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# Weightlifting: A Brief Overview

Michael H. Stone, PhD
East Tennessee State University, Johnson City, Tennessee

Kyle C. Pierce, EdD
USA Weightlifting Development Center, Louisiana State University, Shreveport, Louisiana

William A. Sands, PhD
Coaching and Sports Science, United States Olympic Committee, Colorado Springs, Colorado

Meg E. Stone
East Tennessee State University, Johnson City, Tennessee

**summary**

This is the first part of a 2-part discussion on weightlifting and will describe the historical and scientific background of the sport.

Before we can begin a meaningful discussion of weightlifting it is pertinent to begin with appropriate definitions. For the purpose of this discussion the appropriate term for training with added resistance/load is *resistance training* (RT). RT can be used as a general term to describe training with different modes. These modes can include free weights and machines. *Weight training* is a general term and a type of RT used to describe methods/modes in which a load (weight) is actually lifted; this could include free weights or a weight stack.

The general term RT also includes various training methods having diverse goals. These methods include training for rehabilitation/injury prevention, general fitness and recreational sports, bodybuilding, and competitive sports. From the aspect of competitive sports this includes the following:

- Using RT as an integral part of training for sports other than powerlifting or weightlifting.
- Using RT for *powerlifting*. Powerlifting is actually a strength sport in which 3 lifts are contested. The 3 lifts, in order of execution in a contest, are the squat, bench press, and deadlift.
- Using RT for *weightlifting*. Weightlifting is a strength/power sport in which 2 lifts are contested. The 2 lifts, in order of execution in a contest, are the snatch and the clean and jerk. Weightlifting (one word) should not be confused with weight lifting (2 words) or weight training. Weightlifting refers to a specific sport, whereas weight lifting refers simply to lifting a weight (44). In this context weightlifting is often referred to as Olympic lifting; however, this terminology is misleading in that all weightlifting does not occur in the Olympics. Furthermore, none of the governing bodies (international or national) use the term "Olympic lifting" in their name. Governing bodies consistently use the term weightlifting (e.g., USA Weightlifting, Australian Weightlifting Federation, International Weightlifting Federation [IWF]).

Several performance-associated characteristics impact the ability to perform as a weightlifter. These characteristics include strength, rate of force development, and power.

*Strength* can be defined as the ability to produce force, and this force can be isometric or dynamic (58, 61). Because force is a vector quantity, the display of strength would have primary characteristics of magnitude and direction. The magnitude can range from 0 to 100%. The level of force production and its characteristics are determined by a number of factors including the time period of muscle activation, the type of contraction, the rate of muscle activation, and the degree of muscle activation. The importance of force production can be ascertained from Newton's second law, **F** = *ma.* The acceleration (*a*) of a mass (*m*) such as body mass or an external object depends upon the ability to generate force (**F**). Acceleration in turn results in a velocity; as weightlifting is a velocity-dependent sport, high force production is an essential element. Another important characteristic associated with strength is the rate at which the force is developed. Rate of force development (RFD) is associated with acceleration capabilities (53) and can also be an important factor among strength-power athletes in determining superior performance. For example, the critical aspects of most strength-power sports occur in very short time frames (<250 milliseconds); if a greater force (due to greater RFD) can be produced in this critical time period then greater accelerations and velocities can be achieved. Interestingly, stronger athletes also appear to have RFD advantages (22).

*Power* production is the product of force and velocity (**F** × *V*) and is likely the most important factor in determining success in most sports, particularly weightlifting. Thus, the ability to generate force (strength) and its related component, RFD, is an integral part of power production, and therefore may be a key component in determining athletic success.

*Endurance* can be defined as the ability to maintain or repeat a given force or power output. *High-intensity exercise endurance* (HIEE) is the ability to maintain or repeat very high forces or power outputs. Although weightlifting is not generally thought of as an endurance sport, being able to repeat high forces or high power outputs (HIEE) is a necessity both in training and competition.

The development of these characteristics (strength, RFD, power, HIEE) is important for success in weightlifting. It is also important to note that RT can emphasize one or more performance characteristics, such as training for maximum strength, power, or HIEE. The emphasis can then be termed strength training (training for maximum strength), speed-strength training (training for power), strength-endurance training (training to repeatedly lift heavy loads), or power-endurance training (training to sustain or repeat high power outputs). Training for weightlifting is largely performed using free weights, and typically there will be an emphasis on different aspects (performance characteristics) of training during a training cycle (see *Training the Athlete* section).

## Historical Perspective

Weightlifting can trace its beginnings to more than 4,000 years ago. Evidence for both strength training and strength contests can be found in the illustrations of weight-lifting and strength movements on the tomb of the Egyptian Prince Baghti dating from approximately 2040 BC. Detailed writings from *Lu's Annals* (54) dating from 551 BC also indicate that feats of strength and strength training were valued athletic endeavors in ancient China. Ancient records indicate that contests of strength/power were apparently not included in the ancient Greek Olympics. However, ancient Greek writings, statues, and training/competition implements (e.g., *halteres,* or throwing stones) indicate that resistance training and contests of strength/power were quite popular in ancient Greece at least as early as 557 BC and that exhibitions and strength contests were likely included in other ancient games (54). Such contests of strength/power gained in popularity into the modern era.

The present day sport of weightlifting requires not only great strength but also exceptional power, speed of movement, and flexibility. The beginnings of modern weightlifting can be traced to the mid 1800s, when several clubs devoted to weightlifting and general strength training began to spring up in Europe, particularly in Austria and Germany. The first World Weightlifting Championships were held in London in March 1891. Weightlifting, as a sport, rapidly spread to the United States; through the 1930s to the early 1960s the United States was a world leader in weightlifting, producing several world and Olympic champions (15).

Men's weightlifting was included in the first modern Olympics in 1896 as a part of track and field. Its own international federation was formed in 1905 and was recognized by the International Olympic Committee (IOC) in 1914. Weightlifting became a permanent fixture in the Olympics at the 1920 Antwerp Games. During the early 1980s, women's weightlifting increased in popularity, particularly in the United States and China, and the first women's world championships were held in Daytona Beach, Florida, in 1987. Women were first included as part of the Olympics weightlifting program during the 2000 Games in Sydney, Australia. In most countries weightlifting includes both junior (12–20 years) and open men's and women's competitions; these competitions are held at the local, regional, national, and international level.

From 1896 until 1925, weightlifting competition included both 1- and 2-arm lifts. In 1925 the IOC limited competition to 3 lifts: the 2-hands press, snatch, and clean and jerk (54). These 3 lifts were contested from 1925 until 1972 when the press was dropped from competition, largely as a result of difficulties in judging press technique. Presently, weightlifting is contested in approximately 165 countries and, by number of countries, is consistently 1 of the 7 largest participant sports in the Olympics.

