strengthening a particular muscle group, it is also important to strengthen the antagonistic group in order to maintain a proper "strength balance". This is particularly true for younger and growing athletes where strength imbalances may effect posture and increase the frequency of muscle injury.

Once the proper muscle groups have been selected, the task is now to select exercises and training modes which will isolate and overload each muscle

group.

[b] **Training for strength and size.**

A large portion of the increase in strength, due to training, can be attributed to an increase in muscle size (greater number of cross bridges). The mechanism(s) by which repeated contractions at maximal or near maximal strength stimulate an increase in protein synthesis is not known.

**What is known is that it is the magnitude of the loading which is the main variable for increasing muscle size. The total volume of training (number of reps) is of lesser importance as to its effect on muscle size.**

Since muscles are comprised of thousands of motor units, it follows that the greatest increase in muscle size will occur when there is a greater total number of motor units.

When a single contraction is made at 100% MVC, almost all motor units will be activated; when a contraction is made at 75% MVC a significant number of units will not be activated.

**It is known, however, that if the athlete performs a series of contractions at 75% MVC until the point of failure or fatigue, progressively more units are activated as some of the original units begin to fatigue. Thus, at failure (i.e., that point where he cannot complete a repetition despite a maximum effort) all available units will have been recruited.**

There is, however a limit to which training volume (number of reps) can compensate for decreased loading (% MVC). When athletes perform strength training at loads which are less than 60% of their MVC it is known that little or no hypertrophy will



occur despite the performance of large numbers of repetitions.

It has become conventional to express the intensity of the loading as a function of maximal repetitions (RM). For example, 1 RM would be the maximum weight which could be lifted for a single repetition, 2 RM would be the maximal weight which could be lifted for 2 repetitions, and so on.

The relationship between various RM's and their percentage of a single MVC is presented in Figure 8. It can be seen, for example, that the maximum weight which would permit an athlete to complete 10 repetitions would be approximately 75% of what he could lift for a single repetition.

Traditionally it has been thought that the greatest gains in strength would result from training with sets of 1-3 RM, while the greatest gains in size would result from training with sets of 6-8 RM. However, it has recently been shown that subjects who trained one arm with 6 sets of 10-12 RM showed the same gains in strength and greater gains in size when compared to the

other arm which they trained with 6 sets of 2-3 RM. There was also less muscle soreness and a lower incidence of injury in the high rep arm.

#### (1) Loading

**Based on present literature, it appears that loading of approximately 75-80% 1 RM continued to failure (~10 RM for upper body, ~15 RM for legs) would be most effective for athletes, in most sports, who wish to increase the size and strength of a muscle group.**

In sports which require maximum strength from a single contraction (e.g., weightlifting and powerlifting), training at higher loading (i.e., 1-2 RM) would be more effective because of its specific training effect on the nervous system.

**Occasionally coaches are of the belief that continuing repetitions to failure results in a greater risk of muscle injury. This is a myth, since**

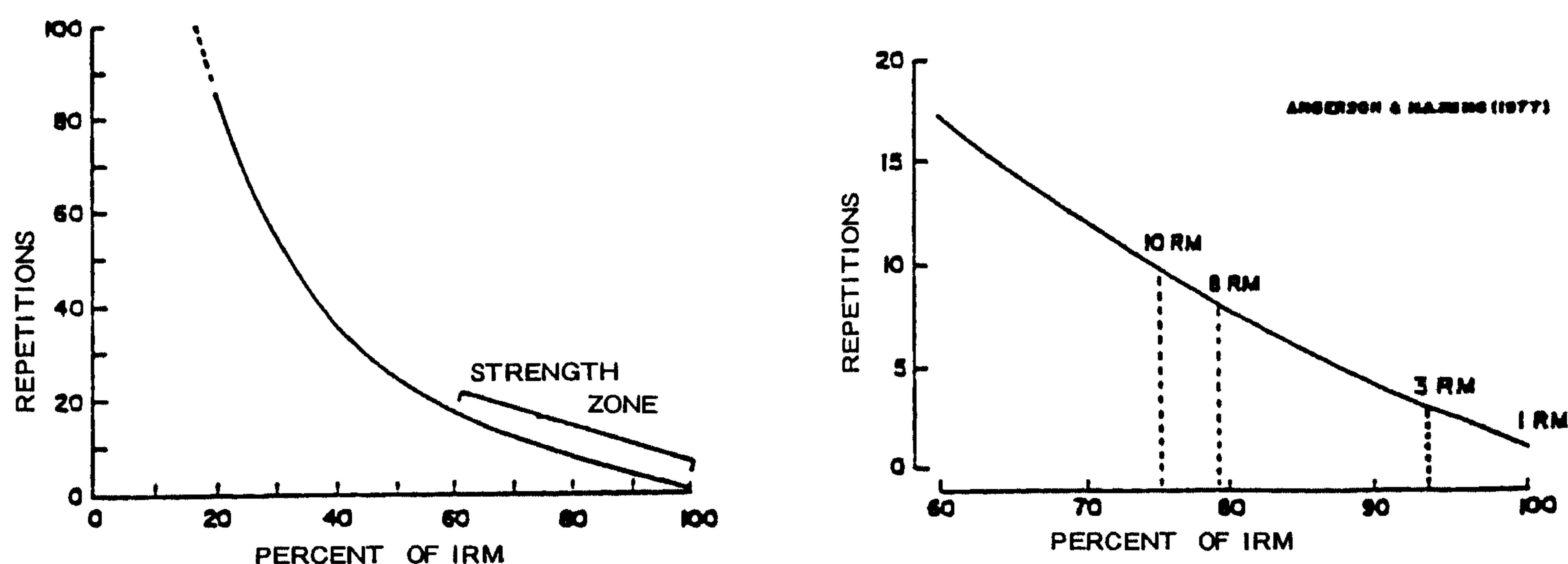


Fig. 8 Relationship between percent of 1 RM and the number of repetitions that can be performed. Also indicated is the normal strength training zone between 60 and 100% of 1 RM. Right: The training zone has been expanded to illustrate the percentages of 1 RM and the number of maximal repetitions that could be performed. [From Sale and MacDougall, 1981, with permission.]

it is known that the greatest muscle tension occurs in the first repetition and the least in the last or "failure rep".

(2) Frequency

Following a 10-12 RM, approximately 3-4 minutes should elapse before repeating a similar set with the same muscle group.

This recovery period appears necessary in order to allow restoration of CP and removal of metabolites. Even allowing this recovery period, after 2 or 3 sets the muscle will (for unknown reasons) become fatigued to the point where fewer and fewer reps can be performed before failure.

