***Pediatric Exercise Science*, 2016, 28, 580-587**
http://dx.doi.org/10.1123/pes.2016-0070

Human Kinetics
ORIGINAL RESEARCH

The Effect of Steroid Hormones on the Physical Performance of Boys and Girls During an Olympic Weightlifting Competition

Blair Crewther and Zbigniew Obminski
Institute of Sport - National Research Institute

Christian Cook
Bangor University

Purpose: To examine the steroid hormone effect on the physical performance of young athletes during an Olympic weightlifting competition. ***Methods***: 26 boys and 26 girls were monitored across 2 weightlifting competitions. Pre- and post-competition testosterone (T), cortisol (C) and dehydroepiandrosterone-sulfate (DHEA-s) were measured in blood, with pre-event free T (FT) and the free androgen index (FAI) calculated. Body mass (BM) and weightlifting performance were recorded. ***Results***: The boys had a larger BM, superior performance with more T, FT and a higher FAI than girls ($p < .01$). Although C (32%) and DHEA-s (8%) levels were elevated across competition, no sex differences in hormone reactivity were seen. In boys, DHEA-s correlated with performance ($r = .46$), but not after controlling for BM ($r = .14$). For girls, T correlated with performance ($r = -0.51$) after BM was controlled. ***Conclusions***: The sex differences that emerge during puberty were observable, whereby the boys were larger and stronger with a more anabolic profile than girls. Individual DHEA-s (boys) and T (girls) levels were related to performance, but BM appeared to be acting as a mediating (boys) or suppressing (girls) variable. This adds new insight regarding the hormonal contribution to competitive performance in young athletes.

Keywords: androgen, adrenal, neuromuscular, maturation, strength

Puberty is an important developmental period characterized by rapid changes in body size, shape, and composition, all of which are sexually dimorphic (35). Under the influence of testosterone (T) and other growth factors, boys experience a significant increase in bone and muscle size, along with a reduction in body fat (35,36). Conversely, girls exhibit much smaller skeletal and muscle growth, whereas body fat increases (35,36). Temporal differences also exist, such that girls start and finish each pubertal stage before boys (35). Changes in cortisol (C) availability during this period, and in later life, can potentially support muscle growth via different metabolic processors (6). Dehydroepiandrosterone-sulfate (DHEA-s) is another important steroid, acting as a precursor to other classes of steroid hormones (e.g., androgens, estrogens) (27) that facilitate these developmental changes.

Individual differences in many hormones (e.g., T, DHEA-s, T/C ratio) are also related to physical performance in athletic boys (1,9,30,31). Likewise, training studies on young athletes have demonstrated associations between the individual changes in hormones and subsequent physical adaptation (18,21,33). Similar cross-sectional and longitudinal results were found in healthy boys and girls (34,36), but the T relationship with muscle strength was stronger for boys than girls (34) and T was an additional predictor of strength (along with height and weight) in boys, but not girls (36). Since hormones exhibit large individual variability at rest (14,15) and in response to exercise (6), these results could potentially reflect genetic differences in trainability and adaptability (6). These findings suggest that individual variation in steroid production, which overlaps larger developmental changes, could provide another mechanism to regulate the physical abilities of young athletes.

Hormone dynamics have been studied in children and adolescents during actual sporting competition (e.g., taekwondo, tennis, golf; 2,3,17,24,25), but this work focused primarily on C and typically as a dependent variable, rather than a predictor of physical performance.

Crewther and Obminski are with the Institute of Sport -National Research Institute, Warsaw, Poland. Cook is with the School of Sport, Health and Exercise Sciences, Bangor University, Bangor, Wales. Address author correspondence to Blair Crewther at blair.crewther@gmail.com.

Nevertheless, these studies confirm that sporting competition is inherently stressful and complex, thereby promoting a divergent hormonal profile from that achieved under testing and training conditions (17,25), which might then influence the expression of athletic performance and any subsequent hormonal linkage (7,32). To our knowledge, no research has investigated the T, C and DHEA-s responses of adolescents across a sporting competition and their relationship to a key performance outcome. Sex comparisons would add further value, as a framework to examine male to female differences in body size, anabolic hormones and muscle strength (34,36), but in a cohort of athletes within a competitive setting.

