Weightlifting for Children and Adolescents: A Narrative Review

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The involvement of youth in the sport of weightlifting and the use of weightlifting methods as part of training for youth sport performance appears to be increasing. Weightlifting for children and adolescents has been criticized in some circles and is a controversial aspect of resistance training for young people. Although injuries can occur during weightlifting and related activities, the incidence and rate of injury appear to be relatively low and severe injury is uncommon. A number of performance, physical, and physiological variables, such as body composition, strength, and power, are improved by weightlifting training in children, adolescents, and young athletes. Manipulating program variables, when appropriate, can have a substantial and profound influence on the psychological, physiological, physical, and performance aspects of weightlifters. An understanding of the sport, scientific training principles, and musculoskeletal growth development is necessary to properly construct a reasonable and appropriate training program. A scientific background aids in providing an evidenced basis and sound rationale in selecting appropriate methods and directing adaptations toward more specific goals and enables the coach to make choices about training and competition that might not otherwise be possible. If weightlifting training and competition are age group appropriate and are properly supervised, the sport can be substantially safe and efficacious.

Keywords: youth resistance training; applied sport science; strength/power training

Resistance training is a general term used to describe exercises that cause the muscles to contract against an external resistance. The expectations of a resistance-training program can include positive alterations in body composition including muscle hypertrophy, increases in maximum strength, power, and endurance. Instruments/devices supplying the external resistance can include body mass, elastic bands, bricks, bottles of water, and typically barbells and dumbbells.

Weightlifting is a competitive sport in which the athletes use barbells in competition to perform 2 competitive lifts, the snatch and the clean and jerk. In training, weightlifters may use both dumbbells and barbells as well as a variety of benches and racks. Weightlifting is governed internationally by the International Weightlifting Federation.

PART I: WEIGHTLIFTING FOR CHILDREN AND ADOLESCENTS: BRIEF OVERVIEW OF TRAINING-INDUCED ALTERATIONS

The participation of children and early and late adolescents in resistance-training activities, including training for sport, appears to be rising. Recently published scientific information supports the notion that properly supervised resistance-training programs can improve sport performance, reduce injury potential, and enhance health aspects in these groups.[12,25,68,77,89,92] Although potential benefits of strength training are recognizable to most medical/scientific groups, weightlifting for children and adolescents is still a controversial topic.[70,90,92]

The involvement of youth in the sport of weightlifting and the use of weightlifting methods as part of training for sport performance also appear to be growing.[63] The International Weightlifting Federation (IWF) held its first Youth World Championships in 2009. Youth is defined by the IWF as ages 13 to 17 years. Weightlifters as young as 15 years can compete in the IWF World Championships.[56] In 2010, the first Youth

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Olympic Games were held that included weightlifting for ages 16 and 17 years. USA Weightlifting has age groups for ages 16 and 17, 14 and 15, ≤13, and ≤11 years with no minimum age.[123]

Risks Versus Benefits

Considerable study has been devoted to the sport of weightlifting and its effects on competition performance, acute and chronic transfer to other sports' performance, and injury probability.[11,14,49,92,102,108,109] Over the past 25 years, weightlifting has been substantially scrutinized and, in some circles, continues as a controversial aspect of resistance training for young people. Most of this controversy revolves around the explosive nature of weightlifting and use of semiballistic movements.[16,100]

Although injuries can occur during weightlifting and related activities, the incidence of injury appears to be relatively low and severe injury is uncommon.[1,47,66,116] Interestingly, over a 1-year period, no training days were lost from injuries resulting from weightlifting training and competition performed by 70 male and female children ranging in age from 7 to 16 years (girls, n = 1, 12.3 ± 2.6 years; boys, n = 55, 11.6 ± 2.0 years).[90] Maximum and near-maximum lifts in competition were allowed provided appropriate skill level (reasonable technique) was maintained; if technique was observed to deteriorate, no further attempts were allowed. As measured by training records and weightlifting performance, both boys and girls showed increased strength and explosive strength.[90]

In a more detailed follow-up of 3 girls (13.7 ± 1.2 years) and 8 boys (12.5 ± 1.6 years) across 1 year's competition (534 competition lifts), both the boys and the girls showed marked improvements in weightlifting performance. Furthermore, no injuries requiring medical attention or loss of training time occurred.[17]

