Conditioning

Strength Training Fundamentals in Gymnastics Conditioning

James J. Major
Motor Behavior Laboratory
Dept. of Exercise and Sports Science
University of Utah
Salt Lake City, Utah

Often coaches must be a jack-of-all-trades, but masters of one. Gymnastics coaches are responsible for not only skill training, routine composition, safety, education, and mental health of their gymnasts, but also their conditioning. To help the coach with conditioning, there is a plethora of advice and equipment. However gymnastics coaches need fundamental information to evaluate these products and suggestions; and yes, even see through the grantsmanship of the sport scientists. Understanding basic principles, coaches can sift through the advice and choose the best conditioning for their gymnasts.

To help coaches towards understanding basic principles of strength training, the U.S. Elite Coaches Association for Women's Gymnastics (USECA–W) has had translated an excellent article on strength training fundamentals (Bührle and Werner, 1984). The translation of "The Muscle Hypertrophy Training of the Body Builder" (Bührle and Werner, 1984) is available from the USECA.

I want to explain how these fundamentals should be applied in gymnastics. Four basic principles that will help coaches to evaluate strength training are:

- Consistent, special strength training is necessary for maximum performance in gymnastics;
- Training to increase muscle size and strength is important, but maximum strength from minimum size is the most important training goal;
- Rest and recuperation are important aspects of strength training, also in gymnastics;
- Strength training must be integrated with the skill training in gymnastics.

Consistent, special strength training is necessary for the best possible performance in gymnastics.

One of the most important insights of modern training is that a highly developed level of strength cannot be maintained even by intensive performance of the event itself (Bührle and Werner, 1984). This insight has proven to be true in such very different events as swimming, cross-country skiing, and gymnastics. Gymnastics alone will not develop nor even maintain an adequate level of strength for advanced gymnastics (Oppel, 1967). Special conditioning must be performed, besides countless elements, combinations, parts, and full routines. Inconsistent strength training can explain the decline in performance, or at least the stagnation, of a number of athletes who had promising performances during the preparatory season. Once those athletes started to compete, their results did not live up to these expectations (Bührle and Werner, 1984). Gymnastics specialists have warned against decreasing strength training during the competition season (Borrmann, 1978: Hartig and Buchmann, 1988; Plotkin, Rubin and Arkaev, 1983; Ukran, 1969).

Special strength for gymnastics training must answer the demands of gymnastics. The principle of specificity implies that the exercises used in training should be similar to the exercises that must be performed in the competition routine. Therefore, we might imagine that the best training for gymnastics would be more gymnastics. However, long ago this was proven not to be the case (Borrmann, 1978; Oppel, 1967; Plotkin, Rubin, and Arkaev, 1983). Special training is necessary to develop the strength and power in the athlete sufficient for correct technical performance of skills (Hartig and Buchmann, 1988; Oppel, 1967). Repetition of the skill alone will not guarantee even a minimum level of strength to perform the skill correctly.

The observation that a highly developed level of strength cannot be maintained even by the most intensive performance of the movements of the competition routines does not contradict the principle of specificity, but completes it (Bührle and Werner, 1984; Martin, 1991; Verchoshanskij, 1985). Special strength training is necessary, but it must specifically meet the demands of the event, in this case gymnastics skills. What is specific for gymnastics will be discussed below.

Training to increase muscle size and strength is important, but maximum strength from minimum size is the most important training goal.

Muscle size and strength are related. The thicker a muscle fiber, the stronger it can contract, and the more tension or force the muscle can generate. The sum of all the cross-sectional surface areas of all of the fibers determines the size of the muscle cross-section, and thereby the potential for strength. This fact is particularly true for the lean, well-trained muscle of an athlete. The cross-sectional surface area of the muscle thereby becomes the most important trait for estimating strength (Bührle and Werner, 1984).

Increasing the cross sectional area of the muscle, or muscle hypertrophy, is fundamental for maximal improvement of strength (Bührle and Werner, 1984). However, we must admit that the exact biochemical mechanism for muscle hypertrophy, what factors cause it, and therefore how to best go about achieving or avoiding muscle hypertrophy is still unknown (MacDougall, 1986; Hartmann and Tünnemann, 1988). Muscle hypertrophy is most important in body building, but a survey of elite Swedish bodybuilders found no agreement on how to best achieve muscle hypertrophy (Tesch, 1986).