For most athletes 3-5 sets of each exercise are recommended, however the optimal number of 10 RM sets has not yet been investigated.

The most efficient means of sequencing the exercises is to use what is known as a circuit set system. With this method, one set of a particular exercise is followed by one set of a different exercise using different muscles until

all exercises have been performed once. The circuit is then repeated 3 or more times. The advantage of this system is that while one muscle group is exercising, the other is recovering – hence a shorter total training time per workout.

Based on recent research at McMaster University, following such training, at least 2 days of recovery appear necessary for tissue repair and protein synthesis. Thus, for a given muscle group, such training should be no more frequent than 2 or 3 times per week. More frequent training will be counterproductive.

[c] Training for speed and power.

- (1) The force-velocity curve. The relationship between force of contraction and velocity of contraction during a maximal effort is shown in Figure 9. As the force of contraction increases, the velocity at which the muscle can contract decreases.

Thus, with heavy loading, the movement velocity will be slow. When contraction velocity is rapid

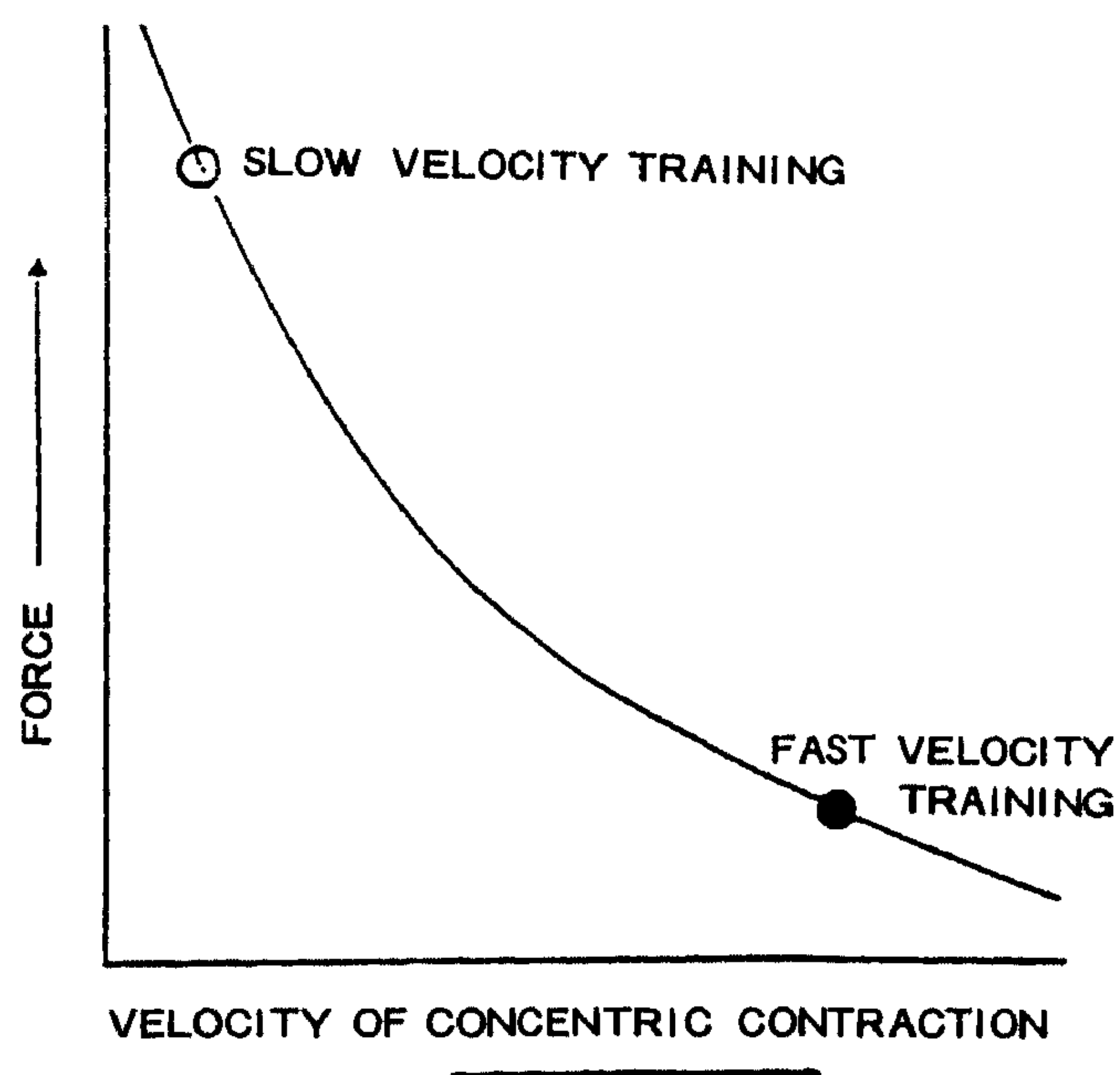


Fig. 9 Schematic force-velocity relationship for concentric contractions. As the velocity of contraction increases, the force that can be developed decreases. A disadvantage of fast velocity training may be that the tension (force) developed within the muscle may not be great enough to stimulate maximal adaptation within the muscle. The advantage of fast velocity training is that it "trains" the nervous system. Motor unit recruitment is similar in slow and fast training. See text for further discussion. [From D.G. Sale and J.D. MacDougall, 1981]

the loading must be very light.

(2) Loading.

To develop power or the ability to exert force rapidly, the movement must be rapid or explosive, since it is primarily the nervous system which is being trained.

This requires that the amount of weight lifted (force of contraction) be decreased (according to the force-velocity curve) to perhaps 50% of the 1 RM. The more rapid the desired movement velocity, the greater must be the decrease in resistance.

The movement can now be made very rapidly and thus simulates the selective recruitment of motor neurons as would occur in throwing, jumping, etc. As the athlete begins to fatigue (e.g., after 20 reps), the movement begins to slow down and thus is no longer effective for increasing power.

It is also apparent that the resistance which is light enough to be effective for power training is not heavy enough for strength training.

It should be stressed that it is only the concentric phase of the lift which should be performed explosively, while the eccentric phase should be performed slowly. If this is not the case, athletes will try to incorporate a "rebound" or "plyometric" effect into the movement which could damage connective tissue — especially in younger athletes.

(3) Frequency.

Three to five sets of 15-20 reps of low resistance, high velocity movements appear optimal for power training.

As with strength training, 3-4 minutes of recovery for a particular muscle group, should occur between sets and frequency should not exceed 3 times per week.

To summarize, the strength training program for the strength and power athlete should include both slow velocity, high resistance movements in order to train the muscles, and high velocity, low resistance movements in order to train the nervous system.

[d] Specificity.

