Influence of Resistance Training on Anabolic Hormones in Pre-Pubertal and Pubertal Males

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Abstract

This review focuses on the hormonal responses to resistance training in pre-pubertal and pubertal males with the aim to elucidate possible mechanisms that may be responsible for the increases in strength and power following systematic training in these age groups. Studies that have controlled for the confounding effects of growth and motor skill acquisition, have shown that resistance training results in significant increases in muscular strength even before puberty. Although the training induced muscle hypertrophy in pre-pubescents is possible, it is much less compared that of post-pubescents. On the other hand an equal or greater improvement in neuromuscular activation, motor skill and intrinsic muscular adaptations are reported in the pre-pubescents compared to the post-pubescents following resistance training programs. Resting serum testosterone concentration has been found to increase following 2-12 month resistance training programs and this is accompanied with an increase in muscle strength. Changes in strength and hormonal concentrations depend on the characteristics of the resistance training program, with the most important being exercise intensity and volume.

Key Words: Growth Hormone, Testosterone, Children

Introduction

Resistance training for children and adolescents has been a topic of great interest among scientists, physicians, coaches, young athletes and their parents. The research conducted in this area during the last two decades has provided valuable information on the responses of the young organism to this type of training and has advanced our understanding on mechanisms responsible for these adaptations (*Falk and Tenenbaum, 1996*). This review focuses on the hormonal responses to resistance training in pre-pubertal and pubertal males with the aim to elucidate possible mechanisms that may be responsible for the increases in strength and power following systematic training in these age groups.

Effectiveness of resistance training in pre-pubertal and pubertal males

The participation of boys in resistance training programs leads to a positive influence on their fitness that results in an increase in sport performance and offers protection from sports injuries (*Kraemer-Fleck, 1993*). Resistance training in young boys also improves quality of life and contributes to positive attitude toward wellness and exercise (*Shephard, 1984*). One of the most important characteristics of resistance exercise programs for children must be safety. Emphasis should be placed on proper technique and sessions should be supervised by a qualified instructor. Exercise intensity and interval between exercises should be chosen according to the maturation level of the young athlete, but maximal loading should be avoided (*Bases, 2004*).

Heavy resistance exercise in adults' results in significant adaptive responses, including increases in strength and power and muscle hypertrophy that, are dependent on the type, intensity of loading and volume of training (*Fleck and Kraemer, 1987*). It is well known that in adults, the increases in strength during the early phase of training are attributed mainly to neural factors, but as training proceeds, there is a gradually increased contribution of muscular hypertrophy to the increases in strength (*Moritani, 1992*). The effectiveness of resistance training in children seems to be dependent primarily on the provision of a sufficient training intensity and volume and to a lesser degree on training duration, following the principle of specificity. Strength increases ranging from 5 to 50% have been reported using isometric, isotonic and isokinetic training methods involving high intensity loads (*Kraemer et al., 1989, Sale, 1989*). As training progresses there is an interaction between neural factors and muscle hypertrophy. In pre-pubescent children, neural factors would predominate, but as the child reaches puberty the growth and maturation related hormones favor muscle hypertrophy (*Kraemer et al., 1989, Sale, 1989*). The optimal combination of training method, mode, intensity, volume and duration of training for maximal strength gain during preadolescence however, has yet to be determined.

Irrespective of the mechanism responsible, muscular strength gains have been evident across all maturity stages, including pre-pubescents (*Nielsen et al., 1980, Weltman et al., 1986, Blimkie et al., 1989, Ramsay et al., 1990, Hassan, 1991, Fukunaga et al., 1992, Faigenbaum et al., 1993, Ozmun et al., 1994*), pubescents and post pubescents individuals (*Pheifer-Francis, 1986, Sailors-Berg, 1987, Sale, 1989*). Studies that have controlled for the confounding effects of growth and motor skill acquisition, have shown that resistance training results in substantial and significant increases in strength before puberty beyond what would occur due to the normal growth (*Nielsen et al., 1980, Weltman et al., 1986, Sailors-Berg, 1987, Hassan, 1991, Fukunaga et al., 1992, Ozmun et al., 1994,*). The trainability of strength during the post-pubertal period is a less contentious issue. Significant strength gains in this age group have resulted from isometric training, dynamic or isotonic weight training, isokinetic and hydraulic resistance training and appear to be directly related to training frequency (*Blimkie & Bar-Or, 1996*).

