Published in final edited form as:

J Strength Cond Res. 2009 October ; 23(7): 2054–2060. doi:10.1519/JSC.0b013e3181b86712.

Youth Versus Adult “Weightlifting” Injuries Presenting to United States Emergency Rooms: Accidental Versus Nonaccidental Injury Mechanisms

Gregory D. Myer^{1,2}, Carmen E. Quatman^{1,3}, Jane Khoury^{1,4}, Eric J. Wall^{1,5}, and Timothy E. Hewett^{1,6}

¹Sports Medicine Biodynamics Center and Human Performance Laboratory, Cincinnati Children’s Hospital Medical Center, Cincinnati, Ohio 45229

²Graduate Program in Athletic Training, Rocky Mountain University of Health Professions, Provo, Utah 84606

³Engineering Center for Orthopaedic Research Excellence, University of Toledo, Toledo, Ohio 43606

⁴Division of Biostatistics and Epidemiology, Cincinnati Children’s Hospital Medical Center, Cincinnati Ohio

⁵Division of Pediatric Orthopaedic Surgery, Cincinnati Children’s Hospital Medical Center, Cincinnati, Ohio

⁶Department of Pediatrics, Orthopaedic Surgery, College of Medicine and the Department of Biomedical Engineering and Rehabilitation Sciences, University of Cincinnati, Cincinnati, Ohio 45221

Abstract

Myer, GD, Quatman, CE, Khoury, J, Wall, EJ, and Hewett, TE. Youth versus adult “weightlifting” injuries presenting to united states emergency rooms: accidental versus nonaccidental injury mechanisms. *J Strength Cond Res* 23(7): 2054–2060, 2009—Resistance training has previously been purported to be unsafe and ineffective in children. The purpose of this investigation was to evaluate resistance training-related injuries presenting to U.S. emergency rooms by age, type, and mechanism of injury. We hypothesized that older athletes would sustain greater percentages of joint sprains and muscle strains, whereas younger athletes would sustain a greater percentage of accidental injuries that would result in an increased percentage of fractures in youths. The U.S. Consumer Product Safety Commission (CPSC) National Electronic Injury Surveillance System was queried from 2002 to 2005 using the CPSC code for “Weightlifting.” Subjects between the ages of 8 and 30 were grouped by age categories 8 to 13 (elementary/middle school age), 14 to 18 (high school), 19 to 22 (college), and 23 to 30 (adult). Injuries were classified as “accidental” if caused by dropped weight or improper equipment use. Multiple logistic regression was used to compare accidental injuries between age groups. The sample

consisted of 4, 111 patients. Accidental injuries decreased ($p < 0.05$) with age: 8 to 13 > 14 to 18 > 19 to 22 years = 23 to 30 years. Conversely, sprain/strain injuries increased in each successive age group ($p < 0.05$). Evaluation of only the nonaccidental injuries ($n = 2, 565$) showed that the oldest categories (19–22 and 23–30 yr) demonstrated a greater percentage of sprains and strains relative to younger age categories ($p < 0.001$). Two thirds of the injuries sustained in the 8 to 13 group were to the hand and foot and were most often related to “dropping” and “pinching” in the injury descriptions, and there was an increased percentage of fractures in the 8 to 13 group relative to all other groups ($p < 0.001$). The study findings indicate that children have lower risk of resistance training-related joint sprains and muscle strains than adults. The majority of youth resistance training injuries are the result of accidents that are potentially preventable with increased supervision and stricter safety guidelines.

Keywords

pediatric resistance training; weight room injuries; resistance training injuries; weight room safety guidelines; resistance training safety

Introduction

With increasing participation in youth sports, there is an increasing desire for young athletes to achieve peak performance (1, 37). Resistance training may be one of the most popular and effective forms of conditioning aimed at enhancing sports performance, and its use is widespread among high school, college, and professional athletes (11, 39). However, resistance training in the young athlete has been controversial. Clinicians once considered open growth plates in a child as a contraindication to resistance training because of a potential, perceived risk of injury to these growth plates (37). It was originally the position of the American Academy of Pediatrics that weightlifting in children was an unnecessary risk, and it was concluded that prepubertal children were unable to increase strength or muscle mass because they lacked circulating androgen hormones (40). This position, in conjunction with isolated reports of catastrophic injury associated with weight training, significantly affected the medical community's stand on this mode of exercise in the past (20, 37). The purpose of this investigation was to evaluate injuries presenting to U.S. emergency rooms by subject age and type and mechanism of injury. We hypothesized that older athletes would sustain greater percentages of joint sprains and muscle strains during resistance training, whereas younger athletes would sustain a greater percentage of injuries related to accidents (e.g., dropping weights on their fingers and toes, misuse of equipment, and tripping/falling) than from actual musculoskeletal injury (e.g., muscle strains) from the intended use of the equipment, relative to the older age categories. A corollary hypothesis was that there would be an increased percentage of fractures in the younger age categories, specifically to the fingers and toes, indicative of accidental injury mechanisms.