Each country has its own governing body responsible for holding competitions and certifying athletes and officials according to international rules. Additionally, national governing bodies may

**Table 1a**
**Physical Characteristics of U.S. Male Weightlifters**

| Number | Age (year) | Body mass (kg) | % Fat | LBM | Height (cm) | W/H |
|---|---|---|---|---|---|---|
| EL (*n* = 14) | 24 ± 3 | 89.1 ± 18.0 | 10.1 ± 4.0 | 80.1 ± 13.0 | 171.0 ± 9.5 | 0.52 ± 0.12 |
| M + 1 (*n* = 7) | 26 ± 4 | 84.9 ± 20.9 | 11.7 ± 5.0 | 74.1 ± 14.9 | 173.5 ± 11.0 | 0.48 ± 0.13 |
| C2< (*n* = 13) | 24 ± 4 | 86.2 ± 18.2 | 12.4 ± 6.9 | 75.4 ± 15.2 | 172.5 ± 13.0 | 0.50 ± 0.14 |
| UT (*n* = 7) | 20 ± 3 | 90.1 ± 5.4 | 18.2 ± 7.4 | 74.0 ± 9.6 | 179.0 ± 3.5 | 0.05 ± 0.13 |

Note: W/H = body mass (kg)/height (cm); EL = elite; M + 1 = master and first class; C2< = class 2 and below; UT = untrained men (group match statistically on body mass); LBM = lean body mass. Body composition was measured by skin folds. UT, C2, M, first, and elite data collected 1978–1983. Elite data collected fall 2003 and presented at USOC in-house seminar 2004.

**Table 1b**
**Physical Characteristics of Elite Female Weightlifters**

| Number | Age (year) | Body mass (kg) | % Fat | LBM | Height (cm) | W/H |
|---|---|---|---|---|---|---|
| WL (*n* = 14) | 27 ± 5 | 61.3 ± 11.5 | 20.4 ± 3.9 | 49.0 ± 12.2 | 161.6 ± 8.6 | 0.38 ± 0.06 |
| UT (*n* = 13) | 26 ± 7 | 61.1 ± 9.9 | 27.0 ± 7.4 | 44.6 ± 16.8 | 164.2 ± 8.6 | 0.37 ± 0.09 |

Note: W/H = body mass (kg)/height (cm); WL = elite weightlifters; UT = untrained women (group matched statistically on body mass); LBM = lean body mass. Body composition was measured by skinfolds. WL and UT data collected 1987; elite data collected fall 2003 and presented at USOC in-house seminar 2004.

be engaged in the education of coaches, which includes clinics and seminars. The IWF was founded in 1905 and is headquartered in Budapest, Hungary. Information concerning the history, results of international competitions, and educational aspects of weightlifting are provided via the IWF web site at www.iwf.net.

## The Athlete: Physical Characteristics

Elite male weightlifters' somatotype and physical characteristics are somewhat similar to those of wrestlers and throwers in track and field (73). Preliminary measurements of female weightlifters made by the authors also indicate that there are somatotype similarities between female weightlifters and female wrestlers and throwers. Although there are exceptions, superior weightlifters tend to have shorter limbs and a relatively long trunk compared with sedentary individuals (75). At the same body mass, elite weightlifters typically posses a relatively high lean body mass and low percent fat compared with untrained subjects or athletes in other sports (66).

Percent fat among elite male weightlifters may range from 5 to 6% in the lighter body weight classes to >20% in the unlimited body weight class. For female weightlifters these values (% fat) are typically 5–10 percentage points higher than male weightlifters. Additionally, weightlifters generally have a relatively high body mass and lean body mass : height ratio (66, 73); thus at the same body mass weightlifters tend to be shorter than other athletes. Based on an achievement classification of weightlifters, Table 1a shows some of the physical characteristics of male weightlifters of different abilities. Note that percent fat tends to decrease with the increasing level of athlete (66). The physical characteristics of female weightlifters are shown in Table 1b. The data for weightlifters (Tables 1a and 1b) were collected between 1978 and 1988. Table 1c shows the physical characteristics of 9 male and 7 female elite U.S. weightlifters training for the 2003 World Weightlifting Championships. Comparison of Tables 1a and 1b with 1c indicate that the physical characteristics of elite weightlifters have been generally consistent over time. However, the ratio of body mass : height appears to have increased, particularly among the women.

The relatively high body mass : height ratio compared with untrained subjects (and other athletic groups) is advantageous because it may confer some leverage. For example, a shorter stature would decrease the relative height to which the bar must be moved in order to complete a lift. Additionally, there may be a force-generating advantage that results from having a high body mass : height ratio. For example, if 2 athletes of different heights and different limb lengths have the same muscle

| Table 1c<br>Physical Characteristics of Elite U.S.A. Male and Female Weightlifters (2003) | | | | | | |
|---|---|---|---|---|---|---|
| | Age (year) | Body mass (kg) | % Fat | LBM | Height (cm) | W/H |
| **Elite Males (*n*=9)** | 23 ± 4 | 95.2 ± 19.0 | 13.2 ± 5.8 | 80.4 ± 11.8 | 171.4 ± 4.8 | 0.56 ± 0.11 |
| **Elite Females (*n*=7)** | 23 ± 4 | 68.9 ± 7.5 | 19.6 ± 4.4 | 54.9 ± 3.7 | 161.1 ± 5.8 | 0.44 ± 0.04 |

Note: W/H = body mass (kg)/height (cm); LBM = lean body mass. Body composition was measured by skinfolds. Data were collected fall 2003 and presented at USOC in-house seminar 2004.

mass and volume, the shorter athlete will have the greatest muscle cross-section and therefore a greater muscle force–generating capability. The relatively low body fat associated with a high lean body mass, typically observed in elite weightlifters, can be associated with the extensive training programs used (42, 43). Thus, elite weightlifters can be described as generally mesomorphic, shorter than other athletes at the same body mass, and having a relatively low body fat content.

## Performance Requirements

### *Basic Technique for Pulling Movements*

The performance capabilities of a competitive weightlifter primarily depend upon leg and hip strength and power (18). In the snatch, the bar is raised from the floor to an overhead position in 1 motion; the lifter splits or squats under the bar and then stands erect (Figure 1). The second lift contested is the clean and jerk. The bar (weight) is first cleaned (Figure 2a) by lifting it from the floor to the shoulders (in front of the neck); the lifter either splits or squats under the bar and then stands erect. After cleaning the bar it is jerked overhead. The jerk results from driving the bar overhead using the legs and catching it on straight arms; at the completion of the drive, the lifter either splits or squats under the bar and again stands erect (Figure 2b).