The conclusion from these 2 observations was that, if training and competition are age group appropriate and are properly supervised, weightlifting training and competition can be substantially safer and more efficacious than had been generally believed.[70,92] Note, these results must be viewed in the context of a scientific and reasonable approach to training and competition.[17,90,92] Furthermore, training was organized and supervised by well-qualified coaches.[17,90] Indeed, understanding developmental factors, appropriate supervision, and coaching are absolutely essential during training, especially for children and adolescents.[91,92]

With appropriate supervision and coaching, most injuries among children and adolescents are preventable during resistance training. Injuries are largely related to avoidable accidents.[85] Indeed, under proper supervision, these activities are no more (and usually less) injurious than other sports activities.[1,47,70,115] Compelling arguments indicate that weightlifting training and related strength-training activities can substantially reduce the injury potential of other activities and sports[25,47,61,77,102] and enhance health-related outcomes and potentially longevity.[4,69,125]

Although injuries in resistance-training sports are relatively low compared with other activities,[61] many injuries in training and competition that do occur are a result of acute and accumulative fatigue.[59] Fatigue highlights the importance of appropriate monitoring and fatigue management. For weightlifting, monitoring and fatigue management are especially crucial during periods of high-volume training, periods of intensification, and changes in acute training load; otherwise, there is a substantial risk for injury, maladaptation (poor response to training stimuli), or overtraining.[20,87] Observations in college-age men and women indicate that periods of high-volume resistance training, especially when coupled with training to failure, can result in a number of potentially negative effects.[20,87] These potential negative effects appear to result from high levels of training monotony and strain that may be related to hormonal alterations, such as adipokine alterations, increased cortisol and decreased testosterone, potentially increased inflammation, and perhaps immunosuppression.[20,53,87] Indeed, immunosuppression can occur as a result of rapid increase in training load or long periods of sustained high volumes, and these athletes often are at higher risk of illness.[59] Body composition, training history, achievement level, injury history, and age can all have a considerable impact on response to training loads engaged in by the athlete.[82] Therefore, longitudinal fatigue management and monitoring are strongly recommended to reduce the risk of injury and illness.[59,92,103] Monitoring and fatigue management are not only critical during periods of rapid growth but throughout the training process.

Physical, Performance Related, and Physiological Effects

Among children and adolescents, resistance training has been shown to result in a number of positive effects, including strength improvements, transfer of training effects to other activities, increased health outcomes, and general well-being.[12,92,116] However, only a few studies have specifically examined the effects of weightlifting training on children and adolescents.

A number of performance related, physical, and physiological variables are altered by weightlifting training in children, adolescents, and young adults.[17,22,23,44,77,96,98,119] For example, among boys aged 11 and 12 years, weightlifting training produced distinct increases in strength and speed-strength parameters, as well as measures of cardiorespiratory fitness.[99] These data agree with both cross-sectional and longitudinal weight-training/weightlifting studies of late adolescents and adults that indicate positive alterations in indicators of cardiorespiratory fitness and endurance performance.[105,106,114]

Dvorkin[29] detailed the results of a series of observations from the Soviet Union beginning in the 1950s and continuing through the 1980s. In these studies, investigators examined the effects of weightlifting training on the physical development, physiology, and performance of children and adolescents. The data indicate that from 12 to 22 years of age, weightlifting training can produce positive alterations in body composition,

cardiorespiratory variables (eg, resting heart rate, blood pressure, physical working capacity), and a range of motor fitness qualities (eg, jumping and sprinting), as well as in weightlifting performance. This information is particularly compelling, as, in many cases, large groups (ie, several hundred participants) of weightlifters were tracked continuously from the age of 13 to 19 years and compared with control groups of nonexercising peers and similar age groups involved in athletics (track and field).[30]

More recent observations also indicate that weightlifting training can result in substantial alterations in body composition, hormonal responses and adaptations, maximal strength, rate of force development, and weightlifting performance among young weightlifters.[17,21,38,54,62,90,117] Interestingly, training age (≥2 years' experience), not chronological age, appears to influence hormonal responses, and likely other parameters, among late adolescents.[62] These studies indicate a clear improvement in body composition and weightlifting performance from childhood into adulthood. Interestingly, the largest annual rate of increase in the total weight lifted for lower body mass athletes (<80 kg) was achieved between 16 and 17 years of age for both boys and girls and between 21 and 22 years with a heavier mass.[54] This information can establish progression trajectories and effective training programs for young athletes.