The cross-sectional area of the muscle increases with strength training because amino acids (proteins) are added to the muscle after training. There are at least two theories of exactly why and how proteins are added to the muscle because of work or training. One is the ATP-deficit theory of muscle hypertrophy, Adenosintriphosphate (ATP), is the immediate source of energy for contraction in the muscle. The ATP-deficit theory states that muscle growth is stimulated by a disturbance of the balance between production and consumption of ATP. ATP is essential for life but is only stored in limited quantities in the muscle (Figure 1). ATP-deficit in the muscle, particularly if it is the result of intensive maximal strength and power efforts, seems to provoke extra riboneucleic acid (RNA) synthesis. In turn, RNA stimulates muscle growth. Although it has been demonstrated that increased synthesis of messenger RNA is an essential requirement for the hypertrophy process (Lundholm, 1986), the stimulus for increased muscle uptake of protein apparently occurs before there is any evidence of increased RNA synthesis (MacDougall, 1986). An ATP-deficit probably also influences protein metabolism because the body requires ATP to compound amino acids into protein and more muscle.

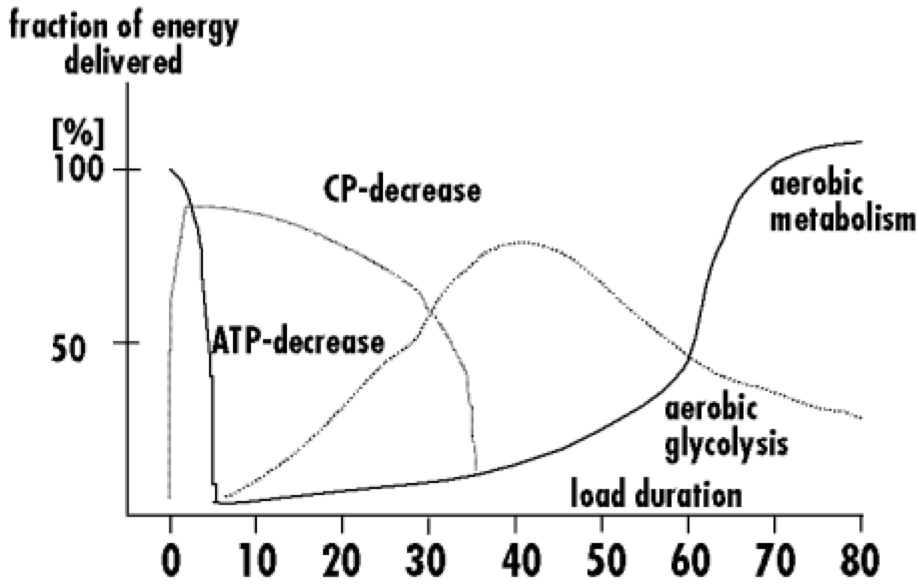

Figure 1. Fraction of the different metabolic substances in the supply of energy at continuous, maximum effort.
ATP and CP are the sources of energy for gymnastics. ATP and CP stores can be rapidly replenished. It is well known that there is little lactic acid in the blood of elite gymnasts after the floor exercise and optional pommel horse, so these routines apparently do not substantially tax anaerobic glycolysis and aerobic metabolism. Perhaps there are enough relatively easy phases during which ATP and CP can be restored. (Modified after Kuel et al in Bührle and Werner, 1984)

Intensive maximal strength and power exercises cause not only ATP-deficit but also damage to the body proteins. This damage occurs to components of the muscle fibers (structural proteins) as well as enzymes and hormones (functional proteins). Both structural and functional proteins are important for muscular contraction. Large concentrations of nitrogens excreted by the body after such efforts is evidence of the use of these proteins. These proteins are then rebuilt and supercompensated (Figure 2).

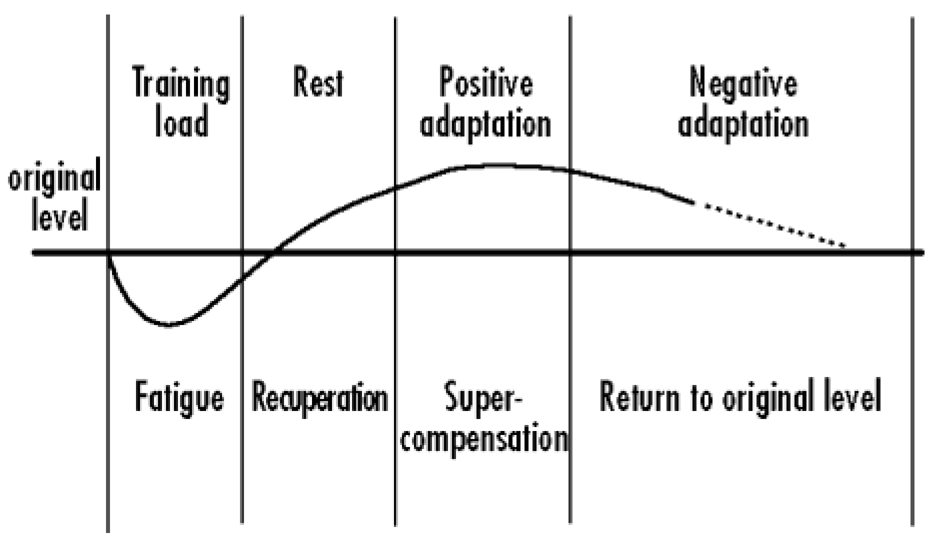

Figure 2. Schematic process of training load and adaptation (Matveyev, 1971)