To determine the physiological significance of hormones in sport and exercise, one must first verify the mechanism/s at play. The traditional perception is that steroid hormones like T, C and DHEA-s are regulating human performance via a body size or body composition effect (6,35). This is however too simplistic given that T and C can influence many neuromuscular outputs important to force production and athletic performance (e.g., emotions, behavior, second messenger signaling, neurotransmitter release, neural drive), coupled with varying time scales reflective of both genomic and nongenomic pathways (6). Surprisingly, few hormonal studies on adolescents have adjusted performance for body mass (BM), an indicator of body size, as the first logical step toward delineating the most widely accepted mechanism of the hormonal effect. Addressing this issue and the others outlined would provide new insight regarding the hormonal contribution to competitive performance in young athletes.

This study examined the steroid hormone effect on the physical performance of boys and girls during an Olympic-style weightlifting competition. Olympic weightlifting is a strength and power sport involving 2 multijoint, whole-body exercises; the snatch and clean and jerk (CJ) (40). We first compared the competition profiles of boys and girls, in terms of BM, pre-competition hormones, hormone reactivity across competition and weightlifting performance. Next, exploratory testing of the BM, hormonal and performance relationships was conducted separately for boys and girls. We hypothesized that; (i) the boys and girls would exhibit differences in T, BM and performance; (ii) competition would elevate T, C and DHEA-s levels, but with similar relative changes in both sexes; (iii) T and DHEA-s would correlate with BM and performance, but the relationships would be stronger for boys than girls; (iv) controlling for BM would weaken or remove the hormone-performance relationships.

Materials and Methods

Participants

A cohort of 52 (boys $n = 26$, girls $n = 26$) youth Olympic weightlifters volunteered for this study, with participant age ranging from 14.1 years to 17.8 years. All youth weight classes for boys (50 kg to 94 kg+) and girls (44 kg to 69 kg+) were represented within this cohort, producing a BM range from 41 kg to 116 kg. The athletes were considered to be highly trained, based on their participation in National and/or International competitions. Prescreening indicated that the participants had no injuries, medical issues or health conditions that would influence the study outcomes. Likewise, no athletes reported taking any drugs, medicines or anabolic doping agents. The athletes were routinely tested for doping substances. The girls were further questioned about contraceptive use (e.g., implants, contraceptive pills), but none were reported. All females were menstruating and they reported normal cycles of between 26–32 days. We did not strictly monitor each cycle phase, as several hormones relevant to this study and muscle strength do not appear to be influenced by the menstrual cycle (13,16). Participant and parental consent were given before the study commenced and ethical approval was provided by an Institutional Ethics Committee.

Experimental Design

A descriptive, cross-sectional design was employed to address the study hypotheses. The athletes were monitored across 2 National Olympic weightlifting championships held in November 2008 (boys $n = 14$, girls $n = 14$) and November 2009 (boys $n = 12$, girls $n = 12$). Each event lasted 2–3 days with all weight classes assessed over this period. Both events were conducted at the same time of day (3–8 p.m.), thereby reducing the influence of circadian variation in hormones and performance (20,27). Blood samples were taken pre- and post-competition to assess T, C and DHEA-s. To better characterize the hormonal milieu, pre-competition measures of sex hormone binding globulin (SHBG), free T (FT) and the free androgen index (FAI) were also taken or calculated. The loads lifted during the snatch and CJ exercises were recorded, as the primary reference for physical performance. Data from the 2 competitions were pooled for analysis. To ensure the athletes were in peak physical condition, a standard periodisation cycle comprising of 4–8 days of reduced training volume and/or intensity, followed by 1–2 days of rest or light exercise, was used before each event.

Competition Monitoring

The monitoring schedules were similar for all athletes on the day of competition. After waking between 7 a.m. and 9 a.m., the day started with a self-selected breakfast with lunch consumed around midday, after which the athletes traveled to the event location to being the registration process around 2 hr before event commencement. Once registered, BM was measured (to the nearest 0.01 kg) using digital scales. Before testing, a 20-min warm-up was performed in a designated area comprising of lifting incremental loads (up to 90% of their first attempt) for the snatch exercise. The competition began with the snatch exercise followed by a 10-min break, allowing for a further warm-up, before resuming with the CJ. Both exercises were performed on a raised platform in front of an audience, so any additional environmental stress would be comparable between athletes and competitions. No specific arousal techniques were employed before, or during, these competitive efforts apart from verbal support from the coaches and spectators (27). The participants were instructed to get at least 7 hr of sleep before their event and to maintain their normal dietary intake across the day, so there would be no interference with their normal competition routines. Water was taken ad libitum, but sports drinks were avoided until all samples were collected.