The most efficient technique for the pulling movement is termed the "dou-

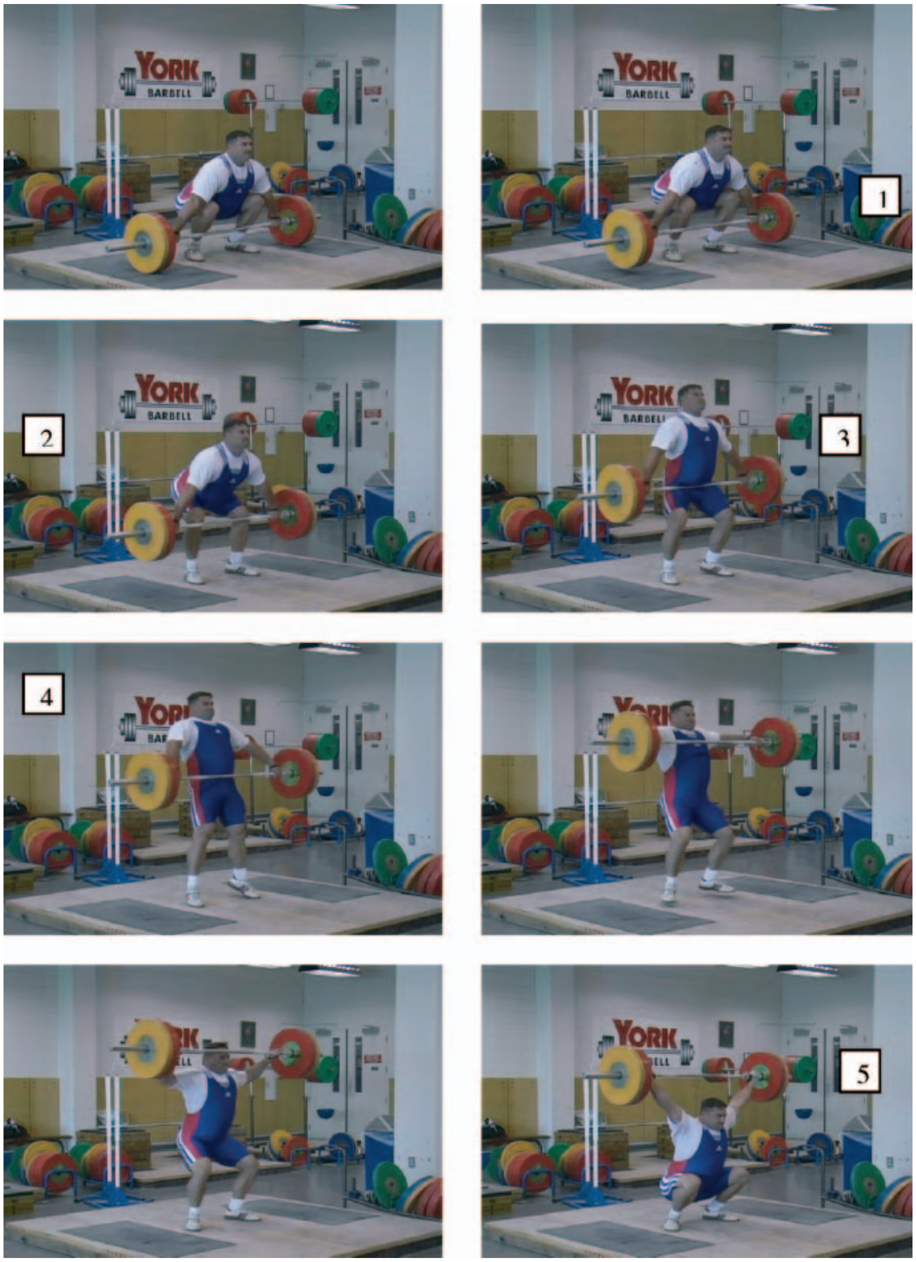


**Figure 1.** The snatch.


**Figure 2a.** The squat clean.

ble-knee bend" (DKB; 1). The pulling sequences shown in Figures 1 and 2a depict this technique. In these sequences (Figure 1 and 2a) of the snatch and clean we can clearly observe the DKB occurring. Several key positions can be noted in this series of photos. Position 1 corresponds to liftoff at which point the shoulders are over and in front of the bar and the back is flat or in a normal "lordotic" position (arched) and remains in this position throughout the pull. The feet are flat on the floor and the center of foot pressure is forward near the ball of the foot. At position 2 the bar has moved to the knees, the shoulders are still above and in front of the bar, the feet are still flat on the floor, and the center of pressure has now moved toward the heel. The bar and lifter have moved up and back primarily as a result of extension at the knee. Position 3 corresponds to the DKB position at which the bar has moved to the midthigh, the feet are still flat, the knee angle will be approximately 130–140°, and the trunk is nearly vertical. The center of foot pressure has now moved toward the middle of the foot. Position 3 is the strongest of the entire pulling sequence and is crucial for high-level success. In position 4 we can observe complete extension; the weightlifter has moved onto the balls of his (or her) feet and the shoulders are shrugged—after which the lifter moves under the bar for the catch (Position 5).

A stretch-shortening cycle occurs when a concentric muscle action immediately follows a lengthening (eccentric) muscle action. Most elite lifters use a rather pronounced DKB or stretch shortening during the transition (moving from position 2 to position 3), with a final knee angle of about 130–140º, the final knee angle in the snatch typically being somewhat smaller (greater knee bend) then in the clean (4, 48). Some elite weightlifters use a much shallower DKB with greater knee angles. It is not completely known why this difference in knee angle occurs; however, it may be due to differences in elastic properties or muscle-activation abilities.

During the transition (positions 2 and 3) into the DKB there is an unweighting phase as the knees are rebent and the trunk is brought into a near vertical position. During the second pull (positions 3 and 4) there is a sharp increase in vertical force until the weightlifter drops under the bar for the catch. Even at maximum weights the entire lift (floor to catch) should be completed in less than 1 second.

Elite weightlifters will typically complete the transition phase more rapidly than unskilled lifters. RFD may play an important role during the transition phase. A faster transition (DKB) among skilled lifters likely results from the ability to apply eccentric force at faster rates and greater magnitudes (33). Furthermore, the elite skilled lifter can accelerate the bar faster during the subsequent concentric phase (after the DKB). In analyzing (both qualitatively and quantitatively) over 1,000 lifts from national (United States and Britain) and international contests, it is quite clear that the majority of high-caliber and elite lifters (>99%) placing in the top 5 of these contests use a DKB pulling technique.

Bar position relative to the body is particularly important during the DKB. As the bar rises, the bar should actually touch the thigh during the DKB. This is because leaving the bar in front of the thigh (not touching) creates a position from which less force can be exerted, as this position creates an extended-moment arm. Furthermore, the further the bar is in front of the lifter's center of mass, the greater the energy that must be expended in order to bring the bar back toward the lifter so that it can be successfully caught on the shoulders or overhead. Although brushing the thigh (not a drag or bang) may increase the friction encountered during the pull, this is more than offset by the ability to accelerate the bar from the DKB position. Transmission of peak force to the bar occurs just after the initial thigh contact, and peak velocity occurs shortly after peak force. Peak power typically occurs between peak force and peak velocity.

