A Primer on Weightlifting: From Sport to Sports Training

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**Summary**

Weightlifting exercises and methods are essential for the strength and conditioning professional. This article reviews the underlying physiology and biomechanics of these exercises and training methods.

Weightlifters are arguably the most powerful athletes. As such, the training methods and modalities used in weightlifting are often looked at for the training of other athletes in sports in which strength, speed, and power contribute to elite athletic performance. In addition to the musculoskeletal and mechanical adaptations, cardiorespiratory, motor behavior, and psychological adaptations also result from weightlifting training. The purpose of this article is to provide a rationale for the inclusion of weightlifting training in the training of athletes by briefly reviewing the areas of proposed benefit. This article provides a condensed review of important concepts and applications of weightlifting.

**Nomenclature**

Weightlifting is defined as the sport in which athletes attempt to lift the most weight in the snatch and the clean and jerk. Strength and conditioning professionals should be clear to differentiate between weightlifting and weight or resistance training, which is the broad category of exercise against resistance (38). The term Olympic lifting, although commonly used, is inappropriate for most athletes, as this should be reserved for the elite individuals who compete in weightlifting at the Olympics games (38). Similarly, the term weightlifter refers distinctly to individuals training and competing in weightlifting.

**About the Sport**

In competition, the weightlifter has 3 attempts in the snatch followed by 3 attempts in the clean and jerk. The heaviest successful attempt in each event is added together to create the total (28). The snatch is often described as the more technical event and is characterized by greater speed, while the clean and jerk requires more brute strength, and is characterized by greater force production. Thus, success in weightlifting is a combination of technical excellence and physiological adaptation.

In competition, the order of lifting is primarily determined by the barbell load, which is always increasing (28). Following each lift, a lifter will have a minimum of 2 minutes and a maximum of approximately 20–30 minutes before the next attempt. If the lifter takes 2 successive attempts, he or she is given 2 minutes to begin the next attempt (28). If a number of lifters are lifting similar loads, a lifter may have a longer period before the next attempt. These characteristics of competition are important in considering the physiological adaptations discussed later.

The primary style used in competition for the snatch and the clean is the squat-style, and for the jerk, the split-style. Prior to the 1960s the split-style was also used for the snatch and clean. Some elite weightlifters use the power jerk or squat jerk, although this is rare. In strength and conditioning programs, other variations of the lifts are used, including lifts from the hang and power lifts. Lifts from the hang are performed with the barbell in a starting position not on the floor. Power lifts are those for which the barbell is racked overhead or on the shoulders in a partial rather than a full weightlifting competition squat position.
Safety

While rumors and anecdotes abound regarding the dangers of weightlifting, there is no evidence that weightlifting training causes excessive injury. In fact, the rate of occurrence of injuries in weightlifting is less than that of more common sports, such as basketball, football, and gymnastics (25). While injuries do occur in weightlifting and weight training, these are rare incidents and are typically associated with maximal performance in competitive situations (53).

Byrd et al (6) reported longitudinal data over approximately 2 years in children training and competing in weightlifting. Performance improved in these children, who participated in an average of 8 competitions; however, no injuries occurred nor were there any lost days of training. The authors emphasized the importance of scientific theory in the design of training and coaching (6). This emphasis may explain the different injury rates in weightlifting and weight training, the latter having slightly more injuries per thousand participation hours (25). In weightlifting, participants are more likely to be supervised by a coach and are more likely to have been instructed in proper exercise technique than in typical weight training.

Furthermore, retrospective analysis of the incidence of injuries in retired weightlifters does not support the notion that weightlifting is dangerous (21). When compared to data from the general Swedish population, former Swedish weightlifters had the same incidence of low back and knee pain. Thus, weightlifting training does not appear to result in increased incidence of degenerative joint diseases.

Aerobic and Anaerobic Metabolism

From the nature of the sport, which involves brief, very high-intensity efforts, it would seem that weightlifting does not result in considerable aerobic metabolic adaptations. However, Fahey et al (11) reported maximal oxygen consumption values in weightlifters that were consistently higher than in sedentary individuals. The authors also suggested that values of maximal oxygen consumption relative to body mass were unfairly biased against larger athletes due to the increased muscle mass (11). In fact, weightlifters, as well as other strength and power athletes, had a higher capacity to perform work than other athletes who had higher maximal oxygen consumptions (11, 46). The adaptations related to maximal oxygen consumption may also be related to the strength or functional capacity of the heart (13).