The degree to which training induced gains in strength and power can be

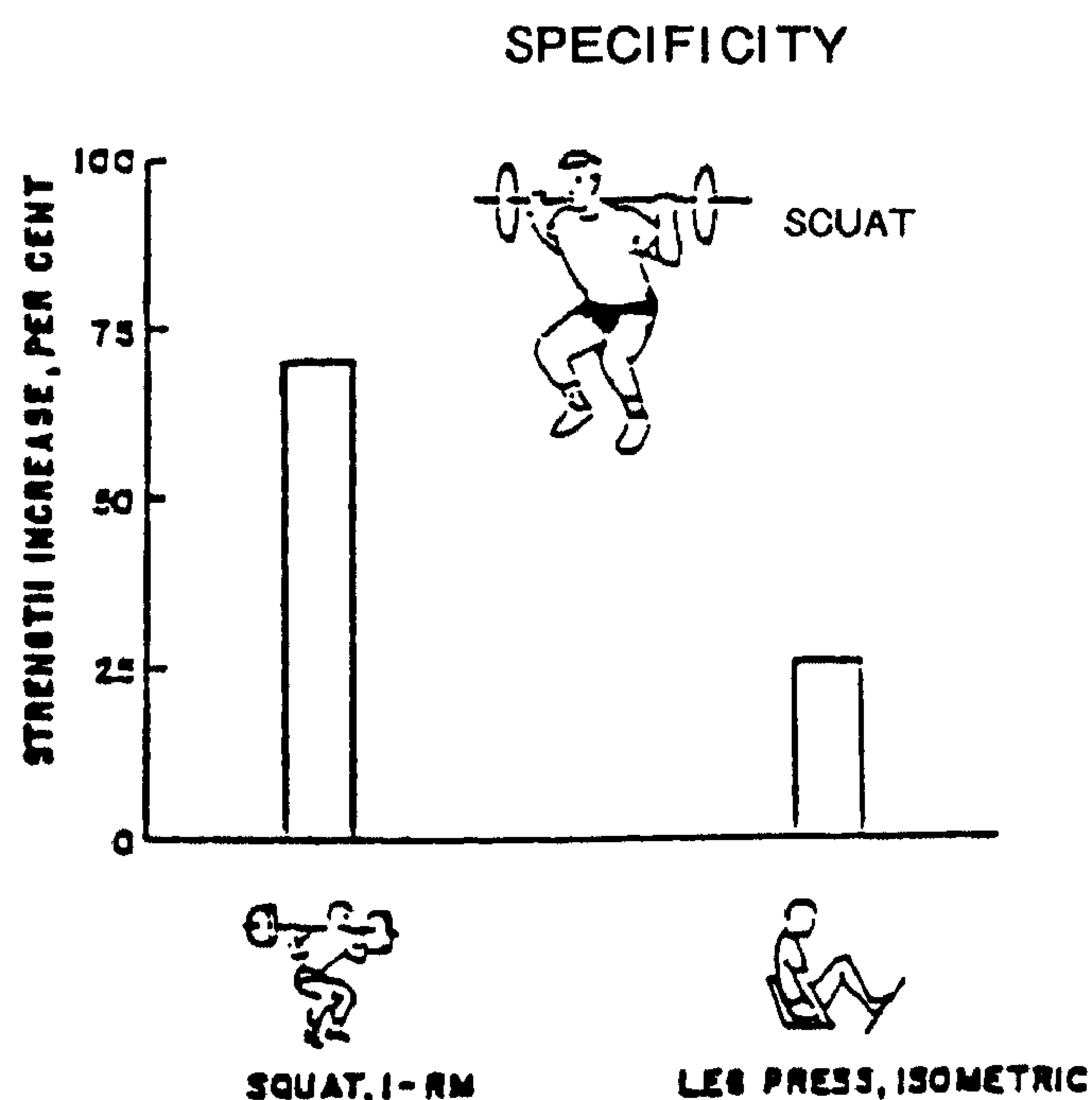


Fig. 10 Demonstration of specificity of movement pattern and contraction type in training. Eight weeks of strength training using the barbell squat exercise (involving concentric and eccentric contractions) caused a large increase in the 1 R.M. for the squat exercise but a relatively small increase in isometric leg press strength. Based on Thorstensson et al. (1976).

transferred to improve actual sport performance will depend upon how closely the training mode stimulates the motor patterns of that sport.

For an example of movement pattern specificity, with training, see Figure 10. In addition to specificity of movement pattern,