Increasing cross-sectional area of the muscle with strength training is the result of the addition of contractile proteins to the muscle after training. However, when a muscle hypertrophies from training, other components also increase. Body builders have increased amounts of connective tissue in the muscle (MacDougall, 1986). Hypertrophied muscles also have increased resting concentrations of ATP and creatin phosphate (CP) (Hartmann and Tünnemann, 1988). More connective tissue and increased stores of ATP and CP also increase the volume, or cross-sectional area of the muscle. Moreover, I suspect that ATP and CP are the key sources of energy for gymnastics performance. I also suspect that ATP and CP are so important because well trained gymnasts have little lactic acid in their blood after completing full routines. The two main endurance problems in gymnastics, the last tumbling pass during the floor exercise and men's optional pommel horse routines, are probably related to ATP and CP stores, and thereby of the size of the main muscles used in those events. ATP and CP stores in the muscles are probably depleted in finishing gymnastics routines (see Figure 1). Therefore, muscle size is basic for endurance in gymnastics.

There are other theories that attempt to explain muscle hypertrophy besides the ATP-deficit theory. However, the bottom line in strength training is that the muscle must be bigger in order to be stronger. It is trite, but bigger muscles identify athletes better than any other physical attribute. This is also true for the male and female gymnast. However, gymnastics coaches also know that among the very best gymnasts many gymnasts with the biggest muscles are the weakest in the strength elements. Many gymnasts with the most exceptional strength moves do not have big muscles for a gymnast. How is this contradiction between physiology and gymnastics explained?

Most important for gymnastics is the insight that maximal strength can **also** be increased without increasing muscle mass (Bührle and Werner, 1984; Poliquin, 1991; Verchoshanskij, 1985). Increasing strength without increasing muscle mass is important in gymnastics because the gymnast must move his or her own body. In gymnastics the power-to-body-weight ratio is a factor that decisively influences performance. It is the power-to-weight ratio that strongly influences gymnastics performance, not strength alone.

We do not use all of the fibers in a muscle at once, but some use more fibers than others. An athlete's maximal strength is mainly determined by the number of muscle fibers recruited by the nervous system for the movement, together with the cross-sectional surface area of these fibers. Only 70 to 90 percent of the potential strength, determined by the cross-sectional surface area of the muscle, can be voluntarily activated and applied to athletic movements. Only by stimulating the muscle with electricity at a high frequency (100 Hz and higher) will permit all muscle fibers, and thereby the entire potential of the muscle, to be activated at once (Strojnik, 1995).

With the appropriate assistance, for example, stimulation of the muscle with electricity, the entire potential of the muscle to produce force can be measured. The potential strength value measured in this way is termed the **absolute strength**. The highest strength value produced by voluntary contraction is the **maximal strength** of the athlete. An athlete's maximal strength will usually be lower than that athlete's absolute strength. The difference between the absolute strength and the maximal strength is termed the **strength deficit** (Bührle and Schmidtbleicher, 1981). This is because even well trained athletes cannot use all of the fibers in their muscles at once. A "big" muscle is not necessarily the strongest one, particularly if a substantial fraction of the absolute strength cannot be voluntarily and skillfully applied. This is the strength deficit. Muscle hypertrophy training like the REF program will tend to increase the strength deficit, while maximal strength training like the MAX program will tend to decrease the gymnast's strength deficit (Table 1). For example, body builders usually have a very high absolute strength, but also a relatively large strength deficit.

Table 1. Comparison of the training routines of the three experimental groups in the experiment (Bührle and Werner, 1984)

MAX GROUP: Repeated maximal strength efforts

3 sets of 3 repetitions @ 90% of 1RM
2 sets of 2 repetitions @ 95% of 1RM
2 sets of 2 repetitions @ 97% of 1RM
1 set of 1 repetition @ 100% of 1RM

Total: 18 repetitions in 8 sets with an average intensity of 94.3% of 1RM.
Pauses between sets: 3 minutes
Performance of the movements: explosive contraction

This kind of program is appropriate for reducing the strength deficit.

REF GROUP: Repeated strength efforts until failure

3 sets of 12 repetitions @ 70% of 1RM

Total: 36 repetitions in 3 sets with an average intensity of 70% of 1 RM.
Pauses between sets: 2 minutes
Performance of the movements: repetitions to failure.

This kind of program is appropriate for muscle hypertrophy, increasing absolute strength, or body building.