Collectively, these studies indicate that weightlifting training can produce improvements in body composition, cardiorespiratory variables, and general well-being. However, that positive alterations can be made at both micro and macro levels and the degree of alteration depends on the manipulation of training variables, including volume, intensity, and exercise selection.[43,45,51,78,104,105,106,114] Furthermore, there was no evidence that weightlifting training "stunted" growth.

Psychosocial Effects

There is evidence that appropriate physical training, including resistance training and weightlifting, can promote psychological well-being, self-esteem, enhanced pain tolerance, improved cognition, and perhaps character development.[18,28,31,32,35,54,64,65,78,96,122] Coaches/instructors may link aspects of training to other life aspects and teach that difficult parts of life can be overcome with similar diligence. It is plausible that sport training, including weightlifting, can be a positive force in a young person's life. Sports training has long been recognized as a primary tool for instilling important societal values and "life in microcosm," such that participants are offered opportunities to practice many of our most highly prized character traits.[57,127]

Summary

Age group–appropriate weightlifting training and competition that is properly supervised by well-qualified coaches is considerably safe and efficacious. Such training and competition can also have a substantial and profound influence on the psychological, physiological, physical, and performance aspects of weightlifters.

PART II: WEIGHTLIFTING FOR CHILDREN AND ADOLESCENTS: PUTTING THE RESEARCH INTO PRACTICE

Children, especially beginners at any age should follow an evidence-based resistance/weightlifting training program. An understanding of the sport and scientific training principles is necessary to properly construct a reasonable and appropriate training program.[81,88]

A scientific background aids in providing an evidenced basis and sound rationale in selecting appropriate methods and directing adaptations toward more specific goals. A sound scientific background enables the coach to make choices about training and competition that might not otherwise be possible.[52,89] Part of this scientific underpinning should also entail an understanding of the maturational differences among children, adolescents, and adults.[88]

Age to Begin

When training adolescents, and particularly children, there are various concerns that must be addressed before beginning the training process.

An initial concern is whether the child is physically and psychologically prepared. From a psychological/emotional perspective, it is important that children and adolescents be encouraged to participate in physical activity that challenges and provides enjoyment and satisfaction.[126] Promotion of self-improvement and satisfaction, along with good performance, can be provided through encouragement by the coach/instructor. Care should be taken in helping the children (and adolescents) deal with poor performances or not reaching goals.

Careful explanations are needed to instill realistic development expectations; it often takes a considerable amount of time to learn new skills or change physiology/psychology (eg, get fit). The degree of encouragement used to "push" young people to exceed previous goals must be weighed against application of pressure.[8] Often there is a fine line between "pressure" and "encouragement." Level of emotional and intellectual maturity is important to recognize in children (and anyone else) when initiating a training process. A child who is unable to comprehend what he or she is being asked to do may emotionally react in a negative manner to the rigors and discipline of the training program; the coach must rapidly recognize this aspect and take appropriate action. Correction of this problem can include redirecting the young person toward other types of activities that are less physically demanding.[74]

Because of different rates of maturation, not all children are ready for resistance training at the same chronological age. For children, Tanner staging by medical personnel can be performed; however, this process may be time-consuming, personally invasive, and expensive. A primary conceptual consideration is that the coach/instructor must be able to appropriately distinguish differences between chronological age and physiological age (Tanner stage) as well as recognize

differences in emotional and psychological maturity. In this context, it may be appropriate for coaches to become accredited (certified) by an appropriate governing or professional society.

The appropriate age for the initiation of formal weightlifting training can be as young as 10 to 11 years, provided that the biological age of the child and the emotional maturity of the child are reasonable. Byrd et al[17] followed a group of children (n = 11: 8 boys aged 12.5 ± 1.6 years; 3 girls aged 13.7 ± 1.2 years) for 22 to 34 months of training. The children underwent a long-term weightlifting training program, using block periodization[103] and the evidence-based concepts associated with appropriate training for children and adolescents discussed previously.[81,89] From the group, several performed successfully at national and international competitions. Six went on to compete in Junior World or Junior Pan American Championships. Of these, 2 competed in multiple World Championships. One athlete went on to compete at 3 Olympic Games and win 3 Pan American Championships spanning a 19-year career with no major injuries; a testament to long-term athlete development (LTAD).