These results are not surprising when considering the work of Stone et al (50), who found that a typical weightlifting training session resulted in a peak heart rate of 96% of estimated maximum and averaged 86% over the training session. Ventilation during training was also high, averaging 51 L/min. In sedentary individuals, this type of training results in positive aerobic metabolic adaptations in as little as 8 weeks of training (51).

Anaerobically, trained weightlifters are able to perform more mechanical work and reach higher blood lactate levels than untrained individuals (49). Additionally, weightlifters have lower blood lactate and ratings of perceived exertion at the same intensity of exercise. This result is similar to adaptations occurring in individuals training with aerobic and anaerobic metabolic modalities. Interestingly, these adaptations appear to be by-products of training, as there appears to be little relationship between success in weightlifting and aerobic or anaerobic metabolic performance (22). Thus, it is likely that aerobic and anaerobic metabolic adaptations occur during general preparation (42), rather than specific training phases. General preparation training of the weightlifter involves training with high volume and relatively low intensity (47).

While the source of energy substrates for weightlifting is primarily the phosphagen system (39), the adaptations to the oxidative and glycolytic energy systems can be explained via the recovery processes (43). Recovery between sets during a training session initially utilizes the fast glycolytic system followed by oxidative metabolism to restore high-energy phosphates (39). The large demand on anaerobic metabolic pathways from exercise and recovery leads to excess postexercise oxygen consumption, in which aerobic metabolism is heightened for 90 minutes following exercise (5). Full recovery of homeostasis of the metabolic pathways may not occur for up to 38 hours following exercise (36, 43). The duration of these metabolic responses supports manipulation of daily and weekly training parameters to allow sufficient recovery.

Body Composition

During general preparation training of the weightlifter, as described above, Stone et al (51) have reported increases in lean body mass of 2.4 kg and decreases in body fat of 3% in as little as 5–8 weeks in novice individuals. While other training methods can decrease body fat, to our knowledge no other research has reported concomitant increases of lean body mass of this magnitude in such a brief period of time. The average percentage of body fat in weight lifters has been reported between 6 and 12% (11, 31). The differences among weightlifters may be due, in part, to differing body sizes, where larger athletes tend to have higher body fat percentages. These body fats are low, relative to other strength athletes (11), which may be a result of the high metabolic cost associated with certain phases of weightlifting training (42).

Increases in lean body mass are accomplished by increased bone mineral density and skeletal muscle adaptations. Using simple and multiple linear regressions, Conroy et al (8) explained that 30–65% of higher bone mineral density...
in weightlifters is a function of strength; thus increases in bone mineral density cannot solely be explained by genetic factors.

Muscle fiber adaptations include transition of fiber types and hypertrophy of fibers (16, 24). With training, myosin heavy chain, the protein primarily responsible for contraction force and velocity, transitions from IIB to IIA. Fibers containing myosin heavy chain IIA proteins have the greatest capacity for growth. In U.S. national caliber weightlifters, there are virtually no muscle fibers containing type myosin heavy chain IIB (16). With hypertrophy, the cross-sectional area of muscles increases, thereby increasing muscle force producing capability (24, 30). These increases in skeletal muscle mass with concomitant decreases in percentage body fat allow athletes to express greater strength and power while remaining within weight class limits.

Motor Learning and Control
As with any sport with a technical component, weightlifting training is associated with improvements in motor control. The most noticeable changes in motor control are an increased coordination of activation of muscle groups and motor units (12, 23, 32). Regarding motor unit activation, weightlifters are able to activate more fast-twitch fibers than nonweightlifters during submaximal muscle contractions (12).

Further analysis reveals that the time-course for onset and termination of muscular activity during various phases of the clean is important for successful lifting (32). These patterns of muscle activity contribute to the optimal timing of producing peak force and rate of force development (9, 10). For example, termination of knee extensor activity and activation of the knee flexors as the barbell passes the knees causes the double knee bend action (3). The resulting net joint moment in favor of knee flexion is brief as the knee extensors reactivate to perform the second pull (3).