**Figure 2b.** The split jerk.

### *Importance of the DKB Phase*

The vertical ground reaction forces commonly observed during a pulling movement can be noted in Figure 3. As previously discussed, most weightlifters of reasonable standard use a stretch-shortening cycle in which the knees are rebent and moved under the bar (the DKB phase). This consists of an unweighting period in conjunction with eccentric and concentric muscle actions. This DKB phase is important because (a) it reduces the tension on the back (13), and (b) the sudden forceful stretch in some manner enhances the concentric portion of the pull. The mechanism(s) by which a stretch reflex enhances concentric action is not completely clear, but may involve increased elastic energy use, a myotatic (stretch) reflex, optimizing muscle length, imparting additional energy into the contractile apparatus, optimizing muscle activation patterns, or some combination of mechanisms (5, 13, 45).

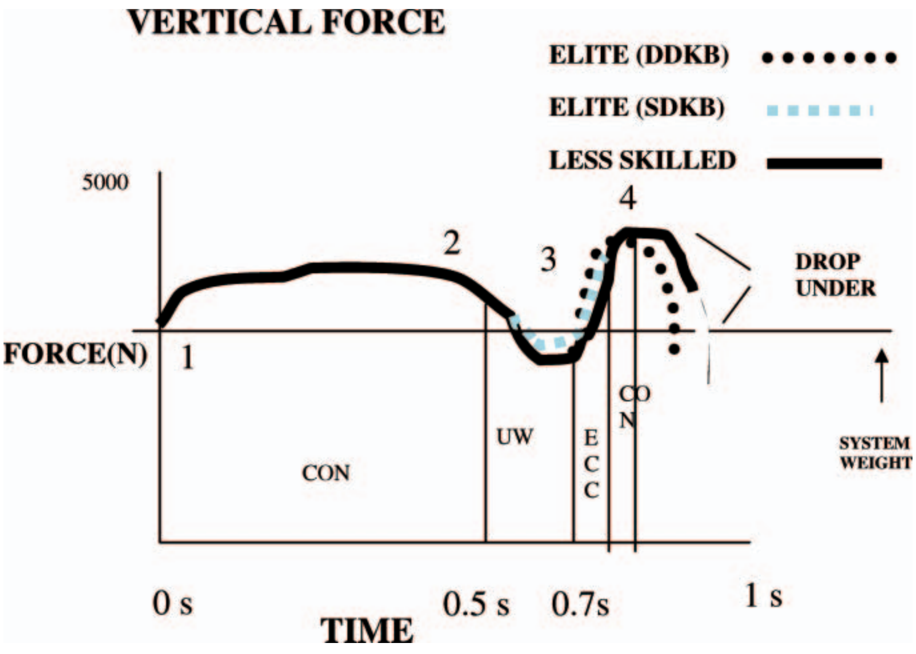


**Figure 3.** Vertical ground reaction forces. CON = concentric phase; UW = unweighting phase; ECC = eccentric phase; DDKB = deep double knee bend; SDKB = shallow double knee bend.

Good technique is essential for a number of reasons including transmitting forces efficiently and in the appropriate direction so that ultimately a greater weight can be lifted, the potential for carryover to other sports performances will be enhanced, and the potential for injury can be reduced.

## Performance Capabilities

As previously defined, strength is the ability to produce force (58, 67). Force in turn is related to the ability to accelerate an object. Power can be defined as the product of force and velocity or as a work rate (58, 67, 69). Higher peak work rates are quite advantageous in strength-power sports, generally separating the winner and losers (41, 67). It is obvious that weightlifters possess great strength and power (10). It is not unusual for elite weightlifters to lift overhead 2–3 times their body mass. For example, 4 male weightlifters (Hailil Mutlu, Naim Suliemonyglu, Stephan Topurov, and Angel Genshev) have lifted 3 times their body mass in the clean and jerk, and over 20 female weightlifters have lifted 2 times their body mass in the clean and jerk; women are now approaching 2.5 times their body mass.

*Strength.* The loads lifted in the snatch and clean and jerk are partially related to body mass. Differences in maximum strength between larger and smaller athletes primarily result from the relationship between muscle force capabilities and muscle cross-sectional area. The relationship between cross-sectional area and maximum strength is a linear function (11, 31, 77), so as cross-sectional area increases so does maximum strength. Larger athletes having a greater absolute cross-sectional area of muscle can produce more force and lift more weight then smaller athletes (provided similar training has taken place). This difference is largely responsible for body weight classes in weightlifting and many other sports.

Body weight classes have been changed several times over the years; these changes result from differences in the number of athletes entering various weight classes from year to year and differences in the average weight lifted in each class at continental and world championships (74). The body weight categories were revised for the sixth time in January 1998. The current body weight (body mass) classes for men are, 56, 62, 69, 77, 94, 105, and >105 kg; for women, 48, 53, 59, 63, 75, and >75 kg.

Although maximum strength and muscle cross-sectional area share a near-linear relationship, strength per kilogram of body mass and body size are not linear. Indeed, relative strength tends to markedly decrease with size largely as a result of the relationship of cross-sectional area, muscle volume, and body dimensions. The cross-sectional area is related to the square of linear body dimensions, and muscle mass is directly proportional to muscle volume. In turn the muscle volume is related to the cube of linear body dimensions (26). Therefore, increases in maximum strength lag behind increasing body mass. Assuming that body proportions remain relatively constant, smaller athletes typically display greater levels of maximum strength on a per kilogram of body mass basis (strength : mass ratio) compared with larger athletes (Tables 2a and 2b).

Appropriately comparing weightlifters of different weights may provide an index as to which athlete is actually the better performer. This type of information is not only of interest from a scientific aspect, but could provide meaningful information in determining the best lifter during weightlifting contests. However, simply dividing the absolute weight lifted by the lifters' body mass biases the results in favor of the smaller athlete because it does not take into account the expected decrease in the strength : body mass ratio with increasing body size. Lietzke (39) indicated that weightlifting world records were approximately proportional to two-thirds of the body mass of the weightlifters (the two-thirds power law). However, this method has been shown to have deficiencies; for example, at-

**Table 2a**
**Body Mass and Performance: Men 2000 Olympics**

| Class | Body mass | Snatch | Clean and jerk | Total (kg) | T/kg | Sinclair | Siff |
|---|---|---|---|---|---|---|---|
| 56 | 55.62 | 137.5 | 167.5 | 305 | 5.48 | 473.43 | 108.51 |
| 62 | 61.56 | 150 | 175 | 312.5 | 5.08 | 447.43 | 98.95 |
| 69 | 68.78 | 162.5 | 195 | 357.5 | 5.20 | 472.20 | 102.78 |
| 77 | 76.20 | 160 | 207.5 | 367.5 | 4.82 | 454.98 | 98.59 |
| 85 | 84.06 | 175 | 215 | 390 | 4.64 | 457.46 | 99.20 |
| 94 | 92.06 | 185 | 220 | 405 | 4.40 | 455.06 | 98.96 |
| 105 | 104.7 | 190 | 235 | 425 | 4.06 | 454.54 | 99.19 |
| 105+ | 147.48 | 212.5 | 260 | 472.5 | 3.2 | 473.28 | 101.85 |

Note: Modified from Stone and Kirksey, 2000 (65). T/Kg = total (Kg)/body mass.