In Bulgaria, from 1983 to 1993, the starting age for weightlifting training decreased by an average of 2 years, leading to 10- to 11-year-olds being "selected" for inclusion in weightlifting programs. In this small country that had been highly successful in weightlifting, the recommended age to begin training was 10 years, and similar programs were established in other Eastern European countries.[27] Furthermore, many (and probably most) of the athletes participating in many Eastern European weightlifting programs were initially selected based primarily on a comprehensive talent identification search.[27] Children at these ages began with general physical development that was compatible with sport-specific weightlifting fitness, and this emphasis was continued for at least 2 to 3 years.[3]

Development

According to Balyi and Hamilton,[6] 8 to 12 years of training is necessary for a gifted athlete to reach elite levels, and there may be "windows of opportunity" or critical ages at which specific types of training can yield the greatest benefits.[7,70] Although this long-term development model has been accepted by many coaches, the scientific evidence for age-related windows of opportunity or so-called critical windows of development has been questioned.[36,124] Despite ambiguity and controversy surrounding this model, there does appear to be a physiological basis for improvements in motor performance throughout childhood and adolescence.[9,27,42,70,73,92]

Recognizing adolescence itself as a critical window for LTAD is quite important. Indeed, Granacher et al[42] noted that a substantial portion of adaptation to resistance training, including weightlifting training, occurs during adolescence. To an extent, LTAD progression can be applied to American football and basketball with 3 years of participation in middle school, 4 years in high school, and generally 4 to 5 years in college before potentially participating in professional sports. However, specialization often occurs too early and, too often, with well-meaning coaches and parents hurrying the developmental process in many sports, including weightlifting.[70,83,84]

One aspect universally agreed upon is that physical literacy should be encouraged early in a child's development (typically before 12 years of age). Indeed, evidence indicates that attaining physical literacy involves the development of proficiency in fundamental movement skills (eg, walking, running, and jumping) and fundamental athletic skills (eg, catching, hopping, and galloping), which, when summated and refined, can result in more skillful movements in a variety of athletic and sporting activities.[50]

Prior research indicates that peak brain maturation occurs approximately between the ages of 6 and 8 years, and again at 10 and 12 years,[94] and that there can be a simultaneous accelerated development of the neuromuscular system.[15] Certainly, by 12 years of age most of the neural pathways for fundamental movement skills will be defined. The degree and rate of this definitive process depends largely on genetics but is also influenced by epigenetic, metabolic, and environmental factors.[70] This evidence suggests that the prepubertal and peripubertal years are likely a critical time frame for introduction and development of superior skill levels, including those associated with weightlifting.[71] In the evaluation of reasonable starting ages for children and the development of appropriate training plans, it is logical that the opinions of experts dealing directly with children be carefully considered.

Aján and Baroga[3] indicated that the "initial stage of training" for weightlifting should take place between the ages of 11 and 16 years. Starting at the age of around 11 or 12 years, the aim of training should focus on general physical preparation (development of fitness characteristics such as strength, specific flexibility, etc), and specialized training should not constitute more than 40% of the total training process during the first year.

During the first year, as a minimum, a variety of dynamic exercises, including exercises that can assist the development of movement characteristics necessary for weightlifting progression (and sport in general), are vital. Additionally, various activities such as basic gymnastics movements, and track and field activities, along with court games such as basketball and volleyball, can be used as part of the training at this age. Free-weight exercises aimed at general strengthening should be used.

Aján and Baroga[3] suggest that the aims and objectives in the second year of training (aged 12-13 years) should largely center on general physical development (50%) and stress "correct habits of execution" when learning the technique of the competition exercises. Specialized training should be added gradually in subsequent years and, to optimize long-term results, each phase of training should be built on the previous phase. According to Aján and Baroga, specialized training should increase relatively gradually. They suggest that more specialized weightlifting training should increase to 55% to 60% of the total weightlifting process in the third year and to as much as 70% in the fourth year.