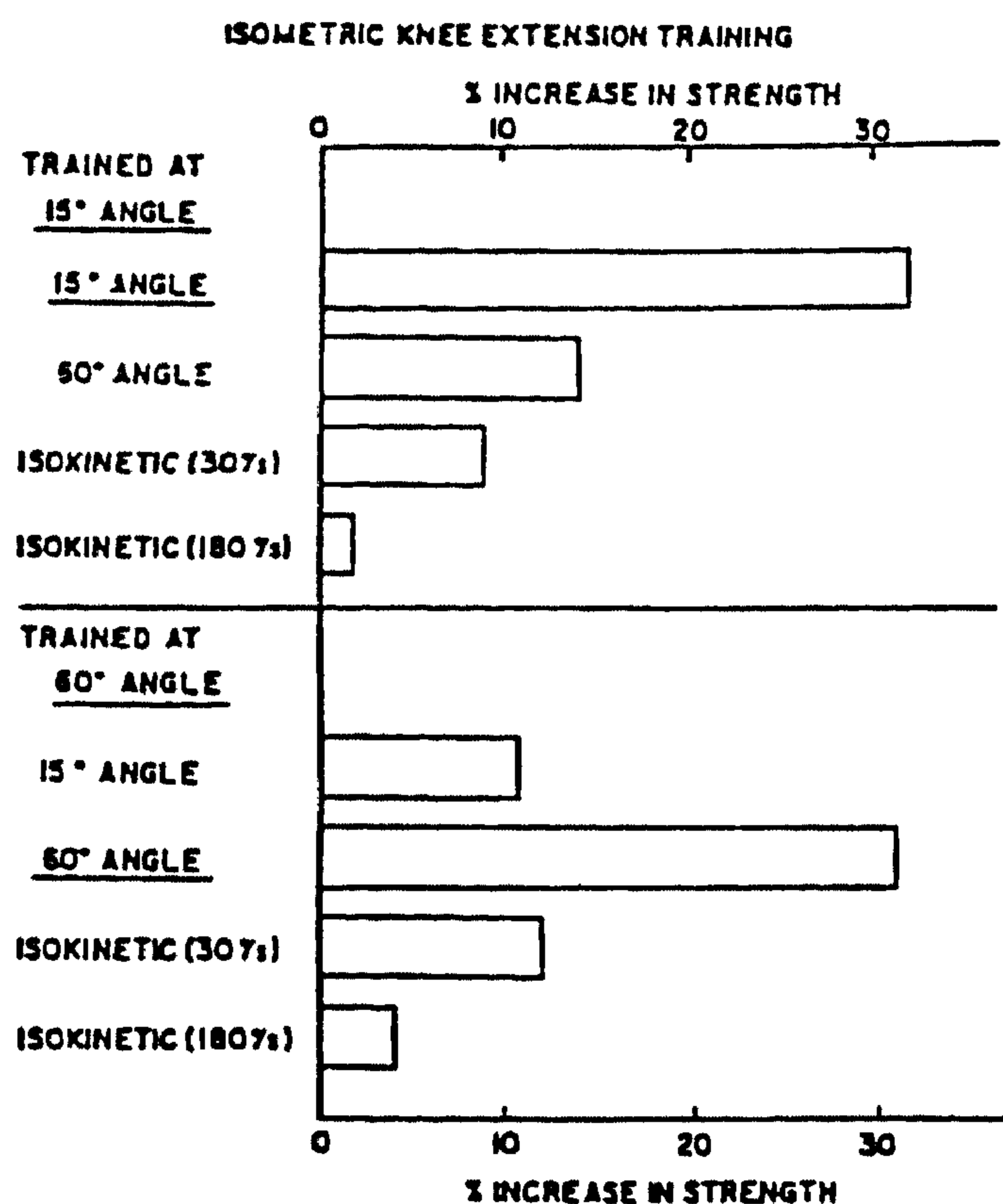


Fig. 11 Demonstration of specificity of joint angle (movement pattern) contraction type and contraction velocity in strength training. Top: isometric knee extension training at a joint angle of 15° caused a relatively large increase in strength at that joint angle, but a smaller increase at an "unfamiliar" joint angle. Measuring strength with a different contraction type (isokinetic = concentric contractions at constant velocity) also revealed less improvement. The isometric (ultimate slow) training caused greater improvement at the low (30°/s) than at the high (180°/s) velocity of isokinetic contraction. Bottom: training at a joint angle of 60° produced a similar pattern of results. Based on Lindh (1979).

the transferability of the "training effect", gained through resistance training, will depend upon the velocity at which the training was performed and even the joint angle where the greatest loading occurred (Figures 11 and 12).

## 5. Training Modalities or Equipment

Considerable confusion exists as to whether athletes should train by lifting free weights

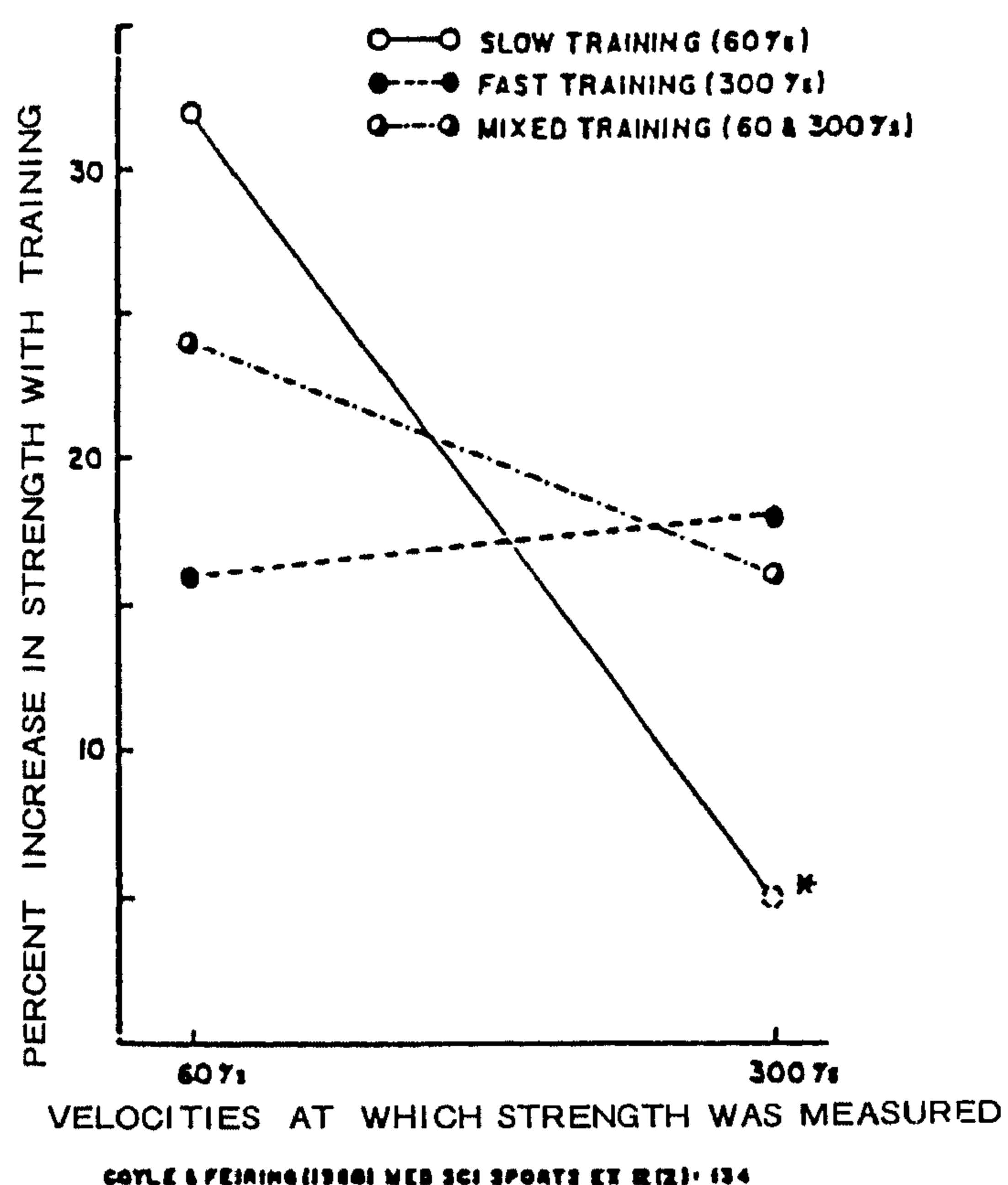


Fig. 12 Specificity of velocity in strength training. Slow velocity, isokinetic, concentric contraction training of the knee extensor muscles caused greater improvement in slow than in fast velocity strength. Similarly, fast training caused greater improvement at the high than at the low velocity, although the difference was not as marked. Mixed (fast and slow) training produced intermediate results. See text for further discussion. The non-significant improvement at high velocity for the slow training group was not reported and has been estimated here. Based on Coyle and Feiring (1980).