POWER GROUP: Power training method

5 sets of 7 repetitions @ 45% of 1RM

Total 35 repetitions in 5 sets with an average intensity of 45% of 1 RM.
Pauses between sets: 5 minutes
Performance of the movements: as rapidly as possible. This kind of program produces almost as much muscle hypertrophy as repeated efforts to failure (REF).

Note: The relative level of the training load was readjusted every week to the improving level of maximal strength (1RM). 1RM is the one repetition maximum or the heaviest weight the athlete can lift one time.

Strength may be increased without increasing the size of the muscle by reducing the strength deficit. The training methods used are similar to that of Bührle and Werner's MAX group (repeated maximal strength efforts). Notice that this group had a substantial increase in maximal strength, but with the least increase in muscle mass (Table 2). With the MAX program the muscle simply does not do enough repetitions to go into ATP deficit and hypertrophy (Bührle and Werner, 1984; Hartmann and Tünnemann, 1988). Instead, here strength is increased by increasing maximal strength without little increase in muscle size, thereby reducing the strength deficit.

Table 2. The results of training with different methods (12 weeks) (Bührle and Werner, 1984).

N refers to Newtons, a measure of force.
1 pound of force is equal to approximately 4.5 Newtons.
Mm² is a measure of surface area of the muscle measured with computed tomography.

	Isometric Maximal Strength				Muscle cross-sectional area – triceps			
	before	after	difference		before	after	difference	
	N	N	N	%	mm²	mm²	mm²	%
MAX	441.3	521.7	79.4	18.0	27.4	30.1	2.7	9.9
POWER	442.3	518.8	76.5	17.3	26.2	29.0	2.8	10.7
REF	421.7	509.0	87.3	20.7	25.2	29.7	4.5	17.8

MAX: This group used a training program for improving maximal strength, with a minimum muscle hypertrophy effect, thereby reducing the strength deficit. This group used the lowest number of repetitions, but the highest average intensity, and intermediate rest periods.

REF: This group used a training program for increasing strength by increasing the cross-sectional area of the muscle (muscle hypertrophy). This group used the highest number of repetitions at an intermediate intensity, and the shortest rest periods. The result was intensive fatigue.

POWER: This group used a training program for improving power and quickness. This group used almost the highest number of repetitions, the next highest number of sets, but the highest speed of movement, and the longest rest periods.

Special, specific strength training for an event provokes an adaptation of the neural innervation processes that control the skill. The fraction of the absolute strength that can be voluntary activated may be increased with maximal strength training. Consequently, maximal strength can be increased by other means than by increasing the cross-sectional surface area of the muscle. An example of a training program that will increase the maximal strength of the athlete, without increasing the muscle size (absolute strength), would be the program of the MAX group in Bührle and Werner's experiment (see Table 1). However, coaches and athletes should recognize the fact that improvement by this method is limited by the morphologically available muscular mass, in other words by the absolute strength level. Therefore, a gymnast's conditioning should alternate between muscle hypertrophy and maximal strength training, between the training processes shown in Figures 3 and 4 (Schmidtbleicher, 1992). During training periods when relatively many whole and part routines are completed, the special strength training should be like that in Figure 4, using a program like that of the MAX group in Table 1. The reason for emphasizing training like

Figure 4 is to keep muscle hypertrophy and the strength deficit as low as possible during this routine training period.

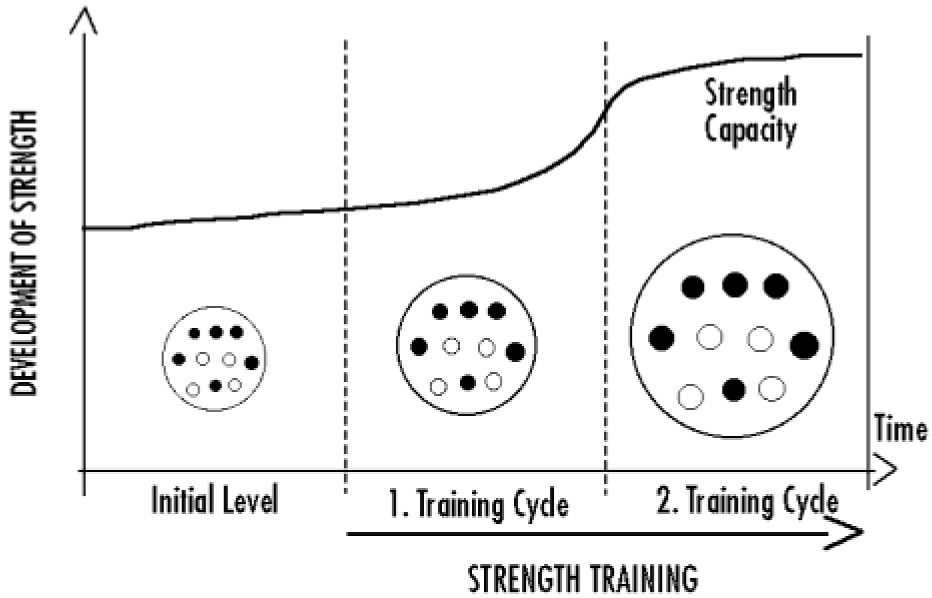

Figure 3. The course of a typical muscle hypertrophy training.
Notice that the diameter of the muscle increases as the diameter of the fibers increases. With this training, the number of the fibers in the muscle that are activated does not increase. This effect is produced by a training like REF in Table 1. (Modified after Hartmann and Tünnemann, 1988)

