

Weightlifting Training and Hormonal Responses in Adolescent Males: Implications for Program Design

Andrew C. Fry, PhD, CSCS, and Brian K. Schilling, MS, CSCS
The University of Memphis, Memphis, Tennessee

THE ROLE OF STRENGTH training for youth has received considerable attention in recent years. In this age of overzealous parents and coaches, an increasing concern has been for what constitutes an appropriate training program for youth. Although it is clear that many elite athletes begin their training at a young age, one must always be concerned for the welfare of the child. Although not all champions begin training for their respective sports at a very young age, it is becoming increasingly common to start serious training during adolescence (the age from the onset of puberty to adulthood), and in the case of sports such as gymnastics, at an even younger age. In weightlifting, for instance, it is likely that an earlier start to training is partly responsible for the dominance that Eastern European and Asian countries display. So, how old must a child be before such difficult training demands are placed on them? Should they specialize in one activity, or should they include many different sports and activities to provide a broad training experience? Furthermore,

what type of training program is best during adolescence? Although not all of these questions are easily answered, the main purpose of this article is to take a brief look at what physiology can tell us about training tolerance during adolescence.

It is readily apparent that many different factors contribute to elite performances in any sport or activity. This article will focus on the insights gained from the sport of weightlifting (i.e., snatch, clean and jerk). Most of the athletes in the studies reviewed here specialize in weightlifting training. Because this is the only lifting sport that is included in the Olympic Games, much research has been performed regarding its physiology. Although not all youth who participate in resistance training perform these exercises, data from these studies may still provide the best opportunity to examine how adolescents respond to stressful weight-training programs. In the pursuit of excellence, talent identification programs have been developed to identify potentially elite performers for weightlifting (6, 7). Al-

though this is certainly a critical step in developing top-notch performers in any sport, such testing has not yet addressed the issues of desire or capacity for the required training. Additionally, a coach or trainer must also be concerned with creating the proper psychological environment to optimize an individual's motivation and increase participant retention in the program (11). Certainly, a major concern is the physical safety of the training of weightlifting. To date, the data indicate that the weightlifting-training programs are as safe or safer than most other youth sport activities and that such training is not detrimental to the young athlete (4). Although all these considerations are important for resistance training of young athletes, the focus of the remainder of this article will be on monitoring the training tolerance of junior-aged weightlifters.

■ Can the Hormonal System be Used to Monitor Training Status?

To look closely at this question, we must examine the scientific literature dealing with overtraining. In-

terestingly, 2 particular hormones have been used to determine how an individual responds to various types, intensities, and volumes of training. Specifically, these are testosterone and cortisol, and the ratio between them (i.e., testosterone/cortisol ratio). For a decade and a half, it has been suggested that this ratio may be one method of quantifying training stress (1). Because of the functional properties of these hormones, they have been used to represent the anabolic-catabolic status of an individual. Although this is certainly an oversimplification of what these 2 hormones actually do, it has been repeatedly demonstrated that the testosterone/cortisol ratio is inversely related to the cumulative training stresses of the body. In other words, as the total training stress increases, the hormonal ratio decreases and vice versa. It should be pointed out here that we are concerned with one's natural production (i.e., endogenous production) of these hormones and not with the use of pharmaceuticals or supplements that simulate or stimulate these hormones. Concerning weightlifting, Häkkinen et al. (12) were the first to provide evidence that the testosterone/cortisol ratio was inversely related to the volume-load (repetitions \times weight) in adult male weightlifters. Furthermore, Alén et al. (2) demonstrated that for adults this ratio was positively related to the changes in isometric strength. As isometric strength increased over the course of a training program, the hormonal ratio also increased. For testosterone to exist for an extended time period in the circulation, it must be bound to its binding protein, sex hormone-binding globulin (SHBG). This protein acts somewhat like a chaperone, protecting

testosterone from degradation. But for testosterone to act at its target sites, it must unbind from SHBG, thus becoming what is known as free testosterone. It is the 1–2% of the total testosterone that is free and available to produce the desired effects of testosterone. The ratio of total testosterone/SHBG is related to actual competitive weightlifting performances (12). In adults, long-term weightlifting training over a 2-year period has been accompanied by increases in the testosterone/cortisol ratio (13). It has been suggested that this may be indicative of increased weightlifting strength and enhanced training tolerance. Although all these data have been generated from mature adults, it is critical for the further study of adolescents.