**Table 2b**
**Body Mass and Performance: Women 2000 Olympics**

| Class | Body mass | Snatch | Clean and jerk | Total (kg) | T/kg | Sinclair | Siff |
|---|---|---|---|---|---|---|---|
| 48 | 47.48 | 82.5 | 102.5 | 185 | 3.90 | 256.59 | 105.57 |
| 53 | 52.46 | 100 | 125 | 225 | 4.29 | 290.64 | 116.11 |
| 58 | 56.92 | 95 | 127.5 | 222.5 | 3.91 | 272.95 | 107.59 |
| 63 | 62.82 | 112.5 | 130 | 242.5 | 3.86 | 281.65 | 110.22 |
| 69 | 66.74 | 110 | 132.5 | 242.5 | 3.63 | 273.51 | 106.91 |
| 75 | 73.28 | 110 | 135 | 245 | 3.34 | 265.75 | 104.02 |
| 75+ | 103.56 | 135 | 165 | 300 | 2.90 | 300.96 | 118.71 |

Note: Sinclair number listed as 1.0000 after 150.0 kg. Modified from Stone and Kirksey, 2000 (65). T/Kg = total (Kg)/body mass.

tempts to obviate differences in size based on the two-thirds law apparently will bias results toward small and particularly middle-sized athletes (28, 29). This deficiency likely occurs because the exact relationship between anthropometrics, body mass, muscle mass, and maximum strength has not been completely determined (28, 29, 34). Furthermore, weightlifting is not a pure strength sport but may be better described as a strength-speed sport in which the ability to produce a very high external power appears to be the major factor determining success (17, 32, 34). Clearly peak power output (or maximum strength) and weightlifting performance among athletes with widely varying body masses is not a linear function (34).

Realizing the deficiencies in the two-thirds power law, a number of different models for comparison of athletes of different body masses have been developed for both powerlifting and weightlifting (28, 29, 34). These formulae (although superior to the two-thirds power law) still do not completely describe the relationship between weightlifting performance and body size (28, 29, 34). Two comparison models commonly used in weightlifting are the Sinclair formula (59) and the Siff II formula (58). These formulae, particularly the Sinclair formula, are often used in weightlifting contests to identify the best lifter. Tables 2a and 2b show the results of the winners of each class for the men and women at the 2000 Olympic Games. In general there is a steady decrease in the total divided by body mass; however, this pattern is not readily apparent using the comparison formulae, especially when considering the performances of the unlimited class for both the men and women.

**Table 2c**
**Relationships (Correlations) Between Maximum Strength (Isometric Midthigh Pull) and Weighlifting Performance (*n* = 9 Men, 7 women)**

| | SN | C & J | CMJPP | SJPP |
|---|---|---|---|---|
| **Unscaled** | 0.83 | 0.84 | 0.88 | 0.84 |
| **Allometric** | 0.5 | 0.5 | 0.64 | 0.67 |
| **Sinclair** | 0.79 | 0.8 | 0.86 | 0.86 |

Note: SN = Snatch; C&J = clean and jerk; CMJPP = countermovement vertical jump peak power; SJPP = static vertical jump peak power. Data collected fall 2003 and presented at USOC in-house seminar 2004.

By attempting to obviate differences in body mass, the importance of maximum strength for weightlifting and weightlifters can be partially ascertained. For example, correlations (Table 2c) between peak isometric force (IPF) from a midthigh position and the snatch and clean and jerk were calculated for 14 male and female national- and international-level weightlifters (51). Relationships were compared using nonscaled, allometrically scaled (body mass $^{0.67}$), and Sinclair formula values to control for size differences. Assuming that scaling can obviate body mass differences, comparisons can then be made independently of body mass. Table 2c indicates that maximum isometric strength is strongly correlated with weightlifting performance and that this relationship is apparently independent of body mass. Furthermore maximum strength (IPF), even when body mass is apparently obviated, is also strongly correlated with measures of explosiveness such as peak power during countermovement and static vertical jumps (Table 2c).

*Power.* Commonly performed tests of power and "explosive strength," such as a vertical jump, consistently show weightlifters to be among the most powerful of athletes (2, 10, 60, 61). Two recent studies comparing the power output of athletes in different sports support this concept. McBride et al. (41) studied elite Australian weightlifters, powerlifters, sprinters, and untrained subjects. Power output, normalized for body mass by analysis of covariance (ANCOVA), was assessed through weighted jumping. Jumps were performed at 0, 20, and 40 kg and at 30, 60, and 90% of their 1 repetition maximum (1RM) squat from a 90° knee angle. The results showed that the weightlifters produced the highest power output at any load (Figure 4). Controlling for maximum strength differences and using weighted jumping, Stone et al. (69) again found weightlifters to produce higher power outputs at any percentage of the maximum 1RM parallel squat compared with powerlifter/heavy weight trainers, wrestlers, or an untrained group (Figure 5). These data (41, 69) indicate that weightlifting training can be advantageous for whole-body power production. There is no reason to believe that these results (i.e., the effects of weightlifting training) would not be advantageous for a variety of sports. The superior power output of weightlifters is likely partially genetic, but also stems from the type of training programs employed by weightlifters (18, 19, 27, 61).

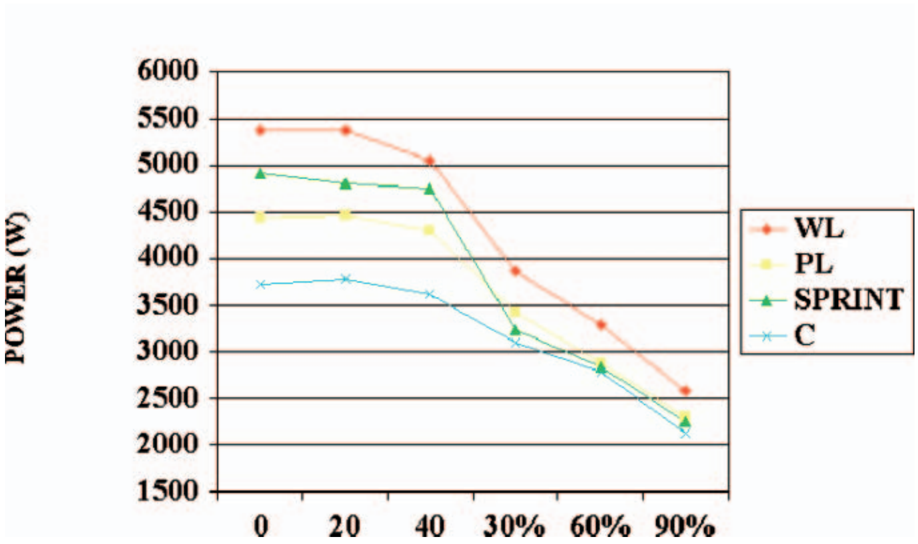


**Figure 4.** Comparative power outputs (41). WL=weightlifters; PL = powerlifters; SPRINT = sprinters; C = control.

The training programs used by weightlifters (63) and conceptually similar training programs (27) have been shown to markedly increase strength and power. It should be noted that in terms of a whole-body movement, the snatch and clean and jerk afford the highest power outputs recorded in sport (18, 19). Examples of the average power outputs from various competition lifts are shown in Table 3. Note that the power output, particularly in the second pull, for weightlifting movements is far in excess of that produced by the powerlifts (squat, bench press, deadlift). This observation suggests that (a) powerlifting is a misnomer, and (b) if the objective of training is to improve whole-body power output, then using high-power–generating exercises such as weightlifting pulling movements are reasonable.