Methods

Experimental Approach to the Problem

After approval from the institutional review board, the U.S. Consumer Product Safety Commission (CPSC) National Electronic Injury Surveillance System (NEISS) was queried from 2002 to 2005 using the CPSC code (Product ID # 3265) for “Weightlifting.” The CPSC sampling weights were used to calculate the national frequency estimates from the sampling frequencies of each age group within the sample (Figure 1). Subjects between the ages of 8 and 30 were included in the study. Subjects were grouped into 4 age categories: 8 to 13 (elementary/middle school age), 14 to 18 (high school age), 19 to 22 (college age), and 23 to 30 (adult age) on the basis of progressive school participation level (Table 1).

Injuries sustained under the influence of alcohol or other recreational drugs as reported by the hospital staff or subjects who left without seeing a physician were eliminated from the analyses. All data were quality controlled by cross referencing the specific comments to the CPSC category code. In addition, each injury was classified into a mechanism of injury termed “nonaccident” or “accident” based on the specific comments to the CPSC category. The mechanism of injury was considered nonaccidental if it resulted from exertion (sprain/strain, fatigue failure, headache), overuse (e.g., tendonitis), or from equipment malfunction (cable snapping, resistance bands breaking). The mechanism of injury was considered accidental if it resulted from dropped weights, improper use of equipment, or tripping over equipment. The mechanism of injury was categorized by 2 separate authors blinded to both the age and sex of the subjects. One author performed the initial categorization, and the second author quality controlled the data and performed a separate, independent categorization. If the authors were unable to reach an agreement about the mechanism of injury or if they were unable to determine the injury mechanism from the description, the data were eliminated from the analysis. Frequency of resistance training injury estimates and data analyses were based upon the sample fulfilling the inclusionary criteria (age 8–30 yr, the mechanism of injury could be determined from the comments, no drug or alcohol use during injury, and patient was seen by a physician). The differences between age categories (8–13, 14–18, 19–22, and 23–30 yr) were determined for mechanism of injury (accident or nonaccident), type of injury (sprain/strain or fracture), and body part injured (head, trunk, arm, leg, foot). In addition, comparisons of injuries classified as “accidental” versus “nonaccidental” were made to further characterize the sample population.

Statistical Analyses

Statistical analyses were performed using SAS, version 9.1 (SAS Institute, Cary, NC, USA). To account for the survey design and use the appropriate standard errors, the survey-specific procedures, which incorporated the sample weights and design clusters, were used for analysis. The independent variable of interest, age group, had 4 categories. Multiple logistic regression was initially used to assess the overall age effect, in which the 23 to 30 year age group was used as the reference category. Comparisons between successive age categories were also made using logistic regression, and a Bonferroni correction was used to adjust for the multiple comparisons. The level of significance was established a priori at $p = 0.05$.

Results

The sample consisted of 4,111 patients for inclusion in the analysis. The distribution of injuries classified as caused by “weightlifting” are presented in Table 1. Table 2 shows the comparison of age group for accidental injury, and each category shows a statistically significant difference by age ($p < 0.0001$). After Bonferroni correction for multiple comparisons, the percentage of the injuries that were accidental decreased significantly ($p < 0.05$) for each successive age group: 8 to 13 > 14 to 18 > 19 to 22 years; those 23 to 30 years of age were not different from the 19 to 22 year group. For sprain/strain injuries, the effect went in the opposite direction, and each successive age group was different ($p < 0.05$) after Bonferroni correction. Sprains and strains were 18.2% of injuries in the 8 to 13 age group, 43.9% in the 14 to 18 age group, 59.6% in the 19 to 22 age group, and 66.1% in the 23 to 30 age group. Evaluation of only the nonaccidental injuries ($n = 2565$) revealed that the oldest categories (19–22 and 23–30 yr) demonstrated a greater percentage (85% and 89%, respectively) of injuries categorized as sprains and strains relative to the other age categories ($p < 0.001$).