■ Puberty and the Hormonal Environment

It is apparent that monitoring the testosterone/cortisol ratio is helpful for tracking the training status of adult males. But because less-mature males do not possess the same hormonal environment, it must be questioned whether the use of this ratio is valid for a younger population such as adolescents. As a young male progresses from prepuberty to puberty, the circulating concentration of testosterone first increases during the sleep hours (3, 14). This increase is regulated by luteinizing hormone secreted by the pituitary gland (3, 14). Because a less-mature male exhibits lower concentrations of testosterone when compared with a mature adult, it is possible that the testosterone/cortisol ratio may not be an appropriate marker of training stress for the adolescent. Conceivably, resting testosterone levels during adolescence may not be great enough

to be markedly influenced by the training program. Mero et al. (17, 18), however, demonstrated that during adolescence, increased weightlifting strength was accompanied by increases in circulating testosterone. Among their suggestions was that strength training should begin during this stage of development, when the anabolic environment is being enhanced. It still needs to be asked, however, whether the hormonal environment is adequate to support the intense training required for elite performances.

■ Can Training Stresses be Monitored by the Hormonal Environment?

As mentioned above, it appears that changes in the testosterone/cortisol ratio are negatively related to the weightlifting-training protocol for adult males (12). As the volume-load increases, the hormonal ratio decreases in a similar manner. We must now ask whether this relationship exists for young male weightlifters who possess incompletely developed endocrine systems. The best opportunity to study this question was with the U.S. National Junior Weightlifting Squad that trains at various times of the year at the Olympic Training Center in Colorado Springs, Colorado (10, 19). These athletes had reached a qualifying total to attend this camp, specifically for athletes aged 16–20 years. This is a well-controlled environment where the lifter characteristics and the training programs can be readily quantified. During the course of a 1-month training camp, 1 week consisted of increased levels of training volume (2–4 sessions/d), after which training returned to normal levels for the last 3 weeks (1–2 sessions/d). Resting testos-

terone and cortisol levels were measured, as were the acute responses to a standardized lifting protocol. As has been reported before (12), the testosterone/cortisol ratio decreased during the 1 week of high-volume training, after which it returned to original levels during the 3-week normal training phase. The hormonal ratio thus appeared to reflect changes in the training stress. It should be pointed out that although Adlercreutz et al. (1) had proposed some specific values for the hormonal ratios as indicators of overtraining (a decrease of at least 30% in the free testosterone/cortisol ratio, or a free testosterone/cortisol ratio of $<0.35 \times 10^{-3}$), these levels were never approached among these young weightlifters. Despite the extremely high volumes of lifting performed by these young weightlifters during the first week, they actually increased their 1 repetition maximum (RM) for the snatch and the clean and jerk during this time (10, 19). Interestingly, it was noted that the barbell trajectories during these lifts indicated an increased swinging of the barbell away from the body (unpublished data), an undesirable trait. On the basis of this, it is likely that the lifting mechanics may be a sensitive indicator of the changes in the training stresses. During this study, the effect of branched-chain amino acid supplementation (leucine, isoleucine, valine) on stressful training was examined. It was determined that these amino acids did not influence any measured variable. These results suggest that although these amino acids have been purported to counter the effects of stressful training via the central fatigue hypothesis, no evidence of this was apparent when using typical dosages with these

young weightlifters (10). In summary, it can be surmised that the young male weightlifters endured the very high-volume training much better than expected. This indicates that the training capacity of adolescent weightlifters is greater than was originally thought.

■ What is the Hormonal Response of Adolescent Weightlifters During a Lifting Session?

The first research on hormonal responses of young males to a heavy lifting task suggested that adolescent males could not increase their natural levels of testosterone (5). When interpreting these data, however, it must be remembered that the hormonal response is highly dependent on the 5 acute training variables for resistance exercise (i.e., choice of exercise, order of exercise, volume of exercise, exercise load [relative intensity], and interset rest intervals) (16). As such, in hindsight, it is likely that the lifting stimulus was not adequate to elevate the hormonal concentrations. To further address this question, junior-aged weightlifters performed a standardized exercise and lifting protocol (15 vertical jumps, single repetitions of the snatch lift increasing to maximal capabilities, 3×10 snatch pulls at 60% 1 RM) (15). As a group, these adolescents exhibited typical hormonal levels for their age, which were indicative of their pubescent status. Immediately after the exercise stimulus, there was a significant increase in the circulating levels of testosterone, cortisol, and growth hormone, whereas the testosterone/cortisol ratio decreased. It thus becomes apparent that although these young lifters possess resting testosterone levels that are

lower than those of mature males, a proper exercise stimulus could indeed result in elevated hormonal responses.