Maximum power for nonballistic movements appears to occur at about 30–50% of maximum isometric force. For most nonballistic exercises the maximum isometric force is very nearly the same as a 1RM value. Thus, a value of 30–50% of the 1RM is a very close approximation of the optimum percentage. However, the snatch and clean and jerk are ballistic movements, and their successful completion is velocity-dependent. Therefore, the optimum percentage-producing peak power is *approximately* 70–85% of the 1RM for pulling movements. This indicates that peak power for the snatch and clean at 70–85% of the 1RM would be approximately 10–20% higher than the power outputs observed at maximum (17). Weightlifters spend a considerable amount of training time using loads of 70–85% of 1RM, particularly in pulling movements; this type of training may optimize gains in power production.

Logical arguments and evidence from objective studies indicate that training at high-power outputs will result in superior increases in power compared with typical resistance training methods. Evidence indicates that high levels of maximum strength in association with high-power training, or a combination of heavy resistance training and power training (as occurs among elite weightlifters), can result in superior power performances (19, 23, 27, 61, 63, 69, 76).

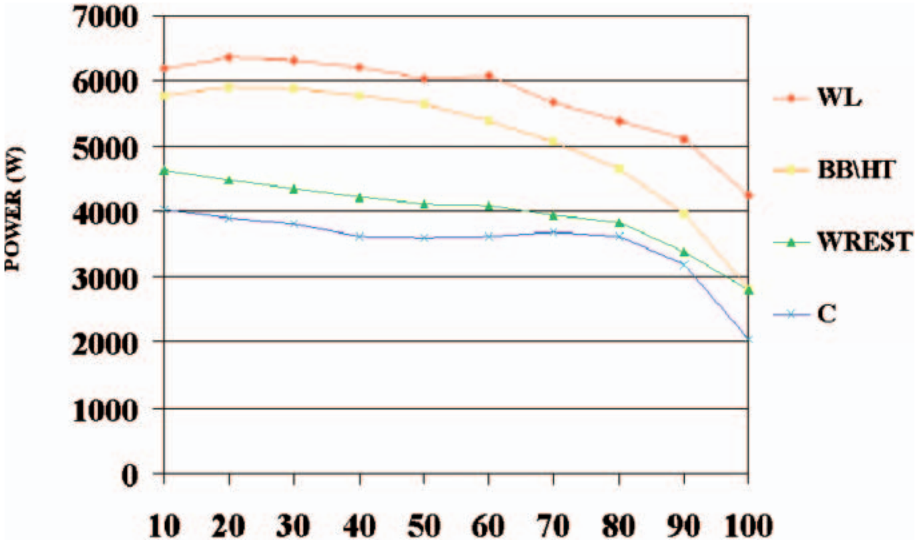


**Figure 5.** Comparative power outputs (66). WL = weightlifter; BB/HT = heavy weight trainer; WREST = wrestler; C= control.

**Table 3**
**Power Outputs of Different Exercises During Competition**

| Exercise | Absolute Power (W) 100 kg male | 75 kg female |
|---|---|---|
| Bench press | 300 | |
| Squat | 1,100 | |
| Deadlift | 1,100 | |
| Snatch* | 3,000 | 1750 |
| 2nd pull† | 5,600 | 2,900 |
| Clean* | 2,950 | 1,750 |
| 2nd pull† | 5,500 | 2,650 |
| Jerk | 5,400 | 2,600 |

* Total pull = lift off until maximum vertical velocity.
† 2nd pull = transition until maximum vertical velocity.
Note: Modified from Garhammer (18,19).

## Metabolic Considerations

Coaches and athletes have often underestimated the energy cost of resistance training, particularly weightlifting. Additionally it is believed that resistance training has no effect in altering body fat. Some of these misconceptions may arise from the commonly held belief that the caloric cost of typical aerobic exercise is substantially higher and that only aerobic exercise can burn fat. However, these beliefs may not be correct.

For elite weightlifters, during the competition phase it is not uncommon to lift 30,000–70,000 kg/wk. During the preparation phase of weightlifting volume loads of >90,000 kg/wk can be associated with energy expenditures as high as 600–1000 Kcals/h and >3000 Kcals/wk (37, 52). When peaking/tapering, the energy cost is somewhat lower. Much of the energy expenditure resulting from weight training and weightlifting takes place during recovery (7, 8, 43, 56). Furthermore, as a result of heavy weight training, the magnitude of energy expenditure during recovery appears to be dependent upon the volume of training (43), and complete recovery may take as much as 24–38 hours (56). Therefore, during a high-volume training session, with large muscle mass exercises, it is probable that most of the energy cost oc-

| Activity | Expenditure (Kcal × $kg^{-1}$ × $D^{-1}$) | Consumption (Kcal × $D^{-1}$) |
|---|---|---|
| **Men** | | |
| Untrained | ≤40 | 2,000–3,000 |
| Cross country | 50–80 | 2,500–6,000 |
| Marathon | 50–80 | 2,500–6,000 |
| Basketball | 55–70 | 5,000–6,000 |
| Sprinting (track) | 50–65 | 3,300–6,000 |
| Judo | 55–65 | 3,000–6,000 |
| Throwing (field) | 60–65 | 6,000–8,000 |
| Weightlifting | 55–75 | 3,000–10,000 |
| **Women** | | |
| Untrained | ≤33 | 1,000–1,800 |
| Cross-country | 45–60 | 1,500–3,000 |
| Gymnastics | 40–60 | 1,200–2,500 |
| Sprinters (track) | 40–55 | 2,000–3,000 |
| Throwers (field) | 35–50 | 2,000–3,200 |
| Weightlifters | 35–50 | 2,000–3,200 |

**Table 4**
**Caloric Expenditure and Consumption of Sports Activities (Elite Athletes)**

Note: Expenditure and consumption represent the possible ranges across a variety of training phases (i.e., preparation, competition, peaking). Modified from Stone (62), and food records from elite athletes at the USOC Colorado Springs, CO (Judy Nelson and Karen Daigle, USOC nutritionist, July 2004).

curs during recovery. The relatively high energy cost of weightlifting training coupled with an increased mobilization and use of fats during recovery (30, 42, 64) partially explain the relatively low percentage of body fat found among elite weightlifters.