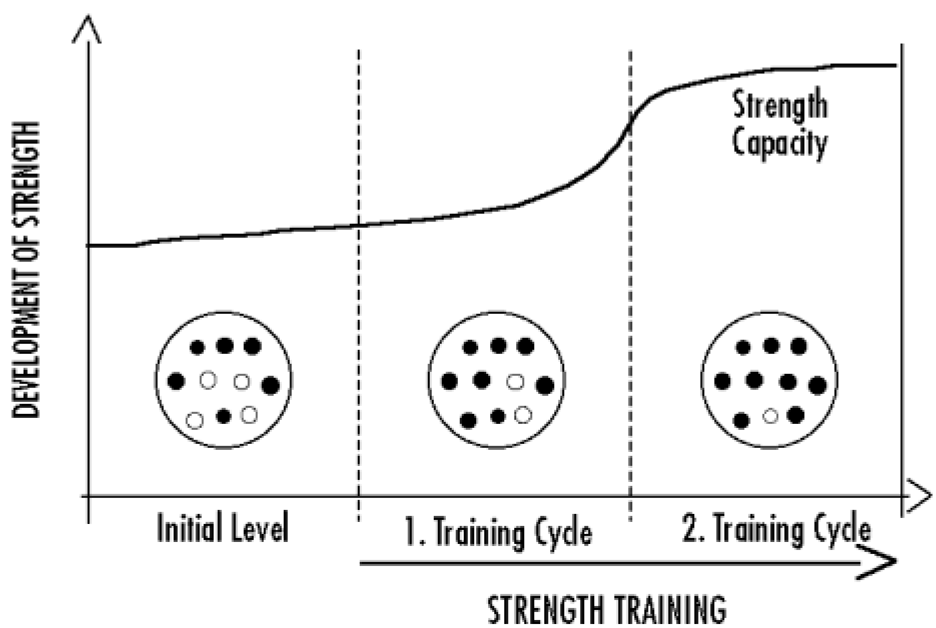

Figure 4. The course of a typical maximal strength training.
Notice that the diameter of the muscle depicted as circles does not increase while the ability to activate more muscle fibers increases. This effect is produced by a training like the MAX group in Table 1. (Modified after Hartmann and Tünnemann, 1988)

Rest and recuperation are important aspects of strength training, also in gymnastics.

It is a common idea in training that fatigue develops strength. This idea is particularly popular among athletes who train for muscle size, for example bodybuilders, football players, and throwers in the field events (Brunner and Tabachnik, 1990; Bührle and Werner, 1984). A rapid exhaustion of ATP stores has been associated with the "burning" feeling in the muscle. This painful feeling often accompanies strength training sets with heavy loads (70%) and many repetitions (8-15). This kind of strength training tends to be very fatiguing and is also the kind of training that make the muscles increase in size, or hypertrophy. If the load is less, but the speed of movement is very fast, the effect may be the same: muscle growth (Table 2; Bührle and Werner, 1984).

Figure 2 shows the time course of the training process. Notice that this graph also shows that rest is also necessary if strength is to increase. Chronic fatigue tends to reduce effects of the strength training on muscle size. In fact, it has been shown that strength and power training while chronically fatigued decreases the effects of strength training (Verchoshanskij, 1985). Bodybuilders often use split routines strength training every day, but a muscle group only every other day (Bührle and Werner, 1984; Tesch, 1986).

Heavy fatigue from strength training has other effects that are important in gymnastics. Heavy fatigue from strength training can be very detrimental to coordination and technique. When gymnasts perform powerful movements, their nervous system is heavily involved and their coordination is also improved by this training (Borrmann. 1978). Therefore, maximal strength training should be performed when the gymnast is warm, but relatively fresh. Training periods where strength training is emphasized should be separated from periods where skill learning is emphasized (Major, 1993; Verchoshanskij, 1985).

Strength training must be integrated with the skill training in gymnastics.

Modern strength training and conditioning has two priorities:

- On one hand, training should improve the cross-sectional surface area of all muscle fibers, and thereby the absolute strength.
- On the other hand, this potential, absolute strength must be able to be applied with maximal effect, in a manner specific to the event. Applying strength, with maximal effect, specific for the event, is achieved with skill practice and training (Bührle and Werner, 1984).