The oldest age groups demonstrated the greatest percentage of trunk-related injuries. Figure 2 represents the anthropometric location breakdown of weighted percentages of injuries for the youngest and oldest age categories. Two thirds of the injuries sustained in the 8 to 13 age group were to the hand and foot and were most often related to “dropping” and “pinching” in the injury descriptions. Consequently, when comparing injury type, there was an increased percentage of injuries classified as a fracture in the 8 to 13 group relative to all other groups ($p < 0.001$).

Discussion

On the basis of this analysis of resistance training injuries that resulted in visits to U.S. emergency rooms, it appears that children have lower risk of resistance training-related joint sprains and muscle strains than adults. The majority of youth resistance training injuries that occurred in this study were the result of accidents that could have potentially been prevented with increased supervision and stricter safety guidelines. Evidence accumulated over the last decade has clarified the relative injury risk of resistance training compared with other forms of sport participation. These reports have demonstrated both the general safety and efficacy of resistance training for children and adolescents (13–16, 21). Resistance training that incorporates appropriate technical instruction is accepted as both a safe and effective mode of exercise for preadolescent and adolescent children by most major medical communities, including the American Academy of Family Physicians (AAFP), American Academy of Orthopaedic Surgeons (AAOS), American College of Sports Medicine (ACSM), American Medical Society for Sports Medicine (AMSSM), American Orthopaedic Society for Sports Medicine (AOSSM), American Osteopathic Academy of Sports Medicine (AOASM), The National Strength and Conditioning Association (NSCA), American Academy of Pediatricians (AAP), and The President’s Council on Physical Fitness and Sports (4, 10, 12, 24, 37).

In addition to increased evidence on the safety of supervised resistance training in young athletes and adolescents, there is evidence that resistance training may reduce injury in a young athlete's chosen sport (6, 22, 29). This evidence is based on the beneficial adaptations that occur in bones, ligaments, and tendons after training and is further supported by epidemiology-based reports (18, 28). Lehnhard and colleagues (29) reported significant reductions in injury rates with the addition of a strength training regimen with a male soccer team. Cahill and Griffith (6) incorporated weight training into their preseason conditioning for adolescent football teams and reported a reduction in knee injuries as well as a reduction in knee injuries that required surgery over 4 competitive seasons. Hejna et al. (23) reported that young athletes (13–19 yr) who included resistance training as part of their exercise regimen demonstrated decreased injuries and recovered from injuries with less time spent in rehabilitation when compared with their teammates. Training regimens that incorporated resistance training into preseason and in-season conditioning reduced injury risk factors and anterior cruciate ligament injuries in female athletes (25, 26, 30, 35, 36, 38). Thus, there is evidence that indicates that resistance training is not only a relatively safe activity for young athletes but that it may also be useful to reduce injuries during competitive play (21, 37).

The positive effects of a sound resistance training regime on increases in strength in adult athletes have been widely documented in the literature (3, 5, 7, 19, 47). Strength improvements achieved from resistance training occur by way of muscle hypertrophy (increases in muscular cross-sectional area), muscle fiber structural changes (pennation angle changes), and neuromuscular (increased motor unit synchrony and recruitment) and metabolic (improved energy delivery) adaptations (2, 27, 32, 33, 43, 46, 47). In contrast, earlier reports on resistance training in children purported that no similar adaptations would occur, mainly because of lack of circulating androgens in young children (9, 48).

Although earlier studies suggested an absence of significant effect of resistance training in youth, subsequent studies that incorporated more rigorous experimental designs demonstrated marked improvements in strength measures for prepubescent and pubescent subjects after resistance training regimens (13, 15–17, 41, 42, 44, 45, 49). The measured benefits from resistance training are now considered to be greater than those attributable to normal growth and development in children and adolescents (37). These gains stem largely from neural adaptations (more complete and synchronous firing of muscle units) associated with the training. Faigenbaum and Bradley (10, 11) listed the potential benefits of resistance training for young athletes to range from increased muscle strength and power to enhancement of mental health as well as a stimulation of positive attitude that can foster a lifelong activity of resistance training.