Compatibility with sport-specific fitness is important, as some evidence indicates that noncompatible exercise (eg, endurance activities plus strength-power activities) may compromise the desired goals.[101,104,130] For example, weightlifting developmental fitness for children would include considerable training dealing with basic body strengthening (eg, weight training, gymnastics, tumbling), strength-endurance factors, and enhancement of cardiorespiratory capacity through interval training and metabolically stimulating resistance exercise, as well as exercise aimed at increasing mobility and range of motion.

Evidence among adults and adolescents indicates that emphasis on cardiovascular endurance that includes typical aerobic exercise (eg, long-distance running, swimming, cycling, etc) should be limited or avoided, as this may compromise the ability to gain strength and particularly rate of force development (explosiveness), power, and speed of movement.[39,45,79,101,120]

A typical timeline for a child's development and a typical training program to be used with a weightlifting beginner should encompass basic strength training—including body weight movements in the youngest age group (eg, gymnastics) and fairly rapid progression to free weights (eg, squats, pulls) with minimal loads—and emphasize the attainment of superior technical skill levels. Indeed, at the initiation of technique training, wooden sticks[17,34] should be used, progressing to age- and size-appropriate bars before using standard bars and additional loading as skill level and physical development become appropriate. The aim of this type of training should be to develop technical proficiency in weightlifting movements and exercises that are associated with development, such as weightlifting derivatives, squats, and presses, and will overlap with strength training.[71] Basic conditioning should be integrated with weightlifting training and can include flexibility, sprints, bounding, hopping, games such as soccer and basketball, and gymnastic exercises.[71,84,110]

Safety in the Weight Room

The athlete as well as the supervisor must understand safety standards, correct spotting techniques, and when and how these techniques should be used. Although injuries are relatively uncommon in comparison with most sports, resistance training can result in injuries, and on occasion severe injuries. However, the incidence of injury in weightlifting, including in adolescents, is relatively low compared with other physical activities and sports.[1,47] Most resistance-training injuries appear to occur as a result of poor fatigue management, especially among advanced athletes. Furthermore, acute injuries experienced in training usually result from poor technique, lack of concentration, or lack of adherence to simple safety procedures, including reasonable supervision.[33,70,76,89,92,96,107,116]

By using common sense and implementing reasonable safety guidelines, injury potential can be markedly reduced.[60] Safety guidelines can be considered in 2 general overlapping areas—athlete safety and equipment/facility safety[60,92] (Table 1, Panels a and b).

In addition to the safety guidelines, participants should have easy access to fluids during and after training, and the importance of proper hydration should be instilled. Of special note, weight loss techniques, particularly through means of intentional dehydration, are often unsafe and tenuous weight loss practices should not be permitted. This would include but is not limited to use of the improper use of saunas, use of body wraps, and intentional reduction in fluid intake.

Furthermore, instilling proper weight room etiquette and awareness not only enhances the weight room environment but may also contribute to young athletes becoming more disciplined and diligent.

Teaching Correct Technique

The coach, beginners, and especially children must understand proper lifting techniques for every exercise in the program. Technique refers to an idealized mechanical movement pattern that, based on sound evidence, should provide optimum performance for a specific exercise. The degree of skill achieved by a lifter deals with the level to which an ideal technique can be achieved. A thorough understanding of appropriate technique and the achievement of high skill levels are important for a number of reasons, including the following[70,81,92,93];

- As evidence indicates that skill levels tend to be long lasting,[5] good technique (skill) should be taught and learned initially in a child's or any beginner's development.
- Poor skill levels create poor adaptation, will limit gains in performance, and result in stagnation of progress.
- Good technique decreases potential for injury.
- From a sports perspective, high skill levels can substantially enhance the "transferability" of the exercise to sport performance. Therefore, low skill levels markedly reduce potential for enhanced gains in sport performance.

Considering these reasons, it is paramount that appropriate technique learning should begin at the initiation of developmental training, and the achievement of high skill levels should proceed as rapidly as is feasible. This realization demands a clear and detailed understanding of technique, recognition of skill level achievement, and an ability of the coach to teach it effectively. Indeed, coaches working with beginners, particularly children, have a responsibility to instill good technique (high skill levels) in their athletes.