It is not unreasonable to think that such elevations in the hormonal concentrations would result from most training sessions for elite weightlifters. Although resting levels of anabolic hormones are certainly critical, it is likely that such acute responses also contribute to the resulting training adaptations. Because elite competitors are often more experienced in their sport than are average competitors, it would be of interest to examine the role of training experience on the hormonal responses to weightlifting. Using the results reported by Häkkinen et al. (13), junior weightlifters were divided into highly experienced (>2 years) and less experienced (<2 years) groups. Greater training experience was accompanied by a greater testosterone response to a weightlifting task. It appears that as a lifter's training experience increases, so too does the potential to enhance the anabolic hormonal environment.

■ Increased Volume Training: Does it Help Future Training?

A commonly used training tactic is to prescribe high volumes of training for short periods of time. To study the long-term effects of such training methods, junior-aged weightlifters were monitored over the course of a year of training (9). At the beginning and end of this 1 year, the lifters performed a week of high-volume training (2–4 sessions/d). As with the previous studies, this training was performed under a highly controlled environment at the Olympic Training Center. During the year of training, all the lifters had in-

creased their 1RM capabilities for both the snatch and the clean and jerk. When their hormonal responses were analyzed, it was clear that they had been able to better tolerate the week of stressful training at the end of the year. Although the week of high-volume training was identical at both the beginning and the end of the year, the hormonal responses were not as adversely affected the second time around. The result was a more anabolic hormonal environment. These results were interpreted to suggest that the prior exposure to stressful training had developed a greater resilience to such training. Not only can high-volume training have an immediate effect on performances during the subsequent taper (gradual reduction in training volume) phase, but it can also have a long-term effect on one's capacity to perform such training on a regular basis. Of course, a coach or trainer must be careful about how often training of this type is administered, but it is evident that adolescent weightlifters can readily perform high volumes of training that can have long-term benefits.

■ Is Performance Related to Hormonal Levels?

Previous reports have indicated that changes in the hormonal environment in adult males are related to the actual changes in isometric strength (2) or competitive weightlifting performances (12). Specifically, such relationships were evident for the testosterone/cortisol and testosterone/SHBG ratios. These relationships appear to exist for adolescent weightlifters as well. Junior weightlifters who were participating at a 4-week training camp were divided into an elite group that was training for an up-

coming senior-level event (i.e., U.S. Olympic Festival) and the remainder of the lifters were classified as nonelite but were members of the Junior National Squad (8). Correlations were calculated between the changes in the testosterone/cortisol ratio and the changes in competitive performance. As with previous studies, the 4-week period was divided into high-volume training for the first week, followed by a taper where training volume returned to normal. During the high-volume week, the nonelite group exhibited a negative relationship between the changes in the hormonal ratio and the changes in the lifting performance ($r = -0.70$). During the ensuing 3 weeks, this relationship became positive ($r = 0.51$). Interestingly, the elite group demonstrated a different profile. During the high-volume week, there was no correlation between the changes in the hormonal ratio and the lifting performances ($r = 0.00$). But during the next 3 weeks of taper, there was a very high correlation between these 2 variables ($r = 0.92$). Taken in their entirety, these data suggest several critical possibilities. First, similar to what has been reported for mature adults, changes in the hormonal environment are related to changes in the lifting performance. It should be noted though that one must be careful when interpreting these data. Correlations such as these do not imply that changes in one variable necessarily cause the changes in the other variable. Secondly, the lack of any relationship for the elite group during the high-volume week suggests that these lifters better tolerated the stressful training compared with the nonelite group, at least as far as the hormonal data is concerned. Lastly, the elite

group responded in a more favorable manner to the training taper, as indicated by the very strong correlation.

■ So What are the Practical Implications?