Physical maturity and size, which may limit the use of certain resistance machines, should not limit participation in appropriately designed and supervised resistance training protocols. However, mental maturity level could limit participation (37). Faigenbaum and colleagues (14) demonstrated that with appropriate supervision children can be safely tested and trained even with applied maximum effort resistance. In general, if young athletes maintain sufficient emotional maturity to accept and follow directions, then they should be ready for strength training. If they are unable to follow supervision, then participation should be limited. All children and adolescents should be closely supervised and provided with

competent and consistent feedback related to their exercise performance. Although injuries during resistance training are less frequent than in actual sport performance, they can occur and may be related to maturity level (21). The current study indicated that two thirds of the injuries sustained in the younger aged patients were to the hand and foot and were most often related to “dropping” and “pinching” in the injury descriptions. Appropriate attention to teaching weight room etiquette and equipment safety, combined with precautions to prevent horseplay and attention to proper handling of heavy objects in the weight room, may limit the risk of accidental weight room injuries (12, 37).

To reduce the occurrence of nonaccidental injuries in children and adolescents, an emphasis should be placed on safe equipment use and perfecting proper technique. If the athlete is allowed to perform the exercise maneuvers improperly at low resistance levels, then the risk of injury will be amplified as resistance is increased. To improve exercise techniques, instructors should give continuous and immediate feedback to the young athlete, both during and after each exercise bout (37). This will make them aware of proper form and technique, as well as undesirable and potentially dangerous positions. In addition, visual feedback can be useful to help make young weightlifters cognizant of exercise techniques performed with visually identifiable poor biomechanics (34). Instructors can use mirrors or video equipment to help provide visual feedback. Visual and verbal feedback may help young athletes to match their perceived technique performance to their actual technique. Beyond the obvious benefit of appropriate supervision to decreasing injury risk in the weight room, direct supervision increases the efficacy of resistance training. Coutts and colleagues (8) demonstrated that supervised resistance training improved strength gains and exercise adherence in young athletes versus unsupervised training. Mazzetti et al. (31) corroborated these findings when they found similar results in male athletes who had moderate experience with resistance training. Cumulatively, there is strong evidence to support the benefits of direct supervision to improve both the efficacy and safety of resistance training applied to young athletes.

Our study limitations are mainly associated with the NEISS dataset sampling techniques. The manner in which these data were categorized based on the mechanism of injury (accident or nonaccident) is limited by the accuracy of recording of each injury by the separate treating clinicians and by the interpretation of the authors who reviewed each injury description. However, before individual categorization, the authors defined the methods of categorization to improve the systematic nature of the processes. In addition, emergency room technicians provided specific comments linked to each injury mechanism in the NEISS database. This afforded the investigators a secondary assessment of the injury mechanism and “weightlifting” activity to confirm the data quality control. Future prospective investigations should be used that attempt to objectify injury categorization to further diminish this study design limitation. In addition, the authors were blinded to the age and the CPSC sampling weights during the categorization process. It is also not known whether multiple visits were made to the emergency room by the same patient related to the same isolated “weightlifting” injury. If this occurred, an artificial inflation of the overall injury frequency may be reflected in the data. To control for overestimations, the NEISS coding manual instructs hospital workers to record only the first emergency room visit for any specific injury (CPSC NEISS coding manual), and thus it is unlikely that multiple visits

by the same person for a specific injury were recorded. The NEISS coding manual instructs hospital workers to record only the most severely affected body part associated with an injury incident. In some cases, the frequency of additional minor injuries accompanying an injury incident may be underrepresented.

Another potential limitation is that the dataset does not include all “weightlifting” injuries because we cannot account for injuries that may not have resulted in an emergency room visit, perhaps because treatment was available at the setting of injury (e.g., athletic trainers or team physicians), treatment was sought at other medical facilities, or treatment was not sought out for an injury. Finally, this data cannot be generalized to specific populations based on athletic participation, skill level, or physical fitness because the NEISS database does not distinguish between recreational, high school, and collegiate athletes. More importantly, we cannot accurately determine whether the “weightlifting” injury occurred during “structured” (developed programs monitored by coaches, teachers, or trainers) or “unstructured” (no formal program or supervision) activities or any level of supervision that was available at the time of injury to the athlete. Despite these limitations, the results presented in this study provide important information on resistance training injury patterns in young children and adolescents relative to adults. Future work should focus on determining whether technique training, proper supervision, stricter safety guidelines, or other modifications can make resistance training safer for all ages and levels of participation.