Early emphasis on technique and skill level achievement is particularly important for large muscle mass and multijoint exercises, such as those commonly encountered in weightlifting training. Skill level, poor or otherwise, initially developed and used for long periods (ie, several years) may be difficult to alter.[72] Thus, the establishment of high skill levels from the initiation of a developmental training process is critical for enhancing safety, optimizing progress, achieving success in performance, and in providing greater satisfaction. Given the importance of a high skill level, a lack of sufficient strength will limit skill acquisition, especially in strength-power sports.[70,71,93]

Table 1. Athlete safety and equipment/facility safety

Panel a: Athlete Safety
Discipline and procedures
• Insist on good behavior
• Do not allow athletes to train unsupervised
• Insist on correct warm-up/ stretching/warm-down
• While not lifting, ensure athletes are aware of others who are active
• Instill correct spotting techniques
• Make sure that spotters are used correctly where/when required
• Allow no limit (maximum) attempts for early beginners
• Develop evidence-based methodology (periodization and programming) and ensure that the training program provided is being used
• Do not allow athletes to progress too quickly
Technique
• Be aware that weightlifting can be very tiring for beginners
• Be aware that familiarity with the barbell and other apparatus can be quite threatening for beginners
• Sound, mechanically correct lifting technique emphasizing proper "back position management" should be taught
• Instill correct breathing on all lifts
• Use light loads when new skills are being learned
• Teach beginners how to "miss" lifts correctly
• Progress loading at each individual's rate using appropriate monitoring techniques
• Use a "progressive stages" strategy when teaching lifts
• Do not advance progressions too quickly so that beginners are continually failing
Panel b: Equipment/Facility Safety
Athlete—make sure the athletes:
• Use suitable footwear to facilitate a stable base
• Use correct, suitable clothing to allow movement
• Take care of their hands (ie, callouses, blisters, cracks)
Medical
• First-aid kit antiseptic and hand lotion should be available
• Disinfectants should be available for cleaning the bar, etc
• Ice should be available for treatment of sprains, strains, and general fatigue
• Have an established emergency withdrawal procedure

(continued)

Table 1. (continued)

Equipment (ensure)
• Training platforms are well–spaced out (at least 1 m apart)
• Lifting surfaces are nonslip, firm, and level
• Barbells are evenly loaded and unloaded
• The use of collars with early beginners
• Squat racks and other apparatus are stable and pins in good working order
• There is an adequate supply of magnesium carbonate chalk and resin
• Discs are replaced in storage racks immediately after use
• The bar knurling is kept clean and disinfected
• Bars are straight and revolve easily
• The training environment has a reasonable temperature/humidity that is maintained and there are no drafts in the training area

Therefore, maximum strength should be enhanced simultaneously with skill acquisition.[12]

A variety of strength-training programs and methods have been suggested for children and adolescents.[33,116] Examination of the majority of these programs indicates that higher repetitions (10-15 repetitions/set) are recommended initially. Importantly, training of this type should be initiated only after adequate skill levels have been established. In both our experience and that of others,[70] reasonable skill can be best established using 1-on-1 supervision and by performing single repetitions with video feedback from the coach after each repetition. If adequate skill level has not been achieved, then corrections should be made before going on to the next repetition. This 1 repetition at a time approach is particularly important for learning the required technique of complex multijoint movements such as jumping, squatting, snatches or cleans, or their derivative movements.[70]

Multiple repetitions per set should be allowed only after high skill levels are achieved for each exercise. Otherwise, an initial multiple repetition approach can promote poor technique development. After learning proper technique, the type of program used depends on the age and goals of the beginner, but generally, higher repetitions per set would be in order, particularly for children.

As part of early developmental training, young children (aged 8-10 years) should use multiple repetitions per set (8-12 repetitions/set), with a training session frequency of 2 to 3 days per week, and with substantial variation of exercises.[92] When implemented, competition lifts are generally performed for 3 or fewer repetitions.[60] Although not always appropriate in a competitive sport context, allowing children and young adolescents to take part in planning the program (eg, picking out some exercises) may improve motivation and adherence.