Coaches and athletes often underestimate the magnitude and duration of recovery from weight-training sessions. It is important to note that recovery from heavy loads, which can be prolonged, could have effects on subsequent training sessions and may contribute to overreaching and overtrained states. In this respect it is quite important that adequate nutrition is considered. Adequate energy intake (and necessary nutrients) is necessary to maintain body mass and support the extra energy requirements associated with training. Considering the relatively large total energy expenditure, which can occur during weightlifting training, caloric intake (food) can be quite high, especially among the larger weight classes (Table 4).

## Training the Athlete

Training programs for competition are directly aimed at improvements in the snatch and clean and jerk. These training programs are generally based on well-known training principles (68). The training principles are (a) overload of volume and intensity factors, (b) variation, and (c) specificity.

The overload principle relates to stressing the biological system beyond the norm. In order to provide a continued stimulus over a period of years, the training volume and training intensity increases. Volume of training is typically estimated as the volume load (repetitions × mass lifted), and training intensity is estimated by the average weight of the bar per week, month, etc. The volume load can be related to the total work accomplished, and the training intensity can be related to the rate at which training proceeds. Training intensity should be differentiated from exercise intensity, which is the power output of a movement. Relative intensity is the percentage of the 1RM for a given exercise (lift). Weights equal to approximately 30–50% of the maximum isometric capabilities usually produce the highest exercise intensity (i.e., power outputs). This would be equal to about 70–85% of the 1RM snatch and clean and jerk (17); a relative intensity at which most training takes place (79).

Variation relates to the changes in the composition of the training program. These changes can include alterations in volume, training intensity, and exercise intensity, as well as exercise selection. Variation is extremely important in order to avoid the maladaptations associated with various forms of overtraining (46, 65, 70, 71). Variation of training volume and intensity can be used to achieve desired goals; for example, higher-volume, lower-intensity exercise may be used to enhance high-intensity exercise endurance and beneficially alter body composition, whereas high-intensity, low-volume training may emphasize increases in maximum strength. Exercise variation would include the use of different exercises as well as variations of the same exercise.

Specificity relates to stressing the appropriate bioenergetic system and using appropriate mechanics. The specificity principle implies that the greatest training effects will occur if the training lifts are similar to the snatch and clean and jerk. This mechanical similarity includes peak force, rates of force development, velocity, and movement patterns.

*Periodization* can be defined as a logical phasic manipulation of training variables, which can result in a decrease in overtraining potential and an increased probability of retaining training and performance goals. The concept of periodization appears to be the most effective method of applying the principles of training to most sports including weightlifting (46). A periodized program is divided into specific phases, each of which relates alterations in volume, intensity factors, and exercise selection.

Although most coaches use some variation of the periodization concept, there is no universal agreement on the details (46). For example, during the preparation phase in which training volume is typically increased, some coaches increase the number of repetitions per set and others increase the number of sets. Other training differences may include the number and timing of complete competition lifts (i.e., squat snatch and squat clean and jerk) or the number of lifts performed at various relative intensities during a mesocycle, particularly those at 90% or above. In recent years, because of the success of many Eastern European teams, many Western weightlifting coaches have attempted to adopt similar training programs. These Eastern European training programs are typically centered on the snatch, clean and jerk, and squats, with few additional exercises; the loading is often quite heavy, with maximum loads (1RMs) being attempted several times weekly. It is the opinion of the authors that adopting these programs has been no more successful—and in many cases less successful—than programs traditionally used in the West. Indeed, our observation over the last 20 years has been that coaches/athletes adopting Eastern European methods quickly modify these programs. There are several possible reasons why the authors believe that these types of programs have not been particularly successful in the West:

- Differences in athlete selection. In the past, prospective weightlifters have been identified in talent identification programs at relatively young ages in many Eastern European countries such as Bulgaria (12).
- Differences in recovery/restorative practices. This includes the use of drugs.
- Overtraining. Basically, overtraining can be described as an imbalance between training (and other stressors) and recovery. Training too often at high intensities increases the overtraining potential. Fry et al. (16) have demonstrated that frequent training at high intensities can produce decreases in squat performance and symptoms of overtraining in as little as 2–3 weeks. Assuming these results can be generalized to weightlifting training, many Western athletes attempting to use Eastern European weightlifting training methods may simply be in various states of overtraining.

## Special Considerations

### Women

*Peak Power.* Peak power is the highest instantaneous power produced during a movement and is a key to weightlifting success (34). Peak power output for women is about 65% of men during the snatch and clean and jerk, and about 65–75% of men for various jumping tasks (19). Both untrained and trained women appear to generate lower power outputs per volume of muscle and generate lower peak rates of force development compared with men (35, 50). However, the power output—particularly in unloaded exercises such as jumping—for women trained in power and strength-power events such as throwing and weightlifting appear to be somewhat closer to that of their male counterparts than untrained women compared with untrained males (72).

*Upper Body Versus Lower Body.* Because of the relatively lower strength values for upper-body movements, it is possible that by placing more emphasis on upper-body training for women that training for weightlifting and other sports can be enhanced. This may improve performance in tasks that depend in part or whole upon upper-body strength. Part of the reasoning for more emphasis on upper-body strength training is the assumption that the weaker upper-body musculature may limit strength gains in the lower body (21). Therefore as a result of the relatively weak upper-body musculature gains in lifts such as squats, cleans, or snatches could be compromised. Thus, preparation phases for women weightlifters may need extra emphasis on upper-body musculature—particularly those focused on muscles involved with overhead support (72).

*Menstrual Cycle Effects.* Alterations in hormone concentrations can affect physiological and psychological parameters, which in turn can affect force production parameters (36, 42). It is known that anabolic hormones such as growth hormone and testosterone can have profound effects on strength and strength-related characteristics such as RFD and power in both men and women. Indeed, strength gains in women have been correlated to resting serum concentrations of both total and free testosterone (24, 49). In women the concentrations of various hormones, including testosterone, are influenced by the menstrual cycle. The menstrual cycle is characterized by relatively large variations in several hormones on a regular (or nearly regular) basis. Because these hormones (e.g., estradiol, progesterone, testosterone) can have effects on metabolic and neuromuscular function, there is a potential for training/performance alterations to be affected during different phases of the cycle.

Apparently, many women do not believe they function normally during menstruation, particularly during physical activity (20). However, most studies using very active or athletic women do not show substantial effects of menstruation or the menstrual cycle on various parameters of performance. Therefore, these more active women may have overcome the negative aspects associated with the menstrual cycle and menstruation (20, 55). However, some data indicate that endurance performance may be compromised during the luteal phase among some but not all aerobically trained women (38). Furthermore, there is reason to believe that maximum strength and related characteristics may be altered during various phases of the menstrual cycle. For example, Masterson (40) found that measures of power performance on a cycle ergometer (Wingate test) were reduced during the follicular phase and enhanced during the luteal phase in fairly active young women. Additionally, some evidence indicates that strength gains can be negatively affected during the very early follicular phase and positively affected during the late follicular and very early luteal phase (49). The greatest strength gains were noted (49) during the late follicular and early luteal phase and were moderately correlated with resting serum estradiol and testosterone concentrations. Additionally, Reis et al. (49) suggest that altering the number of training sessions (reduced during the luteal phase) during various phases of the cycle may enhance the training effect. These 2 studies (40, 49) indicate that reductions in training load may be helpful because trained women may not perform strength- or power-related activities as well during the luteal phase (particularly the late luteal phase).