Practical Applications

On the basis of the current report, there is an increased risk of joint sprain and muscle strain injury in adults compared with children during resistance training activities. Younger children tend to sustain more accidental injuries, especially fractures, during resistance training activities than older children and adults. If appropriately supervised, resistance training may be safe and effective and may also facilitate injury risk reduction during sports participation. Resistance training programs for young children should focus primarily on the safe use of equipment to avoid accidental injury, then on the acquisition of proper resistance training techniques, and finally on the appropriate intensity progression that allows the development of strength and power. Unsupervised resistance training should be avoided in both preadolescent and adolescents athletes.

Acknowledgments

Financial support was provided from the National Institutes of Health/NIAMS Grant R01-AR049735. The authors also acknowledge Jensen Brent for his assistance with the literature review and Jane Kirwan with her help with the database management.

References

1. Adirim TA, Cheng TL. Overview of injuries in the young athlete. *Sports Med.* 2003; 33:75–81. [PubMed: 12477379]
2. Alway SE, Grumbt WH, Gonyea WJ, Stray-Gundersen J. Contrasts in muscle and myofibers of elite male and female bodybuilders. *J Appl Physiol.* 1989; 67:24–31. [PubMed: 2759948]

3. Ben-Sira D, Ayalon A, Tavi M. The effect of different types of strength training on concentric strength in women. *J Strength Cond Res.* 1995; 9:143–148.
4. Bernhardt DT, Gomez J, Johnson MD, Martin TJ, Rowland TW, Small E, LeBlanc C, Malina R, Krein C, Young JC, Reed FE, erson SJ, Griesemer BA, Bar-Or O. Strength training by children and adolescents. *Pediatrics.* 2001; 107:1470–1472. [PubMed: 11389279]
5. Boyer BT. A comparison of the effects of three strength training programs on women. *J Appl Sport Sci Res.* 1990; 4:88–94.
6. Cahill BR, Griffith EH. Effect of preseason conditioning on the incidence and severity of high school football knee injuries. *Am J Sports Med.* 1978; 6:180–184. [PubMed: 686227]
7. Chilibeck PD, Calder AW, Sale DG, Webber CE. A comparison of strength and muscle mass increases during resistance training in young women. *Eur J Appl Physiol Occup Physiol.* 1998; 77:170–175. [PubMed: 9459538]
8. Coutts AJ, Murphy AJ, Dascombe BJ. Effect of direct supervision of a strength coach on measures of muscular strength and power in young rugby league players. *J Strength Cond Res.* 2004; 18:316–323. [PubMed: 15142000]
9. Docherty D, Wenger HA, Collis ML, Quinney HA. The effects of variable speed resistance training on strength development in prepubertal boys. *J Hum Move Stud.* 1987; 13:377–382.
10. Faigenbaum AD. Youth resistance training. President's Council on Physical Fitness and Sports Research Digest. 2003; 4
11. Faigenbaum AD, Bradley DF. Strength Training for the Young Athlete. *Orthopaed Phys Ther Clin North Am.* 1998; 7:67–90.
12. Faigenbaum AD, Kraemer WJ, Cahill B, Chandler J, Dziados J, Elfrink LD, Forman E, Gaudiose M, Micheli LJ, Nitka M, Roberts S. Youth resistance training: position statement paper and literature review. *J Strength Cond Res.* 1996; 18:62–75.
13. Faigenbaum AD, Loud RL, O'Connell J, Glover S, Westcott WL. Effects of different resistance training protocols on upper-body strength and endurance development in children. *J Strength Cond Res.* 2001; 15:459–465. [PubMed: 11726257]
14. Faigenbaum AD, Milliken LA, Westcott WL. Maximal strength testing in healthy children. *J Strength Cond Res.* 2003; 17:162–166. [PubMed: 12580672]
15. Faigenbaum AD, Westcott WL, Micheli LJ, Outerbridge AR, Long CJ, LaRosa-Loud R, Zaichkowsky LD. The effects of strength training and detraining on children. *J Strength Cond Res.* 1996; 10:109–114.
16. Faigenbaum AD, Zaichkowsky LD, Westcott WL, Micheli LJ, Fehlandt AF. The effects of a twice-a-week strength training program on children. *Pediatr Exerc Sci.* 1993; 5:339–345.
17. Falk B, Mor G. The effects of resistance and martial arts training in 6 to 8 year old boys. *Pediatr Exerc Sci.* 1996; 8:48–56.
18. Fleck SJ, Falkel JE. Value of resistance training for the reduction of sports injuries. *Sports Med.* 1986; 3:61–68. [PubMed: 3633121]
19. Fry AC, Kraemer WJ, Weseman CA, Conroy BP, Gordon SE, Hoffman JR, Maresh CM. The effects of an off-season strength and conditioning program on starters and non-starters in women's intercollegiate volleyball. *J Appl Sport Sci Res.* 1991; 5:174–181.
20. George D, Stakiw K, Wright C. Fatal accident with weightlifting equipment: implications for safety standards. *Can Med Assoc J.* 1989; 140:925–926. [PubMed: 2702529]
21. Hamill BP. Relative safety of weightlifting and weight training. *J Strength Cond Res.* 1994; 8:53–57.
22. Hejna W, Rosenberg A, Buturusis D, Krieger A. The prevention of sports injuries in high school students through strength training. *Natl Strength Cond Assoc J.* 1982; 4:28–31.
23. Hejna WF, Rosenberg A, Buturusis DJ, Krieger A. The prevention of sports injuries in high school students through strength training. *Natl Strength Coaches Assoc J.* 1982; 4:28–31.
24. Herring SA, Bergfeld JA, Boyd JL, Brolinson PG, Chang CJ, Glover DW, Grana WA, Indelicato P, Johnson RJ, Kibler WB, Kraemer WJ, McNerney JP, Pallay RM, Tanji JL. The team physician and conditioning of athletes for sports. American Academy of Family Physicians Consensus Statement. 2000