Correct technical execution is often impossible without sufficient strength. Performance of gymnastics skills with virtuosity often demands a great deal of strength. With insufficient strength, the gymnast learns a skill with one technique only to have to relearn the skill when he or she has increased strength. Relearning can be very time-consuming, frustrating, and is a substantial source of inefficiency in the training process (FKS, 1988). Alternative methods are:

1. Develop sufficient strength before learning the skill (sequential strength-skill development), and
2. Spot or assist the gymnast with insufficient strength for technically good performance during performance of the skill while strength is being developed (simultaneous skill-

strength improvement). As well, any loss of strength will deteriorate the technical performance of a skill that the gymnast has already mastered.

Specific for gymnastics skills are the muscle groups that need hypertrophy, and which muscle groups do not. After observation of the morphology of the world's elite gymnasts in several European, National, and World Championships events, I believe that elite gymnasts of both genders appear to need hypertrophied:

- elbow extensors (movement: straightening the elbow joint; typical exercise: bar dips or hand stand pushups)
- plantar flexors (movement: standing up on toe; typical exercise: standing toe raises)
- shoulder (hyper-) flexors (movement: lifting the arms above and past the head; typical exercise: press to handstand)
- sternoclavicular joint elevators and depressors (movement: lifting or pushing down the shoulders and arms; typical exercise: straight arm lat pulldowns or incline bench press)
- hip extensors (movement: kicking the thigh back; typical exercise: cast to handstand)
- shoulder extensors (movement: pushing the arms down and behind the back; typical exercise: Manna)
- In addition, the male gymnast must have hypertrophied:
- shoulder adductors and horizontal adductors (movement: end of front giant in rings, cross; typical exercise: flys)
- elbow flexors (movement: bending the elbows; typical exercise: initial pull up to Asarjian in rings)

The above list does not ignore the fact that many of the individual muscles that participate in these movements also participate in other movements important for technically perfect gymnastics, for example by stabilizing the joint (stabilizers). For technically correct gymnastics, almost all other muscle groups than the above list must be very strong. The muscle groups must have minimum muscle mass and minimum strength deficit. This is particularly the case for all (remote) joint stabilizer muscles of the body.

Strength Training Principles for Gymnastics

Muscle size is important for strength, but gymnastics conditioning must not become body building. Absolute strength does increase with body mass. Among trained athletes, the bigger the person, the more weight they can usually lift. This relationship between body size and strength can be seen in the graph comparing weight lifted in the Olympic weightlifting events (world records) compared to weight class (Figure 5). However, the strength of an athlete relative to their body size decreases as the body mass of the weight lifter increases (Figure 6). The world record in relative strength is held by an athlete in the 60 kg (125 lb.) class who snatched three times his own body weight with one movement over his head! Olympic weightlifting is an extreme power, technique, and quickness event like gymnastics. We must remember that the power-to-body-weight ratio IS an important performance determining factor in gymnastics. A gymnast must lift his or her body mass with their legs when tumbling or with their arms on bars. As the mass of the gymnast increases, they inevitably tend to slide down the curve in Figure 6, and their gymnastics performance will tend to suffer.

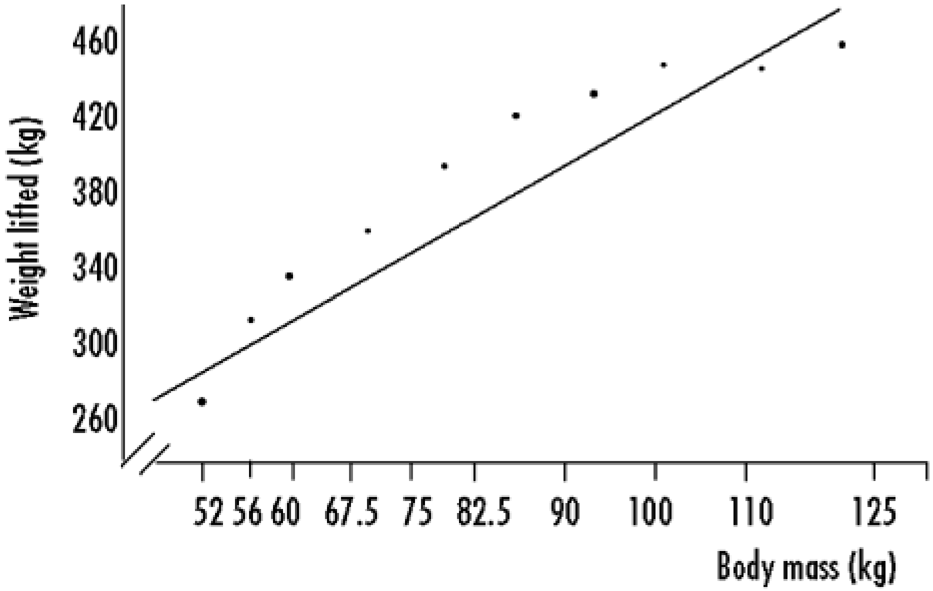

Figure 5. The relationship between maximal strength and body mass exemplified by the World Records in Olympic Weightlifting.
The heavier the athlete, the more weight is lifted. (Modified after Hartmann and Tünnemann, 1988; Tittle and Wutscherk, 1992)