The conclusions from the studies which examine the effectiveness of resistance training during preadolescence compared to training during adolescence and adulthood are still debatable (*Nielsen et al., 1980, Pfeifer and Francis, 1986, Sailors and Berg, 1987, Sale, 1989*). Studies often suffer from methodological shortcomings, such as absence of a control group, inappropriate training program and lack of statistical power to allow for sound conclusions (*Falk and Tenenbaum, 1996*). Nevertheless, most, but not all, studies indicate that when the relative training loads are moderate to high and the groups are formulated according to distinct maturity levels, it appears that pre-pubescents are probably less trainable in terms of absolute strength, but equally if more trainable in percentage improvements compared to adolescents and adults (*Hakkinen et al., 1989, Sailors and Berg, 1987, Sale, 1989, Fukunaga et al., 1992*). Although the training induced muscle hypertrophy in pre-pubescents is possible (*Mersh and Stoboy, 1989, Fukunaga et al., 1992*), it is much less compared that of post-pubescents. On the other hand an equal or greater improvement in neuromuscular activation, motor skill and intrinsic muscular adaptations are reported in the pre-pubescents compared to the post-pubescents following resistance training programs. (*Blimke and Bar-Or, 1996*)

Hormonal mechanisms influencing gains in muscular strength

The pubertal growth spurt is influenced by the release of important hormones such as Growth Hormone (GH), insulin-like growth factor I (IGF-I) and steroid sex hormones that induce increases in growth velocity, bone and muscle maturation, functional ability and several metabolic adaptations (*Rogol, 1994*). These changes may influence the development of physical capacity and performance during childhood and adolescence. Adrenarche (as defined by synthesis and secretion of androgens when the adrenal zona reticularis matures) is characterized by a progressive increase in the secretion of adrenal hormones. The gonadarche (as defined by activation of the testes and ovaries at puberty) follows 2 to 3 years after this first stage and is under the control of GH, IGF-I and steroid sex hormones (Lee, 1995). The release of these hormones is controlled by the pulsatile stimulation of a hypothalamic gonadotrophin – releasing factor. The processes that initiate the onset and progression of human puberty are not completely understood. The dual role of the recently discovered hormone leptin, i.e. as a regulator of fat mass and as a metabolic signal to the reproductive axis, suggests that leptin may be a permissive factor responsible for the onset of puberty (*Matzoros et al., 1997*).

Increased plasma levels of GH, testosterone, estradiol and progesterone have an anabolic effect on structural protein production. The synergistic action of GH and gonadal steroids promotes the pubertal growth spurt mainly in bones and muscles and this may contribute to metabolic and hormonal responses of children and adolescents during exercise. (*Boisseau and Delamarche, 2000*). Such mechanisms appear to be operational in response to a training stimulus provided by heavy resistance exercise and could theoretically influence the growth and remodeling process of various body tissues over the course of a resistance training program.

The endocrine system of the body adapt to the repeated stimulation of exercise training by: a) altering the intensity of the exercise stimulus necessary to increase or decrease hormone secretion, b) altering the tissue responsiveness to the hormone. This is done by increasing or decreasing the number of circulating proteins that bind the hormone and protect it from degradation but also render it biologically inactive, as well as changing the number of cellular hormone receptors or post receptor function, and c) working through neuroendocrine adaptations to alter basal and maximal hormone secretion (*Roemmich, 2005*). The endocrine environment can have a profound impact on the adaptation process of skeletal muscle to resistance exercise and it is well known that acute as well as long-term resistance training activates a wide variety of neuroendocrine mechanisms (*Kraemer, 1988, Hakkinen, 1989, Kraemer, 1992a*).

Hormonal variables have also been used as indicators of the magnitude of training stress during resistance exercise and other forms of training (*Adlecreutz et al., 1986, Hakkinen et al., 1987, Fry et al., 1993*). It has been noted that chronic hormonal adaptations have been correlated to changes in muscular strength and power for competitive Olympic style weight lifters (*Hakkinen et al., 1987, Fry et al., 2000*), as well as to fiber type alterations in previously untrained men (*Staron et al., 1994*) and consequently, the various hormonal mechanisms probably respond differentially in trained and untrained individuals (*Hakkinen, 1989*).