25. Hewett TE, Myer GD, Ford KR, Heidt RS Jr, Colosimo AJ, McLean SG, van den Bogert AJ, Paterno MV, Succop P. Biomechanical measures of neuromuscular control and valgus loading of the knee predict anterior cruciate ligament injury risk in female athletes: a prospective study. *Am J Sports Med.* 2005; 33:492–501. [PubMed: 15722287]
26. Hewett TE, Riccobene JV, Lindenfild TN. The effect of neuromuscular training on the incidence of knee injury in female athletes: a prospective study. *Am J Sports Med.* 1999; 27:699–706. [PubMed: 10569353]
27. Kawakami Y, Abe T, Fukunaga T. Muscle-fiber pennation angles are greater in hypertrophied than in normal muscles. *J Appl Physiol.* 1993; 74:2740–2744. [PubMed: 8365975]
28. Kraemer WJ, Duncan ND, Volek JS. Resistance training and elite athletes: adaptations and program considerations. *J Orthop Sports Phys Ther.* 1998; 28:110–119. [PubMed: 9699161]
29. Lehnhard R, Lehnhard HR, Young R, Butterfield SA. Monitoring injuries on a college soccer team: the effect of strength training. *J Strength Cond Res.* 1996; 10:115–119.
30. Mandelbaum BR, Silvers HJ, Watanabe D, Knarr J, Thomas S, Griffin L, Kirkendall DT, Garrett WJ. Effectiveness of a neuromuscular and proprioceptive training program in preventing the incidence of ACL injuries in female athletes: two-year follow up. *Am J Sport Med.* 2005; 33:1003–1010.
31. Mazzetti SA, Kraemer WJ, Volek JS, Duncan ND, Ratamess NA, Gomez AL, Newton RU, Hakkinen K, Fleck SJ. The influence of direct supervision of resistance training on strength performance. *Med Sci Sports Exerc.* 2000; 32:1175–1184. [PubMed: 10862549]
32. McCall GE, Byrnes WC, Dickinson A, Pattany PM, Fleck SJ. Muscle fiber hypertrophy, hyperplasia, and capillary density in college men after resistance training. *J Appl Physiol.* 1996; 81:2004–2012. [PubMed: 8941522]
33. Milner-Brown HS, Stein RB, Lee RG. Synchronization of human motor units: possible roles of exercise and supraspinal reflexes. *Electroencephalogr Clin Neurophysiol.* 1975; 38:245–254. [PubMed: 46802]
34. Myer GD, Ford KR, Hewett TE. Rationale and clinical techniques for anterior cruciate ligament injury prevention among female athletes. *J Athl Train.* 2004; 39:352–364. [PubMed: 15592608]
35. Myer GD, Ford KR, McLean SG, Hewett TE. The effects of plyometric versus dynamic stabilization and balance training on lower extremity biomechanics. *Am J Sports Med.* 2006; 34:490–498. [PubMed: 16382007]
36. Myer GD, Ford KR, Palumbo JP, Hewett TE. Neuromuscular training improves performance and lower-extremity biomechanics in female athletes. *J Strength Cond Res.* 2005; 19:51–60. [PubMed: 15705045]
37. Myer GD, Wall EJ. Resistance training in the young athlete. *Oper Tech Sports Med.* 2006; 14:218–230.
38. Myklebust G, Engebretsen L, Braekken IH, Skjølberg A, Olsen OE, Bahr R. Prevention of anterior cruciate ligament injuries in female team handball players: a prospective intervention study over three seasons. *Clin J Sport Med.* 2003; 13:71–78. [PubMed: 12629423]
39. NFHS. 2006 High School Participation Survey. Indianapolis, IN: National Federation of State High School Associations; 2006.
40. Pediatrics, AAO. Weight training and weight lifting: information for the pediatrician. *Phys Sports Med.* 1983; 11:157–161.
41. Pfeiffer R, Francis R. Effects of strength training on muscle development in prepubescent, pubescent, and postpubescent males. *Phys Sports Med.* 1986; 14:134–143.
42. Ramsay J, Blimkie C, Smith K, Garner S, MacDougall J, Sale D. Strength training effects in prepubescent boys. *Med Sci Sports Exerc.* 1990; 22:605–614. [PubMed: 2233199]
43. Rooney KJ, Herbert RD, Balnave RJ. Fatigue contributes to the strength training stimulus. *Med Sci Sports Exerc.* 1994; 26:1160–1164. [PubMed: 7808251]
44. Sailors M, Berg K. Comparison of responses to weight training in pubescent boys and men. *J Sports Med Phys Fitness.* 1987; 27:30–37. [PubMed: 3599970]
45. Sewall L, Micheli L. Strength training for children. *J Pediatr Orthop.* 1986; 6:143–146. [PubMed: 3958165]