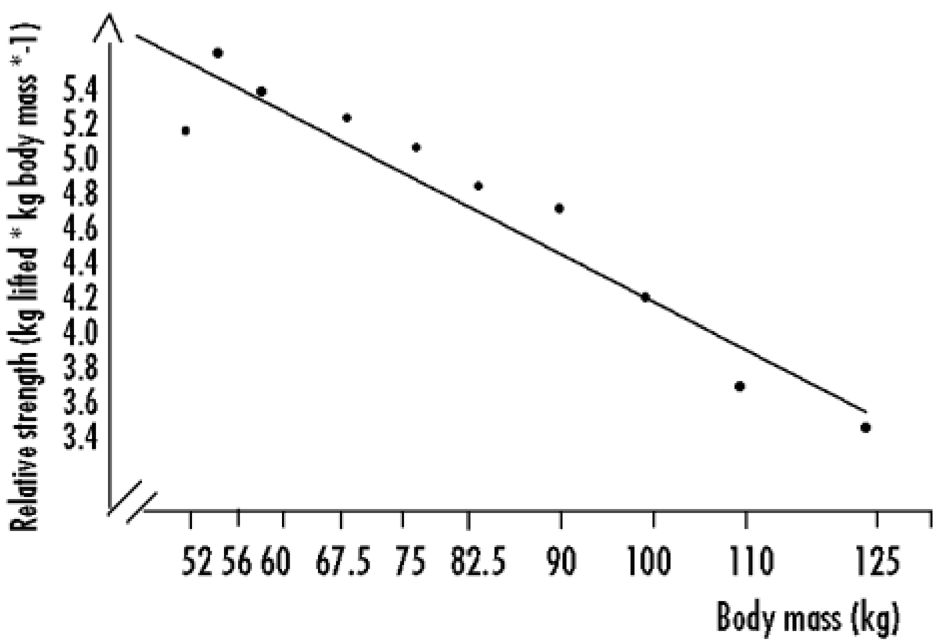

Figure 6. The relationship between maximal strength and body mass exemplified by the World Records in Olympic Weightlifting.
The heavier the athlete, the less weight is lifted per kilogram body mass. (Modified after Hartmann and Tünnemann, 1988; Tittle and Wutscherk, 1992)

The power-to-body-weight ratio is perhaps the real reason why the taller and heavier gymnasts seem to have more difficulty succeeding in gymnastics. The taller the athlete is, the greater his or her body mass will be, and the worse the relative strength. If this is indeed the case, then the training of the taller gymnast must concentrate on the highest relative strength and lowest strength deficit.

I believe the problem of the taller gymnast is analogous to the loss of performance and strength commonly seen in the pubertal gymnast. Well trained 10-year-old girls and 12-year-old boys commonly show comparatively high values of relative strength. But as children and teenagers become taller and therefore heavier, their relative strength should decrease. Relative strength often does seem to decrease, especially during pubertal growth spurts and skill performance deteriorates at the same time. In the case of the pubertal male gymnast, the problem is due to a relative strength that cannot keep up with the increase in body mass due to body height growth (Zatsiorsky, 1995). What might be appropriate here would be muscle hypertrophy training. In the case of the female gymnast who is filling out during puberty, the loss of relative strength is also due to increased body mass, but not only from body length growth. In the case of the female gymnast, more muscle hypertrophy training would be clearly inappropriate. Instead, the maximal strength of the female gymnast must be increased while maintaining body mass. Increasing maximal strength while maintaining mass would reduce the strength deficit and increase relative strength.

Muscle tissue and fat tissue are the two kinds of body tissue that are relatively quickly gained or lost with training. As muscle tissue is much more dense than fat tissue, muscle hypertrophy can cause a greater increase in body weight than a slight loss of fitness. Muscle hypertrophy training must therefore be very judiciously used in gymnastics training. As hard as it is to loose a pound of fat through correct diet and exercise, a pound of excess muscle is comparatively impossible to loose and still maintain fitness. Muscles that are not absolutely essential for gymnastics should not be hypertrophied. The important muscles for gymnastics need to be hypertrophied, but only within strict limits.