The data reviewed herein have practical implications for training adolescents (Table 1). Beginning training at an age when the hormonal changes associated with puberty are present allows for the monitoring of training status and training stress through hormonal markers. Although actual monitoring of the testosterone/cortisol ratio may be unrealistic in most settings, the outcomes of the research performed on the junior-aged weightlifters may be applied to the training of adolescents in general.

The resistance training capacity for adolescents appears to be greater than once thought, and young males elicit similar hormonal responses to training as do mature adults. Among adolescent trainees, more accomplished lifters appear to better tolerate short periods of high-stress training, and prior weight-training experience results in an increased hormonal response to a single training session. Using periods of high-volume-load training can be a beneficial strategy for increasing performance with adolescents because they are better able to tolerate such training in the future. A taper phase seems to be more beneficial to those adolescents who have gone through previous high-volume-load phases. This short-term overreaching with adolescents seems to be as effective as with adults. Some findings support the contention that closely monitoring the lifting technique may also serve as an indicator of training stress in this population.

Table 1
Program Design Considerations for Young Weightlifters

- Skill acquisition can begin before puberty, with increased training volume when the hormonal environment begins to mature
- Pubescent males can experience increased acute hormonal responses to training as do adults
- Resistance exercise training capacity is greater than once thought for adolescents
- Prior weight-training experience may increase the hormonal response to a single training session
- Incorporating stressful phases of training (overreaching) may increase tolerance of such training in the future
- Changes in the hormonal profile of adolescents may reflect changes in performance
- More accomplished lifters appear to better tolerate stressful training
- More accomplished lifters appear to respond more favorably to a training taper
- Lifting mechanics and technique may be indicators of training stress

It is important to note at this point that many aspects of weightlifting and resistance exercise performance in general are not directly related to the hormonal environment, especially in the preadolescent. Weightlifting, as with many other sports and activities, requires gross and fine motor skills, flexibility, and other traits that can be trained even before an anabolic hormonal environment exists. Many neural adaptations do not appear to be hormone dependent and are very important for optimal performance. When acquired at an early age, these adaptations can put an individual in an optimal position to increase training volume and intensity as the individual matures. It is also critical to note that increases in training volume or intensity with children and adolescents should be carefully and cautiously administered. One cannot assume that just because a particular training strategy is effective with adults that it automatically is appropriate for younger lifters. Remember that excessive emphasis

on sport training with young athletes can contribute to ensuing burnout that alienates some individuals from continuing with their respective sports. Variety in training, even if specializing in one sport, can help to avoid burnout.

■ Summary

Whenever attempting to develop elite performers in any sport, it is critical to carefully prescribe the training stresses. This is just as important for junior-aged weightlifters as for mature weightlifters. It appears that the hormonal systems of pubescent weightlifters respond acutely to a single training session and that the training stresses of junior weightlifters are reflected in their hormonal responses. Junior lifters appear to tolerate carefully administered phases of stressful training and do so better with increased training experience and prior exposure to such training. More successful junior lifters also appear to respond more favorably to a precompetition training taper. Such information may help coach-

es develop training programs for young lifters at all levels of competition. ▲

■ References

1. Adlercreutz, H., M. Häkönen, K. Kuoppasalmi, H. Näveri, I. Huhtaniemi, H. Tikkanen, K. Remes, A. Dessypris, and J. Karvonen. Effect of training on plasma anabolic and catabolic steroid hormones and their response during physical exercise. *Int. J. Sports Med.* 7:S27–S28. 1986.
2. Alén, M., A. Pakarinen, K. Häkkinen, and P.V. Komi. Responses of serum androgenic-anabolic and catabolic hormones to prolonged strength training. *Int. J. Sports Med.* 9:229–233. 1988.
3. Boyar, R.M., R.S. Rosenfield, S. Kapen, J.W. Finkelstein, H.P. Roffwarg, E.D. Weitzman, and L. Hellman. Human puberty—Simultaneous augmented secretion of luteinizing hormone and testosterone during sleep. *J. Clin. Invest.* 54:609–618. 1974.
4. Calhoun, G., and A.C. Fry. Injury profiles of elite competitive weightlifters. *J. Athletic Trng.* 34(3):232–238. 1999.
5. Fahey, T.D., R. Rolph, P. Moungmee, J. Nagel, and S. Mortara. Serum testosterone, body composition, and strength of young adults. *Med. Sci. Sports* 8(1):31–34. 1976.
6. Fry, A.C., D. Ciroslan, M.D. Fry, L.T. Ramsey, and S. Chochon. Physical and performance variables discriminating between elite and non-elite junior-aged male weightlifters [abstract]. The National Strength and Conditioning Association Conference. Atlanta, 1996.
7. Fry, A.C., M.D. Fry, and D.