46. Smith RC, Rutherford OM. The role of metabolites in strength training. I. A comparison of eccentric and concentric contractions. *Eur J Appl Physiol Occup Physiol.* 1995; 71:332–336. [PubMed: 8549576]
47. Staron RS, Karapondo DL, Kraemer WJ, Fry AC, Gordon SE, Falkel JE, Hagerman FC, Hikida RS. Skeletal muscle adaptations during early phase of heavy-resistance training in men and women. *J Appl Physiol.* 1994; 76:1247–1255. [PubMed: 8005869]
48. Vrijens F. Muscle strength development in the pre and post-pubescent. *Med Sport.* 1978; 11:152–158.
49. Weltman A, Janney C, Rians CB, Strand K, Berg B, Tippitt S, Wise J, Cahill BR, Katch FI. The effects of hydraulic resistance strength training in pre-pubertal males. *Med Sci Sports Exerc.* 1986; 18:629–638. [PubMed: 2946921]

Figure 1.

Estimated number of “weightlifting” injuries presenting in U.S. emergency rooms between years 2002 and 2005.

Figure 2.

Percentage of injuries of oldest and youngest age categories. Note that small prevalence of leg injuries in 8 to 13 age categories provides invalidated results and should be interpreted with caution.

Table 1

Sample total injuries classified and included into study analyses.

Age	<i>n</i>	Weighted percent
8–13	397	8.3
14–18	1571	38.4
19–22	772	19.1
23–30	1371	34.2

Table 2

Frequency and odds ratios for accidental injuries occurring in each age group.

Age (group)	Frequency of accidental injuries	Weighted percent	OR (95% CI)
8–13	295	77.2	8.91 (6.28, 12.6)
14–18	655	42.2	1.92 (1.58, 2.34)
19–22	239	31.9	1.23 (1.00, 1.53)
23–30	363	27.5	Reference
<i>p</i>		<0.0001	<0.0001