(i.e., barbells and dumbbells) or by selecting from an almost infinite variety of strength training devices available by ingenious equipment manufacturers. Unfortunately there is no simple answer.

**Training machines may be classed as either variable resistance or isokinetic devices. Their main advantage is that (compared to free weights) they can more closely match the strength curve for a particular movement and thus provide greater loading throughout the whole range of motion.**

**[a] Variable resistance devices.**

By utilizing a changing lever-arm (e.g., "Universal" units) or by a variable cam (e.g., Nautilus equipment) the resistance offered by the weight stack changes throughout the range of movement (Figures 13 and 14).

**[b] Isokinetic devices.**

Isokinetic means "at a constant velocity". Thus, as the muscle length changes, the resistance alters in a manner which is directly proportional to the force exerted by the muscle.

Unlike other devices, exercises can be performed at a variety of speeds with maximum resistance (Figure 15). Popular suppliers of isokinetic devices include such companies as "Cybex", Hydra Gym and Kin Kom.

**[c] The ballistic effect.**

When a free weight or weight stack is lifted rapidly, a greater lifting force is required at the initiation of the movement in order to overcome the static inertia of the weight. However, once the weight has acquired moving inertia, less force is required to keep it moving.

With a high velocity movement on an

isokinetic device, little resistance is offered at the beginning of the movement (i.e., while the limb is accelerating to "catch up" to the lever arm) but resistance becomes maximal at the end of the movement (Figure 16).

The appropriateness of a weight lifting method vs. isokinetic training will depend upon the nature of the sport movement. In movements where a mass must be accelerated at the start of the movement (e.g., jumping or throwing), weightlifting will be more specific; in movements where the resistance is encountered after the limbs have been accelerated to a high velocity (e.g., kicking a ball or a slap shot in hockey), isokinetic training will be more specific.

## **6. Sequencing of Strength and Power Training**

As with most training adaptations,

**less training volume is required to maintain gains in strength and power than to achieve the adaptation in the first place.**

For sports which are dependent upon high levels of muscle power, an effective sequencing would be to concentrate, during the off-season or low season, on the development of muscle strength through low velocity, high resistance training. This training should include not only prime movers but also the fixators and synergistic groups (and to a lesser extent the antagonistic muscles). This strength "base" is important for reducing in-season injuries and will have, at least, a partial transferability to the endurance and power characteristics of the muscle group.

As the pre-season phase of the season approaches, the athlete now "phases in"