Not only will exaggerated muscle hypertrophy training ruin the gymnast's power-to-weight ratio or relative strength, muscle hypertrophy training may also make the gymnast slower. It is well-known that bodybuilders tend to have a higher percentage of slow twitch muscle fibers than Olympic weight lifters, power lifters, or other strength athletes (MacDougall, 1986; Tesch, 1988). One explanation is that typical body building sets last so long that the muscle suffers a lack of oxygen (8-15 reps per set). Moderately heavy loads high numbers of repetitions and shorter rest periods restrict the supply of oxygen to the muscles. It appears that this restricted supply of oxygen can cause muscle fibers to change to slow-twitch tissue (Tamaki et al., 1994). The lack of oxygen stimulates the muscle to increase its oxygen binding ability. The ability to extract oxygen is unfortunately also associated with slower contractions and lower peak forces. High numbers of repetitions, and shorter rest periods, describe the training that caused the greatest muscle hypertrophy in the Werner and Bührle's (1984) experiment (Table 1, REF group). This may be the explanation behind the bigger, but relatively weaker, muscles of bodybuilders compared to Olympic weight lifters.

In one particular case, ignorance about hypertrophy training can be potentially catastrophic. When the coach is asking the gymnast to loose weight, while having the gymnast do a muscle hypertrophy training, the gymnast is in an impossible situation. Due to the hypertrophy training, the athlete is gaining weight no matter how little she or he eats. In such a situation, disordered eating behaviors might seem to the athlete like the only solution. Muscle hypertrophy training is therefore potentially connected with eating disorders.

Coaches may unwittingly have their gymnasts complete body building. Many typical gymnastics strength training exercises could in fact cause excessive hypertrophy. Looking at the muscle hypertrophy of gymnasts who claim not to lift weights, but only perform body-weight resistance, (traditional) gymnastics strength training would also lead one to believe that gymnastics in and by itself can cause substantial muscle hypertrophy. I suspect that muscle hypertrophy due to a POWER type program using body weight gymnastics specific exercises and speed is happening too often in gymnastics (see Table 1). Gymnastics training, particularly performing many routines and half-routines during a single workout, is very similar to Bührle and Werner's POWER training program. This group achieved almost as much muscle hypertrophy as the body building group (REF), but without corresponding increases in maximal strength (Table 2). Moreover, among gymnasts there is obviously a wide variety in the ability to build body mass. The observation that individuals have individual ability to hypertrophy their muscles concerns females as well as male gymnasts. Therefore,

Gymnastics Coaches! Critically evaluate your strength training.

It has been noticed for some time that the very best gymnasts in the world have great strength with little muscle mass (Schwermann, 1986). Massive development of quadriceps (women) and upper arms (men) in some of our best gymnasts is also anecdotal evidence that our strength training should be reevaluated. Elite gymnasts who resemble body builders make a nice show, but poor gymnastics. My direct experience with the 1993 World University Games USA men's gymnastics team leads me to believe that the strength deficit is a problem in USA men's gymnastics training methodology. During the first phase of the training camp for those World University Games, the athletes demonstrated an almost daily increase in maximal strength, and excellent performance during gymnastics practice, despite unusually hard and fatiguing training of daily compulsory and optional routines as well as twice-daily strength training. These changes happened over such a short period of time that a change in absolute strength can be ruled out. The morning strength session was according to the same program as the MAX group in Table 1. The afternoon strength training was according to Plotkin, Rubin, and Arkaev (1983). The MAX program involved a maximum lift in each training and therefore the 1RM was measured every day. Almost without exception, the 1RM of the team members increased each day. I believe that what was happening was an increase in their maximal strength before there was any possibility of further hypertrophy because there was not enough time for the muscle to hypertrophy nor were the gymnasts lifting enough to cause muscle growth. Therefore they reduced their strength deficit, and thereby increased their relative strength. Another sign was that their gymnastics performance continued to be excellent, and even improve, despite the fatigue of strength twice a day as well as half-routine and full-routine training (Watanabe, Major, and McKelvain, 1993; Major, 1993). The situation of our elite and collegiate female gymnasts is unknown. The 1991 Women's Senior National Team was stronger than the Junior National Team (Irvin, Major, and Sands, 1992). However, the fact that the Junior National Team had better relative strength indicates that the Senior National Team's strength training was not maximizing strength while minimizing muscle hypertrophy as effectively.

Conclusion

An increase in the cross-sectional surface area of the muscle is fundamental for the maximal improvement of strength because strength improvement is ultimately limited by muscle size, the muscle cross-sectional area. However, the gymnastics coach must also understand muscle hypertrophy training because gymnastics training must keep muscular hypertrophy within strict limits. Hypertrophy must be kept within strict limits to keep the power-to-body-mass ratio of the gymnast as high as possible. Gymnastics coaches must understand body building so that they can conservatively use hypertrophy training with the gymnasts in their care.

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