As a result of individual variation, one practical approach for women weightlifters would be to consider keeping detailed records of their ability to perform during different phases of their cycle. Over a time period of several months it may be determined how training should be altered to match the menstrual cycle phase on an individual basis. Obviously much more research in this area is needed.

## Children and Adolescents

Training programs, with some differences based on maturity factors, follow the same basic principles and concepts regardless of age. The differences for children depend on a couple of factors:

- *Psycho-physiological factors:* The chronological age related to age of expected peak performance, general level of intelligence, physical and mental maturity, and genetic potential.
- *Environmental factors:* Current involvement in sports and prior participation in activities that develop coordination, agility, and flexibility. For example, activities such as gymnastics can be excellent prerequisites to participation in weightlifting.

The starting age for weightlifting training in Bulgaria decreased an average of 2 years from 1983 to 1993. The recommended age to begin training in this small country—which has been highly successful in weightlifting—is 10 years (12). The training plan for these young athletes has been well integrated with their physical development, and each phase of training is built on the previous phase. Compared with most young Western weightlifters, more time was spent on general physical development during the earlier years, and specialized training was added gradually in successive years.

The emphasis for children starting at this age needs to be on general physical development that is compatible with sports-specific fitness early on for at least 2–3 years. For example, weightlifting developmental fitness for children would include considerable training dealing with general body strengthening (e.g., gymnastics, tumbling); endurance factors; and enhancing cardiorespiratory ability, mobility, and flexibility. However, this training should not include a great emphasis on long-term endurance such as distance running. One method emphasizing long-term athlete development and long-term training plans for weightlifting has been described by Ájan and Baroga (1).

According to Balyi (3), developmental factors are absolutely essential considerations when training children/adolescents. He proposes that 8–12 years of training is necessary for a talented athlete to reach elite levels. This is obvious in football and basketball, with 3 years participation in middle school, 4 years in high school, and generally 4–5 years in college before playing professional sports. We often try to hurry this process in weightlifting (and many other sports).

It must be remembered that many and likely most of the athletes participating in Eastern European weightlifting programs were selected, based primarily on genetic potential, through a comprehensive talent identification search. Furthermore, they had previous general physical training and had the means for—and used—methods of enhancing recuperation. As previously pointed out, all aspects of the training programs used by these athletes may not be suitable for Western athletes, particularly children. However, all too often the Western coach applies only a part of the Eastern European program, missing the overall concept of long-term progressive training. Usually, the part that is applied by Western coaches involves early and exclusive high-intensity specialized training, applying it with children/adolescents who often have less physical ability then their Eastern European counterparts, who often have used little or no prior progressive building blocks of training, and/or who put little or no effort toward promoting recovery. Furthermore, many children/adolescents from Western countries may be actively participating in several other sports such as American football, soccer, rugby, or baseball, thus compounding the recovery issue. Therefore, we would argue that in the United States the "big picture" of the program is generally ignored or not completely understood (see Part 2: Program Design in a future issue).

*Injury Potential.* Ballistic movements, particularly those associated with weightlifting, have been criticized as producing excessive injuries (6); however, there is little objective evidence substantiating this claim. Reviews and studies of injury type and injury rates associated with weight training and weightlifting indicate that:

- Rates of injury are not excessive and the incidence of injury is less than those associated with sports such as American football, basketball, gymnastics, soccer, or rugby (25, 64, 78).
- There is no evidence that the severity of injury or incidence of traumatic injury is excessive (25, 64).

Inappropriate training programs may increase the potential for injury. As with adults, resistance-training programs for children that follow appropriate training guidelines have a low risk of injury (14). Indeed supervised weightlifting programs have been shown to have an even lower rate of injury than other forms of resistive training (25). This low injury rate is related to well-supervised programs constructed and implemented by a knowledgeable coach (14).

Considerable controversy and lack of understanding surrounds children and weight-training, especially weightlifting. Little information is available that indicates that weightlifting, under proper supervision, is any more injurious to children or adolescents compared with other sports; indeed, the weightlifting injury rate appears to be lower than in most sports (25). Pierce et al. (47) reported that no days of training were lost as a result of injuries incurred in weightlifting over a period of 1 year's competition and training by 70 female and male children ranging in age from 7 to 16 years. The young lifters were allowed to perform maximal and near-maximal lifts in competition as long as correct technique was maintained. Both the boys and girls increased strength as measured by weightlifting performance. A more detailed study (9) of 3 girls (13.7 ± 1.2 years) and 8 boys (12.5 ± 1.6 years) across a year's competition (534 competition lifts) produced similar results. Both boys and girls showed marked weightlifting performance improvement and no injuries requiring medical attention or loss of training time (9). The conclusion of these observations was that weightlifting is safer than is generally believed, especially if training and competition are appropriate for the age group and are well supervised. The authors of these papers (9, 47) emphasized that these results must be viewed in light of the scientific approach to training and competition with these children. Only under these conditions do the authors suggest that resistive training or weightlifting is appropriate for children—a factor that should be true for all sports.

As with any sport, weightlifting competition and weightlifting training should be carried out with reasonable safety measures in place. In normal supervised environments, the potential for injury is remarkably low.

## Conclusion

Weightlifting is a strength-power sport, and the athletes and their training may be characterized by the following:

- The physical attributes (somatotype) of weightlifters are similar to those of wrestlers and throwers.
- The height : weight ratio of weightlifters is typically lower than for most athletes.
- Although performance is partially related to body mass, stronger weightlifters (independent of body mass) lift more in the snatch and clean and jerk.
- The weight lifted in competition is partially related to body mass and strongly related to peak power.
- Smaller lifters have a higher maximum strength : body mass ratio compared with large weightlifters.
- Weightlifters are among the strongest and most powerful of all sports groups.
- The metabolic cost of weightlifting training can be quite high and is often underestimated.
- Weightlifting training typically follows some type of periodized program.
- Injuries during training and competition are not excessive compared with most sports. ♦

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**Michael H. Stone** is currently the Exercise and Sports Science Laboratory Director at East Tennessee State University.

**Kyle Pierce** is a professor in the Kinesiology and Health Science Department and is the Director and Coach of the USA Weightlifting Development Center at LSU Shreveport.

**William A. Sands** is the head of Sports Biomechanics and Engineering for the United States Olympic Committee.

**Margaret E. Stone** is currently a track and field coach at East Tennessee State University.