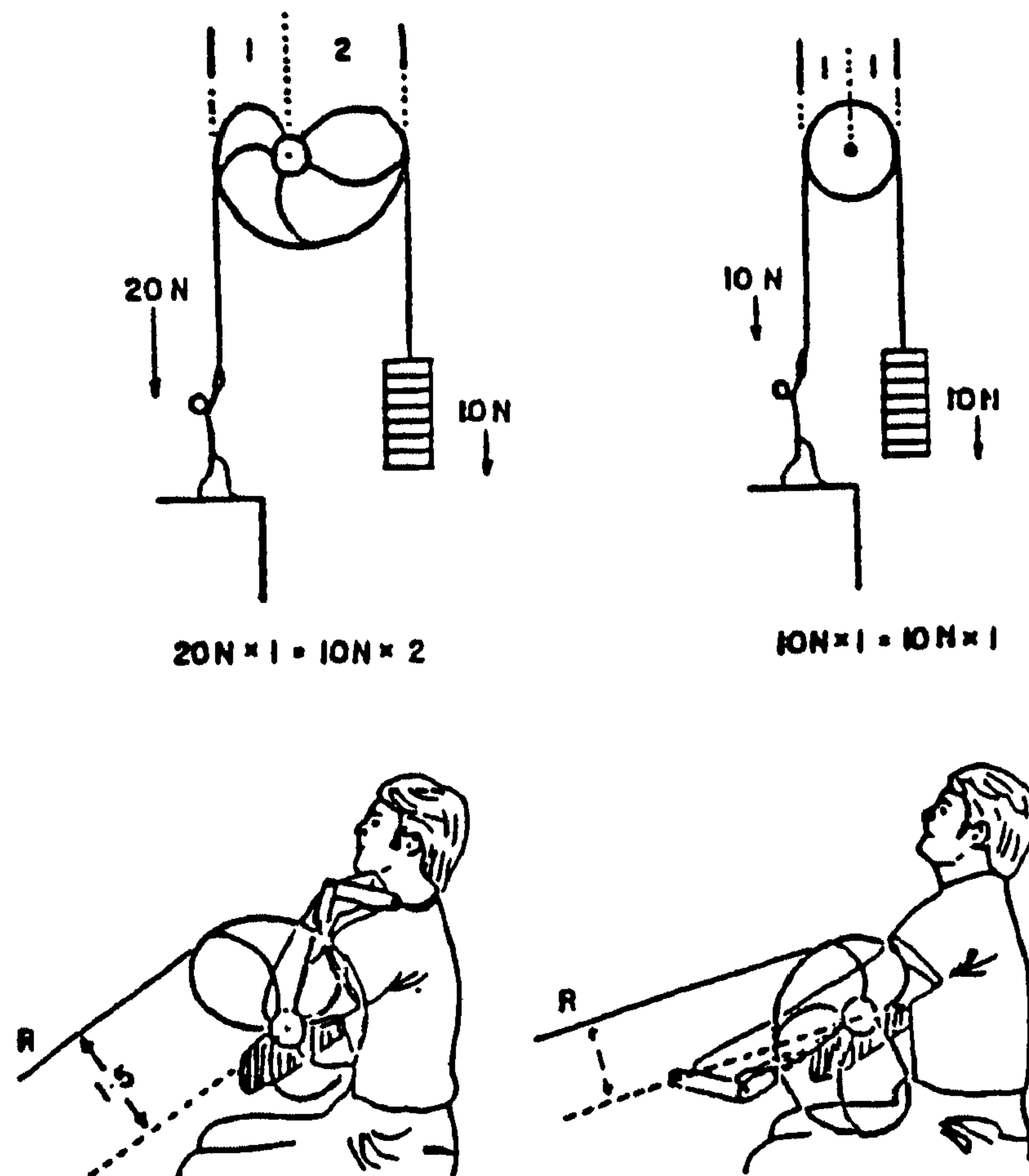


Fig. 13 The variable radius "Nautilus" pulley. "Nautilus" equipment (Nautilus Sports/Medical Industries, Deland, Florida) employs a variable radius pulley or cam to vary the resistance offered by a weight stack through a range of movement. Top right: in the case of a round pulley "wheel", the radius or moment arm of the weight (i.e. the perpendicular distance between the line of pull of the weight and the axis of the pulley) is the same as the radius of the line of pull of the "boy". Thus, the boy can balance or match the torque of the weight ( $10\text{ N} \times 1.0$  units of radius length) with a pulling force of  $10.0\text{ N}$  ( $\times 1.0$  units of radius length). Top left: In the variable radius Nautilus pulley, the ratio of the weight stack's moment arm length (radius) to that of pulling boy does not remain constant at 1:1 but changes as the pulley rotates. In the illustration, the ratio is 2:1 in favour of the weight stack; therefore, to match the resistance torque of the weight stack ( $10\text{ N} \times 2 = 20$ ), the boy will have to pull with a force of  $20\text{ N}$  ( $20\text{ N} \times 1 = 20$ ). Bottom: At right, in the starting position of an elbow flexion "curl" on a Nautilus curling machine, the moment arm has been given a value of 1.0. At the finish of the curl (left), the radius (moment arm) has increased (and thus the resistance torque) by 50% to a value of 1.5. Is such an increase in resistance through the range of movement in accordance with the strength curve for elbow flexion?

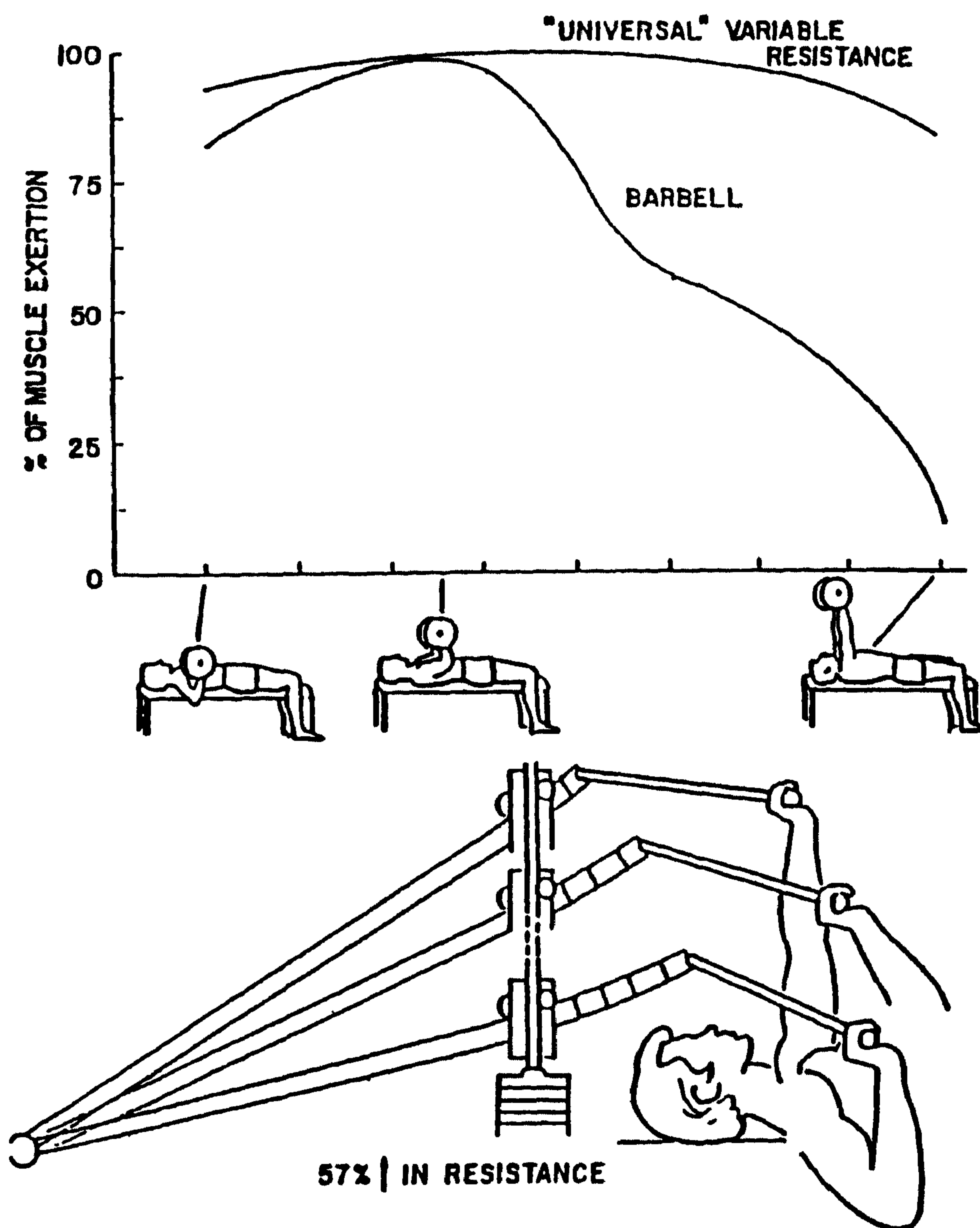


Fig. 14

#### "Universal" Variable Resistance

As described in a previous figure, the resistance curve offered by a barbell falls below the strength curve in the bench press movement (see graph). Bottom: The "Universal" variable resistance mechanism allows the resistance offered by the handle bar to stay up closer to the strength curve. The mechanism consists of a roller system that allows the weight stack to "roll" toward the handle bar; thus, more force must be applied to the handle bar to support the weight stack. The principle underlying this mechanism is described more fully in the following figure.

power or high velocity training, using sport specific exercises. The gains in size and strength which were achieved in the off-season can, for the most part, be maintained by as little as one day per week of slow velocity strength training.