These data indicate that success in weightlifting is not simply a function of producing greater muscle force. Garhammer and Gregor (20) have found that the difference between experienced and inexperienced lifters was not simply the magnitude of force generated, but also the alterations in the duration of near maximal force application. This pattern occurs not only in weightlifting exercises, but also in vertical jumping (20). Vertical jumping performance is highly correlated with other sports performance (2, 14), thus, the concept of time of force application, rather than simply peak force, may also be important for other sports requiring high power output.

Biomechanics
The most thorough review of weightlifting biomechanics is by Garhammer (19). This article will only address the mechanics as is important for strength and conditioning for other sports. The snatch and clean can be broken into three components, which individually, have distinct adaptational benefits. These are (a) the first pull, (b) the second pull (including the preceding double knee bend), and (c) receiving the bar.

The first pull involves removing the barbell from its static position on the floor until the bar passes the knees. In this component, the angle of the torso relative to the floor is more horizontal than vertical (3); thus, in addition to the primary movement produced by the knee and hip extensors, the spinal extensors, scapular retractors, and shoulder extensors are also involved. The spinal extensors create posterior shearing forces to oppose anterior shear from gravitational forces (35), which, along with the compressional forces generated, increases spinal stability. The scapular retractor and shoulder extensors keep the barbell close to the body. In this position, the lifter can apply large forces; however, heavy loads cannot be moved at high velocity (3). Pulling the bar from the floor thus contributes to the training of starting strength, where starting strength is the ability to generate high forces from the onset of muscle activation in a very short period of time. Starting strength relates to the initial defensive positions for sports such as football and volleyball.

As the barbell passes the knees, the knees shift forward and the barbell and hips move towards each other (3). This motion initiates a stretch-shortening cycle and repositions the lifter-barbell system so that the lifter is in joint positions with advantageous leverage to impart a large force to the barbell rapidly, resulting in a high power output (3, 18).

As this large production of power is considered to be the primary benefit of the snatch and clean, strength and conditioning programs typically involve exercises that isolate this component of the lifts. These include lifting from the hang, lifting from boxes, and high pulls. While it is indeed advantageous for athletes to utilize these exercises, the second pull is not the only important characteristic of the snatch and clean exercises.

Perhaps the most overlooked characteristic of the snatch and clean is receiving the bar, whether overhead or on the shoulders. In weightlifting circles, this is performed by “meeting the bar,” or actively resisting the downward momentum of the barbell. This requires activation of the agonist muscles in an eccentric and isometric fashion. The difference between eccentric actions during weightlifting as opposed to weight training (for example the negative phase of a squat) is that overcoming the downward barbell momentum requires a greater opposing impulse during weightlifting. Thus, the rapid production of force in an eccentric manner is necessary, similar to plyometric movements, such as depth jumps. This is also called yielding strength (44) and contributes to reactive strength, the ability to rapidly reverse eccentric to concentric motion.
While plyometric exercises are widely used in strength and conditioning, the landing phases of these exercises are associated with injuries, particularly at the knee and ankle joints. The snatch and clean exercises are a safer, and perhaps more effective, method of training yielding strength, whereas the jerk exercise can be used for training reactive strength. In properly trained individuals, the vertical ground reaction forces produced in receiving the bar are lower than those produced when landing from jumping and during depth jumps (4).

Considerably less research exists for the jerk exercise than for the snatch and clean. The initiation of the jerk by bending the knees, followed immediately by rapid extension, is similar to the second knee bend and second pull of the snatch and clean. In driving the barbell from the shoulders to overhead in the jerk, similar power is imparted to the barbell as in the second pull of the snatch and clean (18). Receiving the bar overhead in the jerk is similar to the snatch, except that greater barbell loads can be lifted in the clean and jerk.

**Long-Term Training**

As is expected, weightlifters can generate greater force and power in comparison to other athletes with similar years of training experience (29). Additionally, the shape of the power-load and power-velocity curves is distinctive for weightlifters and similar to those observed from training with explosive weight training for short periods (37). These data illustrate the importance of muscular (i.e., muscle fiber hypertrophy, in particular type II A fibers) and neural adaptations and demonstrate that these adaptations may only be obtained via explosive training with heavy loads.