The National Strength and Conditioning Association recommends a coach to athlete ratio of 1:10 or lower for "young athletes" (junior high and below) and 1:15 or lower for high school athletes. This contrasts with the 1:20 or lower coach to athlete ratio for college athletes.[121] Specifically, for weightlifting development, a lower coach to athlete ratio is important; particularly for developing proper weightlifting technique (eg, the sport of weightlifting vs strength and conditioning).[121]

Psychosocial Concerns in Training

As much as possible, attempt to create a training environment for the child (or adolescent) that prevents the arising of negative behavior. Children (as well as older trainees) may arrive at the gym with preexisting psychosocial issues, and the coach should be prepared to deal with this problem. However, it is also possible that negative psychological issues develop in training and in competition as a result of poor coaching methods and lack of a developed "sport culture." Just as beginners (particularly children) can be taught poor lifting technique and movement habits that are difficult to alter, it is also possible that they can develop negative psychosocial behavior patterns resulting from poor coaching methods and an emotionally/psychologically negative environment. Whether physiological or psychosocial, both are difficult to correct. It is important to develop correct lifting technique and initiate the development of a sound physiological basis and positive psychological habits from the first day of training. Additionally, psychological strategies employed in competition must be put into practice in

training on a daily basis. One important aspect of developing a positive environment is the development of a sport culture.[58]

Every sport has a historical basis and develops a culture that is influenced by its history as well as current societal influences. A sport culture is a fundamental expression of a team's values, beliefs, and attitudes concerning their sport. Sport cultures, when appropriately developed, can promote superior training habits as well as competitive drive. The sport culture determines whether the team's focus emphasizes having fun, mastery of the sport, or winning or whether it promotes individual accomplishment, team success, or both.[58,75]

Differences in Training Male and Female Children and Adolescents

Currently, the popularity of all forms of resistance training is at an all-time high among women and girls.[129] Although resistance training, including weightlifting, was once considered a man's sport, this is clearly no longer the case. Women and girls have broken with tradition and are now increasingly engaged in various strength-training activities, including CrossFit, bodybuilding, and the strength/power sports of power lifting and weightlifting.

Among children, gains in maximum strength and related characteristics are typically smaller than adolescents, particularly late adolescents, and the gains among all 3 groups do reflect some substantial sex differences.[13,67,68] Qualitative adaptations resulting from strength training for younger athletes are largely similar to those noted in late adolescents and adults.[17,89,90] However, genetic,[41] behavioral, morphological,[2,10,24] and hormonal/metabolic[54,80] differences appear to create enough variance to warrant training alterations for adolescent girls in order to concentrate on specific mechanophysiological differences. A striking difference between the sexes that has received a good deal of attention in the past few years deals with anabolic and catabolic hormones.[13,46,48,95]

Androgens, especially testosterone, influence a variety of sex characteristic–linked physiological and performance differences, such as lean body mass maximum strength, peak rate of force development (RFD), and power output.[46,48] On reaching adolescence, many of these sex differences are accentuated, particularly as it concerns muscle mass– and strength-related performance.[13,95]

For example, adolescents and adult women have relatively less upper body lean body mass and muscle than men.[2,86] This difference is in part reflected in lower absolute and relative strength measures in adolescents and women compared with similar male groups.[86,97,115] Because of these upper body muscle size and relative and absolute strength differences, some sport scientists and coaches advocate additional training of the upper body during specific phases of training, or for specific activities in which the upper body is more active (eg, throwing and aspects of weightlifting). While some evidence indicates that women can increase training-induced upper body strength faster than men, differences in strength-related characteristics between sexes remain.[86,115] This difference may be of importance, as lower body weightlifting training and competition performance outcomes can be linked to the upper body. For example, in the clean and jerk, relatively heavy loads are placed on the shoulders and upper torso. A relatively weak upper body could limit performance ability, as the necessary support for holding the bar along the shoulder girdle and maintaining a rigid upright torso can be reduced. Early recognition and appropriate intervention could largely prevent this potential problem.

Strength is the ability to produce force against an external resistance and ranges from 0% to 100%.[111,112,118] Maximal strength is task specific and can be defined as the greatest force that can be generated under a given set of circumstances. Strength can be conceptualized as a vehicle that is accompanied by several important strength-related characteristics, including impulse (ImP) = $F \times T$ explosiveness (RFD), power = force × velocity, and the ability to accelerate a mass and achieve a velocity of movement [force = (mass × acceleration)]. Maximum strength, RFD, and high-power outputs are key components for most sports, particularly weightlifting. Explosive strength (RFD) is especially important for weightlifters as it is a key characteristic in defining ImP and power output.