In sports which require only high levels of muscle strength (e.g., weightlifting) reduced-load, high-velocity training is of little value and the athlete must train year round for strength. The optimal taper se-

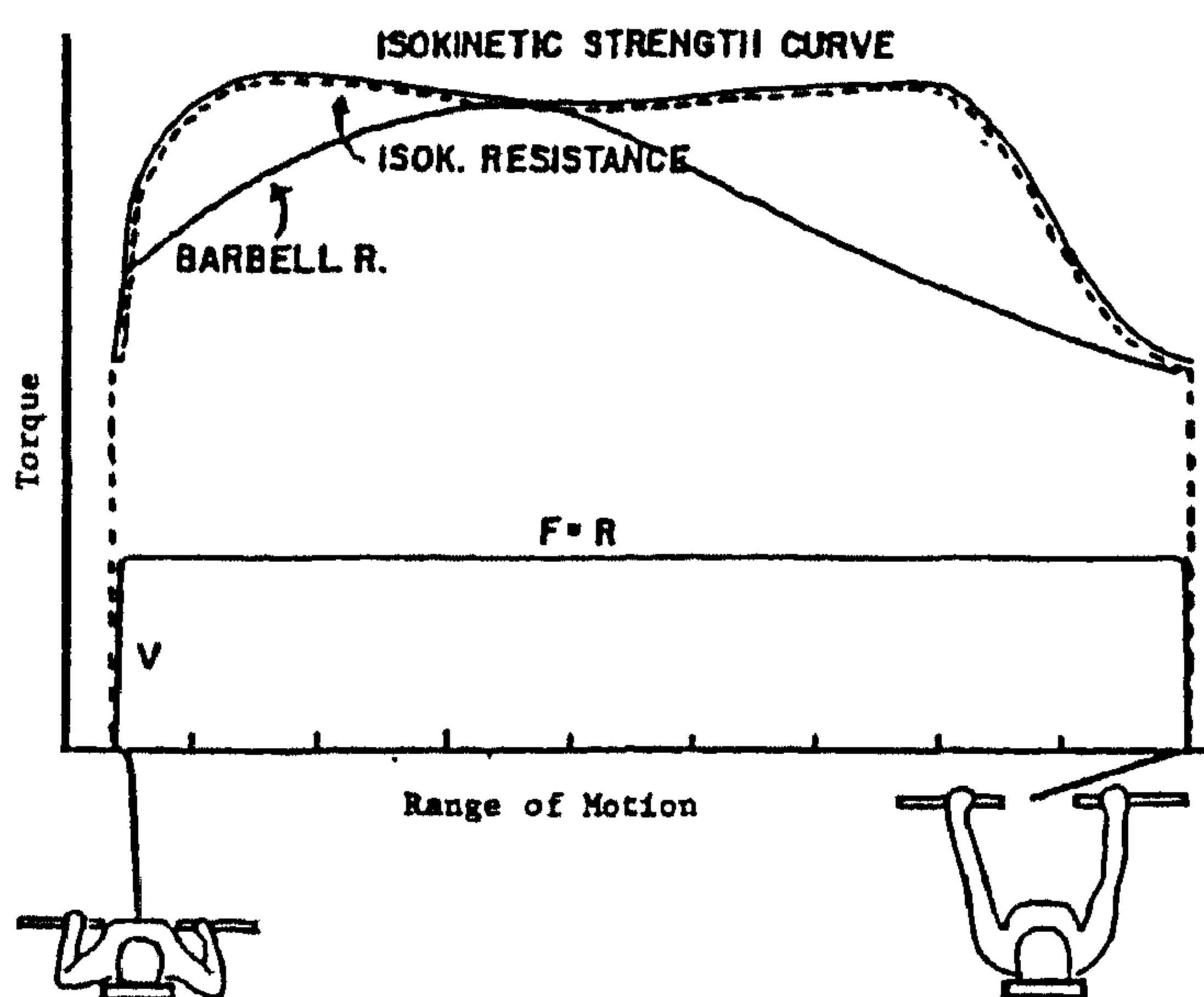


Fig. 15 Matching the strength curve with isokinetic resistance. In this example the Cybex has been adapted to permit performance of the bench press movement. The top solid line shows the strength curve for the movement (isokinetic strength curve). The isokinetic resistance curve (dotted line) precisely matches the strength curve because the machine matches whatever force is applied to it. The lower solid line indicates the velocity (V) of the movement. Notice that after a brief initial acceleration to begin the movement the velocity of movement is constant (solid line is horizontal) until just before the end of the movement. The constant velocity indicates that the resistance (R) offered by the machine is matching the force (F) applied to it ( $F=R$ ), because there is no net accelerating force applied to the machine.