Weightlifters appear to have distinct adaptations from other strength and power athletes, who train comparably with heavy loads and/or explosive methods (34). Weightlifters generate greater power and move at faster velocities than powerlifters at all loads across a load-spectrum. Although power output and velocities were not statistically significantly different between weightlifters and sprinters, a moderate effect size difference exists for peak power (34). Thus, a practically significant difference exists indicating weightlifters generate greater power than sprinters. It was not clear in this investigation whether the powerlifters were training with the intention to maximally accelerate heavy loads. This important concept, which the nature of weightlifting exercises necessitates, develops the ability to rapidly generate force, also known as rate of force development.

Prolonged training may also positively influence the neuroendocrine system to promote a biochemical environment more conducive for enhancing performance (15, 24). Häkkinen et al (24) demonstrated the potential to raise testosterone over a 2-year period of training in weightlifters. This increase in testosterone was also well correlated to power-generating ability (24).

Similarly, when weightlifters of different levels of experience were compared, those with more than 2 years of experience were able to elicit an exercise-induced testosterone response, while those with less than 2 years of experience were not (31). Furthermore, when these athletes returned a year later, their exercise-induced testosterone response was even greater, even following a week of over-reaching (15). These differences in responses before and after 1 additional year of training are indicative of enhanced ability to tolerate stressful training.

**Relationship to Sports Performance**

The rationale for inclusion of weightlifting exercises in strength and conditioning programs to improve athletic performance is based on the similar mechanical structure of weightlifting and explosive sports movements and the relationship between weightlifting and other sports performance. Regarding the former, the biomechanical specificity of training is governed by the principle of dynamic correspondence. This principle states that specificity is a function of the inherent biomechanics of the training and sport tasks and not simply the external movement characteristics (44). For example, on a given task, movement velocity is not as good an indicator of explosiveness as muscle rate of force development.

The inherent biomechanics include the nature and sequencing of muscle and joint actions, the muscle force-time history, and the range and amplitude of motion. Most sports performed on land require the generation of force by musculature to push against the ground. Examples of these movements are running and jumping actions, and the musculature involved are the extensors of the hip and knee and the plantar flexors at the ankle. These same muscles are involved in weightlifting, with similar sequencing of actions.

Additionally, the temporal pattern of force production for weightlifting at different loads corresponds with the temporal pattern seen in jumping (7, 20). It is therefore no surprise to find a strong relationship between weightlifting performance and measures of anaerobic power, such as vertical jumping, with and without external loading, and stair climbing (Margaria-Kalamen test) (22, 23, 45). These various measures of anaerobic power, including weightlifting performance, are also related to sports performance (1, 2, 14, 27, 41).

Maximal strength is associated with improved jumping performance, both with and without additional external loads (48). In untrained individuals, increasing maximal strength alone increases vertical jump height (40). However, maximal force production is not always related to vertical jump height, whereas
power is (17, 33, 52). Additionally, in trained individuals, high force training alone does not improve vertical jump (26). This indicates that explosive strength specifically is important for jumping performance. Thus, while heavy strength training is necessary for optimal performance adaptations, heavy strength training should be performed in an explosive manner (26), such as occurs in weightlifting.

**Recommendations**

Anecdotally, perhaps the most commonly used weightlifting exercise variation is the power clean from the hang. In weightlifting, however, this is only one of many variations of exercises used to enhance performance. Thus, the benefits of weightlifting are best attained by strategically using the many weightlifting exercise variations. The majority of training time spent on these lifts should involve the squat and power versions of the snatch and clean, as well as the push and split jerk. The major benefit of using these variations (pulling from the floor) is that they allow the greatest loads to be utilized. As discussed previously, training with heavy loads in a rapid fashion is important for developing rate of force development, a key contributor to explosive strength. Additionally, athletes are able to develop muscular strength in positions that are mechanically disadvantageous, which, however, they may encounter in their sport. Depending on the needs of the athletes and their technical deficiencies, lifts from the hang or boxes may be warranted, as would the split snatch or clean.

Proper technique in performing these exercises is essential; thus coaches instructing these lifts should, at minimum, have completed a course of study involving hands-on performance/practice of the snatch, clean, jerk, and their variations. Such courses are offered through USA Weightlifting (or other national weightlifting federations, if outside the United States), through the National Strength and Conditioning Association symposia, or through internship with a qualified individual.

**References**


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