- Ciroslan. Variables discriminating between elite and non-elite junior-aged female weightlifters [abstract]. The American College of Sports Medicine Conference. Denver, 1997.
8. Fry, A.C., W.J. Kraemer, M.H. Stone, L.P. Koziris, J.T. Thrush, and S.J. Fleck. Relationships between serum testosterone, cortisol and weightlifting performance. *J. Strength Cond. Res.* 14(3): 338–343. 2000.
 9. Fry, A.C., W.J. Kraemer, M.H. Stone, B.J. Warren, S.J. Fleck, J.T. Kearney, and S.E. Gordon. Endocrine responses to overreaching before and after 1 year of weightlifting. *Can. J. Appl. Physiol.* 19(4):400–410. 1994.
 10. Fry, A.C., W.J. Kraemer, M.H. Stone, B.J. Warren, J.T. Kearney, C.M. Maresh, C.A. Weseman, and S.J. Fleck. Endocrine and performance responses to high volume training and amino acid supplementation in elite junior weightlifters. *Int. J. Sports Nutr.* 3:306–322. 1993.
 11. Fry, M.D., and A.C. Fry. Goal perspectives and motivational responses of elite junior weightlifters. *J. Strength Cond. Res.* 13(4):311–317. 1999.
 12. Häkkinen, K., A. Pakarinen, M. Alén, H. Kauhanen, and P.V. Komi. Relationships between training volume, physical performance capacity, and serum hormone concentrations during prolonged training in elite weightlifters. *Int. J. Sports Med.* 8(Suppl.):61–65. 1987.
 13. Häkkinen, K., A. Pakarinen, M. Alén, H. Kauhanen, and P.V. Komi. Neuromuscular and hormonal adaptations in athletes to strength training in two years. *J. Appl. Physiol.* 65(6):2406–2412. 1988.
 14. Judd, H.L., D.C. Parker, and S.S.C. Yen. Sleep-wake patterns of LH and testosterone release in prepubertal boys. *J. Clin. Endocrinol. Metab.* 44:865–869. 1977.
 15. Kraemer, W.J., A.C. Fry, B.J. Warren, M.H. Stone, S.J. Fleck, J.T. Kearney, B.P. Conroy, C.M. Maresh, C.A. Weseman, N.T. Triplett, and S.E. Gordon. Acute hormonal responses in elite junior weightlifters. *Int. J. Sports Med.* 13:103–109. 1992.
 16. Kraemer, W.J., L. Marchitelli, S.E. Gordon, E.A. Harman, J.E. Dziados, R. Mello, P.N. Frykman, D. McCurry, and S.J. Fleck. Hormonal and growth factor responses to heavy resistance exercise protocols. *J. Appl. Physiol.* 69: 1442–1450. 1990.
 17. Mero, A., K. Häkkinen, and H. Kauhanen. Hormonal profile and strength development in young weight lifters. *J. Hum. Mov. Stud.* 16:255–266. 1989.
 18. Mero, A., H. Kauhanen, E. Peltoja, and T. Vuorimaa. Transfer from prepuberty to puberty: Effects of three years of training. *J. Hum. Mov. Stud.* 16:267–278. 1989.
 19. Warren, B.J., M.H. Stone, J.T. Kearney, S.J. Fleck, R.L. Johnson, G.D. Wilson, and W.J. Kraemer. Performance measures, blood lactate and plasma ammonia as indicators of overwork in elite junior weightlifters. *Int. J. Sports Med.* 13:372–376. 1992.



Fry

Andrew C. Fry is an associate professor in Human Movement Sciences and Education and the director of the Exercise Biochemistry Laboratory at The University of Memphis.

Brian K. Schilling is a doctoral student in the Department of Biology and the research coordinator for the Excercise Biochemistry Laboratory at the University of Memphis.