Physical Performance Assessment

During an Olympic weightlifting competition, the athletes have 3 attempts per exercise at progressively heavier loads, with the aim to produce a maximal lift on the last attempt. The highest load lifted (i.e., 20-kg Olympic bar plus additional free weights and collars) and judged to be a successful attempt by 2 independent referees was recorded. A combined total was calculated based on the best successful attempts for each exercise (7). To account for body-size differences between males and females (34), as well as BM differences between weight-class athletes, each performance outcome (i.e., snatch, CJ, total) was also normalized using an isometric scaling procedure. In other words, the load lifted (in kg) was divided by individual BM (in kg) (34,39). The test-retest assessment of the 2 Olympic exercises are highly reliable in trained weightlifters with coefficients of variation (CV's) of 2.3–2.7% (28).

Hormone Assessment

Capillary blood samples (~0.2 mL) were taken from the ear-lobe immediately before the snatch warm-up (i.e., 20–25 min before competition) and within 5 min of the last CJ attempt (i.e., 65 min at the end of competition), equating to ~90 min between the pre- and post-competition samples. The samples were collected in sterile vacutainers, after which the serum portion was separated by centrifugation and stored at -80 °C to be tested within a 30-day period. The samples were tested in duplicate using immunoassay kits (DRG, Germany). The lower detection limit for the T, C, DHEA-s and SHBG kits were 0.69 $\text{nmol}\cdot\text{L}^{-1}$, 5.5 $\text{nmol}\cdot\text{L}^{-1}$, 0.05 $\text{mmol}\cdot\text{L}^{-1}$ and 4 $\text{nmol}\cdot\text{L}^{-1}$, respectively. The interassay kit CV's were less than 6% (based on low and high control samples in each assay plate) and each athlete's blood samples were tested within the same assay run (either in 2008 or 2009) to eliminate interassay variation. The kits from the same manufacturer were used each year, with no modifications over the 12-month period. The T/SHBG ratio (multiplied by 100) was also calculated, but more commonly referred to as the FAI (41). In addition, the T and SHBG data were combined to estimate FT concentrations (in $\text{pmol}\cdot\text{L}^{-1}$) using a validated empirical algorithm, where $\text{FT} = 24.00314 \times \text{T}/\text{Log10(SHBG)} - 0.04599 \times \text{T}^2$ (37).

Statistical Analyses

Following normality testing, some variables (i.e., SHBG, FT, FAI) did not meet the assumptions of normality and thus, were log transformed before analysis to normalize data distribution (20). To aid interpretation and study comparisons, these measures are presented back-transformed in their original units. The demographic, performance and pre-competition steroid profiles of boys and girls were compared using unpaired T-tests. A 2-way (Sex, Time) analysis of variance was used to examine the pre- to post-competition changes in T, C and DHEA-s. Effect sizes (ES) were computed using Cohen's d. Partial correlations were applied to assess the interrelationships between BM, hormones and weightlifting performance, while controlling for age and BM as possible covariates (1,10). This analysis was conducted separately for boys and girls. The combined total was chosen as the dependent variable, as it strongly reflects ($r > .97$–0.99) both snatch and CJ performance and ultimately determines the athlete's placing in their weight class (40). All pre-competition hormones were included as independent variables, but we omitted the post-competition measures of T, C and DHEA-s to reduce multicollinearity. All data were analyzed using Genstat statistical software (Version 18.0). Significance was set at an alpha level of $p \leq .05$.