Role of Testosterone

Testosterone (T), the male sex hormone, is considered to be an anabolic hormone and contributes also to metabolic control (*Viru and Viru, 2005*). The "free: or biologically available T hypothesis, supports the idea that only the free hormone is transported to the target tissues, suggesting that the level of free androgen index (FAI) may be of importance for trainability (*Kraemer et al 1990*). FAI is the ratio of the concentration of T and the sex hormone binding globulin (SHBG), and thus the amount of active T is determined by SHBG concentration (*Remes et al, 1979*). SHBG may also act as a hormone itself and may have a distinct biological activity, as also suggested for other binding proteins (*Rosner, 1991*). The SHBG declines progressively during pubertal phases in healthy boys (*Anderson, 1974*).

Exercise can acutely increase or decrease circulating T, depending on the mode and the intensity of exercise (*Schmid et al., 1982*). Increases occur during and after relatively short, high intensity work such as resistance training or sprint events, while declines are associated with increasing duration endurance events especially marathon and ultra running events (*Kuoppasalmi et al., 1980, Schurmeyer et al., 1984*). In resistance training, the main role of T is the induction of synthesis of contractile proteins in involved muscles. Beside that, during acute resistance exercises, as well as during competition, T action seems to be essential for mobilizing performance capacity (*Viru and Viru, 2005*). Although there is no evidence that T influences the neural adaptations in resistance training, essential is the influence of high preconditioning T levels on central nervous structures. (*Kurz et al., 1986, Araki et al., 1991, Matsumoto, 1992*)

The initial report of *Fahey et al., (1976)* supports the possibility that resistance training may alter hypopituitary axis in younger males. However, studies on the responses of T to resistance training of young males have only recently appeared in the literature (*Kraemer et al., 1989*). The effect of the increase in T in growing individuals due to resistance training on growth and development remains to de studied.

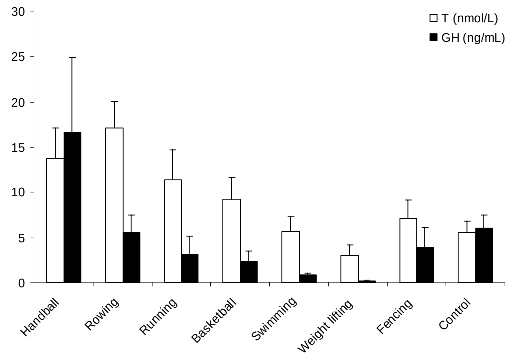

Figure 1. Resting testosterone (T) and growth hormone (GH) in pre-pubertal male athletes of different sports and in non-athletes (Control). Modified with permission from Tsolakis et al. 2003, Hormones: 2(2): 103-112

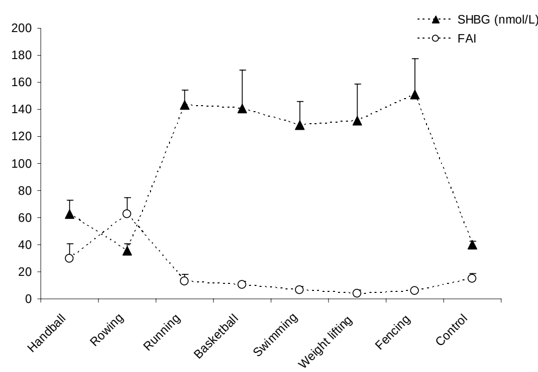

Figure 2. Sex hormone binding globulin (SHBG) and free androgen index (FAI) in pre-pubertal male athletes of different sports and in non-athletes (Control). Modified with permission from Tsolakis et al. 2003, Hormones: 2(2): 103-112

Role of Growth Hormone

Growth hormone (GH) has been linked to the promotion of anabolism in both muscle and connective tissue. Specifically, it enhances cellular amino acid uptake and protein synthesis in skeletal muscle, resulting in hypertrophy of both muscle fiber types (*Crisis et al., 1991*). The anabolic effects of GH result from direct and indirect interactions with androgens (*Jorgensen et al, 1996*), and thyroid hormone (*Weiss and Refetoff, 1996*) and are mediated via IGF-I (*Florini et al., 1996*) The complexity of pituitary production and release of GH and binding proteins is just beginning to be elucidated (*Nindl, 2003*). It appears that GH responses depend upon type, load and volume of exercise. This suggests that a threshold exist for intensity of exercise to elicit a significant response of the hypopituitary axis to resistance exercise (*Kraemer, 1992*). Activation of a relatively large muscle mass also appears to be a vital element of the exercise stimulus to elicit a significant GH response. Resistance exercise workouts that have short rest periods (1 min rest between sets and exercises, moderate-to-high intensities (load: 8-12 RM) and whole body workout protocols (8-10 exercises) results in the highest GH changes in the blood (*Kraemer et al., 1990, 1991, Hakkinen and Pakarinen, 1995, Roemmich and Rogol 1997, Hansen et al., 2001*). Surprisingly, no changes in the resting concentrations of GH have been observed in response to short periods of resistance training in young untrained men (*Kraemer et al., 1998, Kraemer et al., 2005, Hansen et al., 2001*) or even long term trained weight lifters (*Hakkinen et al., 1988, Ahtianen et al., 2003*) at various ages (*Kraemer et al., 1999, Mc Call et al., 1999, Hakkinen et al., 2000*). The response of GH to exercise in children seems to be related to the pubertal and maturity stage of the individual (*Bouix et al., 1994, Marin et al., 1994, Wirth and Gieck, 1994*). Most studies in children and adolescents report resting plasma GH levels (*Caccciari et al., 1990, Mero et al., 1990, Zakas et al., 1994, Tsolakis et al., 2003a,b, 2006*), while there is a scarcity of data for the GH responses to exercise (*Adiyaman et al., 2004; Eliakim et al., 2006*).