#### HIGH SPEED TRAINING

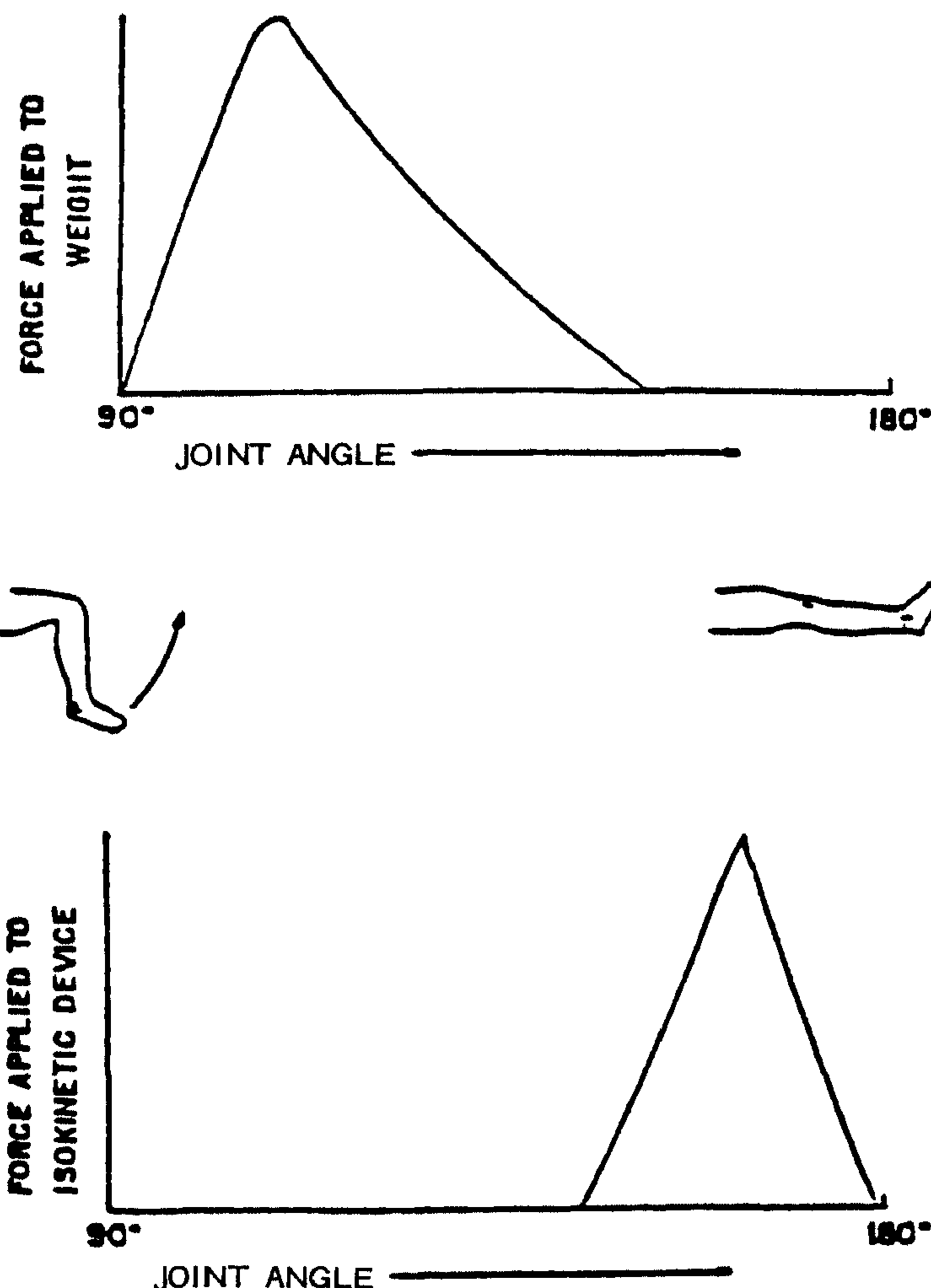


Fig. 16 High velocity training with weights and an isokinetic device. Top: The graph shows the force applied to a weight in knee extension with a ballistic action. Great force must be applied initially to accelerate the weight. By the time a high velocity has been attained at the end of the movement, the applied force will have declined greatly or even ceased. Bottom: In performing high velocity contractions on an isokinetic device, the trainee must first accelerate the limb to attain and attempt to exceed the velocity of the device before it will offer resistance to movement. Thus, the device will offer no resistance movement. Thus, the device will offer no resistance (save the inertia of the lever arm) at the beginning of the movement but will offer resistance near the end of the



quence for strength performance has not yet been investigated, but it is known that performance is enhanced by sharp reductions in the volume of training (i.e., number of sets or total number of lifts) over 7-10 days prior to competition.

## 7. Additional Topics

### [a] Plyometric training.

It is known that the force of a maximal concentric contraction can be increased if it is immediately preceded by an eccentric contraction. An example of this can be seen in the height which can be added to a vertical jump when it is preceded by a counter-movement, or by the wind-up of a baseball pitcher. The eccentric contraction or countermovement can be considered as "taking up the slack" in the series — elastic elements within the muscle and tendons so that the force can be generated more rapidly during the concentric contraction. Because of this, some coaches advocate the incorporation of a rebound or plyometric element into resistance training by such maneuvers as depth-jumping or the rapid lowering of the weight-stack (eccentric phase) followed immediately by the elevation (concentric) phase.

Since much of the adaptation which occurs with this form of training is training of the nervous system, the exercises must be very sport specific. For example, depth jumping (from an elevated platform) in the gymnasium may be of little value to the figure skater who must perform the jump on ice.

Whether or not such training is superior to conventional resistance training (i.e., where the movement is initiated from a static position) is not known.

**What is known, however, is that there is a very high incidence of connective and contractile tissue injury with this form of training.**

**Therefore, for most sports, the potential risks of this technique would seem to outweigh its potential benefits and, until more research is available, it should be discouraged.**

### [b] Eccentric training.

When muscles contract eccentrically (e.g., lowering a heavy weight or resisting an overpowering force) they can develop more tension than when they contract concentrically. Related to this, it has been shown that training with maximal eccentric contractions induces more muscle growth than training with either concentric or isometric maximal contractions.

It thus follows that,

**for athletes seeking maximal muscle hypertrophy, the eccentric phase of each lift is at least as important as the concentric phase. Partner-assisted lifting (during the concentric phase) can be utilized in order to increase the eccentric load beyond that which can be achieved during a conventional lift.**

It must be remembered, however, that such training is non-specific to most sports and thus will have minimal transfer to actual sport performance. In addition, as with plyometric training, this incidence of muscle injury and muscle soreness is very high with heavy eccentric training.

### [d] Nutrition and strength training.

The metabolic costs of a conventional strength training session are relatively low

compared with an endurance training session of the same duration. Large caloric intakes are thus unnecessary for athletes undergoing daily resistance training.

Dietary protein requirements for the increased synthesis and turnover of contractile protein, while higher than that of the sedentary individual, are by no means as high as most athletes believe them to be.

A recent study reveals that the protein requirements for bodybuilders training intensely 90 minutes per day are approximately 1.1 g of protein per kg body weight per day compared to the 0.7 g per kg recommended by Nutrition Canada for the average Canadian male.

It should be noted that this is a minor difference in protein requirement and one which is exceeded by a normal North American diet.

**There is thus no justification for strength athletes consuming extra protein in the form of supplements.**

**[d] Strength training and the child athlete.**

There have been very few studies of the effects of strength training on prepubertal children. Those that exist indicate that significant strength gains can be made but that increases in muscle size are minimal following training.

Controversy exists as to the potential hazards of heavy loading on a yet immature ligamentous and bone structure, as well as to the potential postural problems which might arise from "unbalanced muscular development".

**Until more evidence becomes available it is suggested that resistance training for pre-pubescent athletes should either be avoided or should take the**

**form of lower resistance, high repetition (15-20 RM) training in order to reduce the total mechanical loading on muscle and bone. It is also important to stress balanced training (antagonistic muscle groups as well) at this age and to avoid any form of plyometric training.**

**[e] Strength training and the female athlete.**

Research shows that women respond to strength training with significant increases in muscle strength but with less increase in muscle size, for a given training program, than that experienced by male athletes. It is generally considered that, in such instances, the gain in strength is largely the result of adaptation within the nervous system and that the limited hypertrophy is a consequence of lower androgen (testosterone) levels in females.

**There is no indication that female athletes incur a higher risk of injury with strength training than male athletes.**

**[f] Injuries and strength training.**

The majority of weight training injuries involve mechanical trauma (e.g., hand and foot injuries with weights and weight stacks). When using free weights it is thus imperative that all collars be secured tightly and that a spotter assist in all heavy lifting.

The second most frequent form of injury is overuse injuries such as tendonitis at the attachments of major muscle groups. Such injuries are more common when training frequency is high or when training with very heavy weights (1-3 RM).

Evidence indicates that each training session results in a certain degree of muscular and (to a lesser extent) connective

tissue damage which requires a repair process of 2-3 days. This is especially true for movements which stress eccentric contractions.

Muscle soreness. It is normal for athletes at the beginning of a program or when new movements are introduced, to experience delayed (24-48 hours) muscle soreness and

inflammation following the first 3 or 4 training sessions. Following this the feelings of soreness disappear, but tissue damage continues to occur, even in experienced trainers. This sequence of damage and repair may actually be an important part of the mechanism which stimulates muscle hypertrophy.