To succeed in "explosive strength sports" such as weightlifting, it is necessary to enhance maximal RFD development and peak power outputs. However, several sex differences must be considered. Absolute electromechanical delay times, contraction times, RFD, and power output are typically lower in female compared with male athletes.[40,55,113,131] Some of these differences may be accounted for by androgen differences[19] and, as adolescence is reached (puberty), by menstrual cycle factors. These sex-linked characteristics can be related to differences in performance and injury rate between men and women.

Clearly in terms of performance, maximum strength development is a major factor in weightlifting. Explosiveness and power output are also key elements for weightlifting success and often accompany gains in maximum strength.[104,118] Based on data from the late 1990s to 2000, women's peak power output during weightlifting movements is approximately 65% to 70% that of men.[113] Twenty years later, the difference is essentially the same (Table 2).

Initially, for beginners of either sex, involvement in explosive sports such as weightlifting should concentrate training on gaining maximum strength, as increases in maximum strength (1) have increased gains in explosiveness and power that are equal to or even higher than gains achieved by initially emphasizing power[12,118] and (2) can potentiate later gains in power.[103,128] However, at no time during training should power be neglected; rather, power should be more or less emphasized depending on the current training goals. Over time as maximum strength levels are increased, emphasis should switch toward power and explosive training.[118,128]

Although, male and female weightlifters often train in a similar manner, coaches should be cognizant of sex-linked

Table 2. 2019 World Championships ratio—women:men (%)[a]

	First Place	Second Place	Fourth Place
55-kg category			
Snatch	73.4	78.3	74.1
Clean and jerk	71.1	78.5	78.2
81-kg category			
Snatch	64.9	64.9	65.5
Clean and jerk	68.6	67.5	68.7
Super heavyweight category			
Snatch	66.4	66.0	68.5
Clean and jerk	70.5	71.8	71.0

[a]More than 20 years (1999-2019) later—based on 3 class average: snatch is comparable and clean and jerk has improved.

characteristics that could potentially result in performance problems. These include differences in maximum strength, particularly in upper body strength, electromechanical delay, skeletal muscle contraction time, and menstrual cycle characteristics. As a result of these differences, training may be manipulated, often subtly, at specific points developmentally and during specific phases of a periodized program. Program alterations can include additional upper body work, particularly during preparation phases, specific strength, and reactive strength. Explosive exercises can be implemented to address differences in electromechanical delay, force absorption, active joint stabilization, and biomechanics that have been associated with a relatively greater potential for injury, particularly for the anterior cruciate ligament.

Recovery/Adaptation and Monitoring

Reasonable planning and execution of the training program is necessary to enhance the stimulus-recovery adaptation process. This program should include not only the training stimulus but also built-in rest. Adopting reasonable methods of enhancing recovery adaptation other than training are also important. There are a number of viable methods that can be utilized including record keeping, nutrition, and sleep.[81]

Competition

Clearly, if competition is age group appropriate and properly supervised, weightlifting competition can be substantially safer and more efficacious than has been generally believed.[70] As with other youth sports, without some form of competition continued motivation is tenuous at best and program efficacy will suffer.[26,37] Investigators have observed the training efficacy of young weightlifters over time, and the athletes made substantial training and competition progress.[17,90] One important aspect of these studies was the inclusion of competition as well as other motivational techniques by the coaches, including goal setting, and so on. Goals can provide direction and keep athletes focused.[127]

Summary

This article has presented a brief overview of evidence on weightlifting for children and adolescents. Under qualified supervision, age-appropriate training programs that consider the biological maturity of athletes are associated with improved performance and enhanced physiological and psychosocial health. Although weightlifting for children and adolescents has been heavily scrutinized, the incidence and severity of injury is low; under proper supervision that includes proper technique and fatigue management strategies, these activities are no more injurious than other sports activities. Both observational and empirical evidence indicates that weightlifting can be a safe and efficacious activity for young athletes.

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