Influence of resistance training on T, GH and neuromuscular performance in pre-pubescent, pubescent and adolescent individuals

Since resistance training appears to increase strength in all ages, there appears to be some rationale for recommending resistance training as a means of improving sports performance even during preadolescence. There is insufficient evidence to state unequivocally that resistance training will have a positive effect on sports performance during preadolescence (*Blimkie, 1993*). Improvements in sport performance during preadolescence after different forms of resistance training have also been inferred from more indirect evidence, e.g. improvement in vertical jumping performance (*Mero et al., 1989, 1990a, b, Tsolakis et al., 2003a, b, 2006 in press*). However, even though there is a positive correlation between motor fitness and sports performance the results do not provide unequivocal evidence of a positive effect of resistance training on sports performance during preadolescence years.

The influence of various forms of sports training on the endocrine system has been studied mainly in adults involved in heavy training (*Kraemer and Rogol, 2005*). In fact there are very few data on the relationship between exercise and hormonal levels related to growth and maturation in sedentary pre-pubertal, pubertal and post-pubertal children (*Fahey et al., 1976, Zakas et al., 1993, Tsolakis et al., 2000, 2004*). On the other hand more data exist for athletes in the pre-pubertal (*Mero et al., 1989,1990,a,b, Cacciari et al., 1990, Dally et al.,1998, Tsolakis et al., 2006*) and post-pubertal period (*Fry et al., 1993 Steinacker et al., 1993, Kraemer et al., 1992c, Gorostiaga et al., 1999, 2003*).

Specifically T and FAI mean values have been reported to increase (*Mero et al., 1990, Zakas et al., 1994, Tsolakis et al., 2000, 2004, 2006*), or remain stable *Dally et al., (1998)* following two months to one year training. Some of these studies reported conflicting data on GH levels (*Mero et al., 1990a, b, Zakas et al., 1994, Tsolakis et al., 2006*). However most of these studies have suffered from methodological problems such as the use of small samples sizes that limit their external validity. The impact of acute exercise on the hypopituitary axis of youth has not been widely studied and there is not enough data to draw safe conclusions (*Kraemer et al., 1992b*).

Effects of short and long term resistance training

The effects of short term (2 months) resistance training on hormonal concentrations has been examined in two groups of untrained pre-pubertal and pubertal boys (*Tsolakis et al., 2000*). The mean post - training T concentration of the pre-pubertal group increased by 123%, whereas the respective increase in the pubertal group was 32% (*Tsolakis et al., 2000*). Another study published recently (*Tsolakis et al., 2004*), investigated the influence of two months of resistance training followed by two months of detraining on strength adaptations and selected hormones (T, SHBH) in sedentary pre-pubertal boys. Significant post training isometric strength gains (17.5%) and increases in T and FAI ($p<0.05$-0.001) were observed in the experimental group. Detraining resulted in a significant loss (9.5%, $p<0.001$) of isometric strength whereas the hormonal parameters remained unchanged. The resistance training-induced strength changes were not correlated with changes in the anabolic and androgenic activity. Similar results were observed after six weeks of heavy resistance training in the dynamic strength of upper extremity (23%) and leg extensors (12%) in male 14-16 year old handball players. Moreover a significant increase was observed in throwing velocity in the resistance training group. Muscle hypertrophy did not accompany the strength gains, suggesting specific neurological adaptations (*Gorostiaga et al., 1999*).

The addition of either high or mild intensity cycloergometer training to three month sessions whole body calisthenics significantly increased T and GH levels in pubertal and post-pubertal sedentary boys but not in the pre-pubertal group (*Zakas et al., 1994*). An intensive gymnastic training program (3 h per day) performed by preipubertal male gymnasts was not adequate to alter serum T concentrations over a 10 month period. A possible explanation for this result is that the gymnasts were well adapted to the training (*Daly et al., 1998*). On the other hand, eleven weeks of soccer training combined with a program of explosive strength training resulted in significant increases in vertical jumping performance (14%) and in resting total T concentrations (7.5%) without any significant correlations between changes in performance and T (*Gorostiaga et al., 2003*).

The mean serum testosterone concentration increased significantly after 1 year of specific training in four groups of pre-pubescent athletes (sprinters, tennis players, weight lifters and endurance runners), while GH remained unaltered. Additionally the experimental group increased speed and speed strength. Significant correlations were observed between the relative changes in testosterone, GH and the relative changes in speed. The increased anabolic activity had positive effects on physical performance and trainability at the early stages of puberty (*Mero et al., 1990*).

Influence of specific sports training on hormonal levels

There is a scarcity of data regarding the effects of specific sports training on hormonal levels in young athletes. *Mero et al., (1989),* compared the neuromuscular, metabolic and hormonal profiles of trained pre-pubescent tennis players and an untrained group. Drop jump height was significantly greater ($p<0.05$) in the tennis players than in the control boys. However, there were non significant differences between the group serum hormone levels (*Mero et al., 1990*). Plasma levels of T, SHBG and GH were not different between of junior weight lifters, endurance and sprint runners. Interestingly, T concentration was significantly correlated with jumping performance. It was suggested that the training background and the advanced biological maturation of the athletes affected their strength capacity (*Mero et al., 1990*).

Significant differences were observed in plasma levels of dehydroepiandrosterone sulphate (DHEA-S) and T between pre-pubescent and pubescent football players and untrained controls (*Cacciari et al., 1990*). Plasma levels of T were significantly lower in the pre-pubescent group of athletes and significantly higher in the pubescent group compared to those of the controls. The higher values in pubertal subjects were justified by their advanced maturation level compared to controls, while in pubertal subjects training may produce a decrease in plasma T as in adults (*Lauro et al., 1984, Hackney et al., 1988*).

Tsolakis et al., (2003b) demonstrated the effects of the specificity of training stimulus on the hormonal adaptations among pre-pubertal athletes of different sports. Figures 1 and 2 show the basal concentrations of T, GH, SHBG and FAI in 11-13 years old athletes of various sports (handball, rowing, running, basketball, swimming, weight-lifting and fencing), compared with a control group of untrained children. As can be seen, there are differences in hormonal concentrations between sports, probably because of differences in the content of training programs. The low T and GH in the weight lifting group was not expected, but may possibly be explained by their lower level of maturation compared to the other groups.

Hormonal indices of overtraining and overreaching in young athletes

As also observed in adult studies, the impact of very intense short duration in adolescent athletes of various sports result in significant hormonal changes, indicating a state of overreaching (*Fry et al., 1993, Steinacker et al., 1993, Gorostiaga et al., 1999*). Seven days of high volume resistance training sessions resulted in significant decreases in post exercise T levels in 28 junior elite weight lifters, indicating an impending overtraining syndrome (*Fry et al 1993*) since the high load of training may elicit an excessive endocrine demand in post-pubertal handball players (*Gorostiaga et al., 1999*). Significant increases in T and GH were reported after an acute weight lifting program in the most experienced athletes of the same study, suggesting that training experience in elite adolescent weightlifters is most influential on the hypopituitary-gonadal training adaptations (Kraemer et al., 1992c). T and free T significantly decreased by 20 and 22% ($p<0.05$) after 16 days of high volume intensive rowing training in adolescent rowers. When the training volume decreased by 24% and the intensity was more than double T and free T increased significantly by 23 and 34.5% ($p<0.05$) respectively (Steinacker et al., 1993).

Conclusions

The bulk of the available evidence would suggest that resistance training in children may result in an increase in hormones influencing anabolic activity and has a positive effect in physical performance and trainability even at the early stages of puberty. However, these changes are not always evident, probably due to the different characteristics of the resistance training programs across studies. It seems that there is an "intensity and volume threshold" of resistance training in order to have changes in hormonal concentrations that override the rapid growth process of puberty. Further longitudinal studies are needed to examine the influence of resistance training programs on the mechanisms that control growth and maturation.

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