Results

The demographic and performance results are shown in Table 1. To aid comparisons, the female data are expressed as a percent (%) ratio of the male data. Both groups were of similar age ($p = .889$, Table 1), but the boys were significantly heavier ($p = .002$, ES = 0.9) with a BM ratio of 81%. The boys were also stronger than the girls during the snatch and CJ exercises ($p < .001$, ES = 2.6), thereby producing a higher combined total ($p < .001$, ES = 2.6) and a corresponding strength ratio of 59%. The sex differences in weightlifting ability were reduced when normalized for BM ($p < .001$, ES = 2.2–2.3), producing a strength ratio of 72%. Compared with the gold medallists at the 2009 World Youth Championships (after data were aggregated across all weight classes), the combined and normalized totals for males and females represented about 76–79% of the male winners (293 kg, 3.92 $\text{kg}\cdot\text{kg}^{-1}$) and 64–66% of the female winners (199 kg, 3.47 $\text{kg}\cdot\text{kg}^{-1}$), respectively, from this event. These results suggest that the monitored groups were, on average, close to world championship level.

The girls presented higher SHBG levels (47.9 ± 33.3 $\text{nmol}\cdot\text{L}^{-1}$) than the boys (26.0 ± 13.7 $\text{nmol}\cdot\text{L}^{-1}$) before the competition ($p = .001$, ES = -1.0), whereas the boys had more FT (283 ± 128 $\text{pmol}\cdot\text{L}^{-1}$) and a higher FAI (81.4 ± 59.8) than the girls (FT = 27.5 ± 12.7 $\text{pmol}\cdot\text{L}^{-1}$; FAI =

Table 1 Demographic Profiles and Olympic Weightlifting Performance in the Adolescent Boys and Girls (Means ± *SD*)

Variables	Boys (*n* = 26)	Girls (*n* = 26)	Ratio (%)
Age (years)	16.5 ± 1.10	16.5 ± 0.88	100
BM (kg)	73.3 ± 18.8$^{\#}$	59.2 ± 11.6	81
Snatch (kg)	99.5 ± 19.1$^{\#}$	58.3 ± 11.9	59
Snatch/BM (kg·kg^{-1})	1.38 ± 0.19$^{\#}$	0.99 ± 0.17	72
CJ (kg)	123.3 ± 23.6$^{\#}$	72.6 ± 13.8	59
CJ/BM (kg·kg^{-1})	1.71 ± 0.23$^{\#}$	1.24 ± 0.20	72
Combined total (kg)	222.9 ± 42.4$^{\#}$	130.9 ± 25.5	59
Combined total/BM (kg·kg^{-1})	3.10 ± 0.41$^{\#}$	2.23 ± 0.36	72

Note. BM = body mass, CJ = clean and jerk. Significant from girls $^{\#}p < .01$

5.50 ± 5.11) at this time point ($p < .001$, ES = 4.0–4.9). When expressing the female hormone and binding protein values as a percent of the male results, the following ratios were established; T (11–13%), C (103–114%), DHEA-s (93–95%), SHBG (184%), FT (10%) and FAI (7%).

The analysis of pre- and post-competition hormones revealed a sex effect on T concentrations ($p < .001$, Figure 1A) with the boys exhibiting higher T levels than girls (ES = 2.7), but no significant time or sex × time interactions were identified for this variable. A significant ($p < .001$) time effect emerged when assessing both C (Figure 1B) and DHEA-s (Figure 1C) with a 32% elevation in C from pre to post event (ES = 0.9) and an 8% elevation in DHEA-s ($p < .001$, ES = 0.2). No other significant effects or interactions were seen for the C and DHEA-s measures. To highlight subject variability, the individual hormonal changes across the weightlifting competition are shown separately for boys and girls in Figure 2A, 2B, and 2C.

The correlational results are presented in Table 2. In boys, BM and the combined total were strongly and positively related before, and after, the age adjustments ($p < .001$). Pre-competition DHEA-s levels were also positively related to BM and the combined total before, and after, age was controlled ($p < .018$). However, the DHEA-s and performance association was removed after controlling for BM ($p = .516$). Like boys, the BM of girls was positively correlated with the combined total before and after the age adjustments ($p < .003$), but of moderate strength. For girls, pre-competition T and FT were both positive correlates of BM with and without the age adjustments ($p < .034$). Although no hormonal variables correlated with the combined total in girls, pre-competition T was negatively related to weightlifting performance after BM was controlled ($p = .009$).

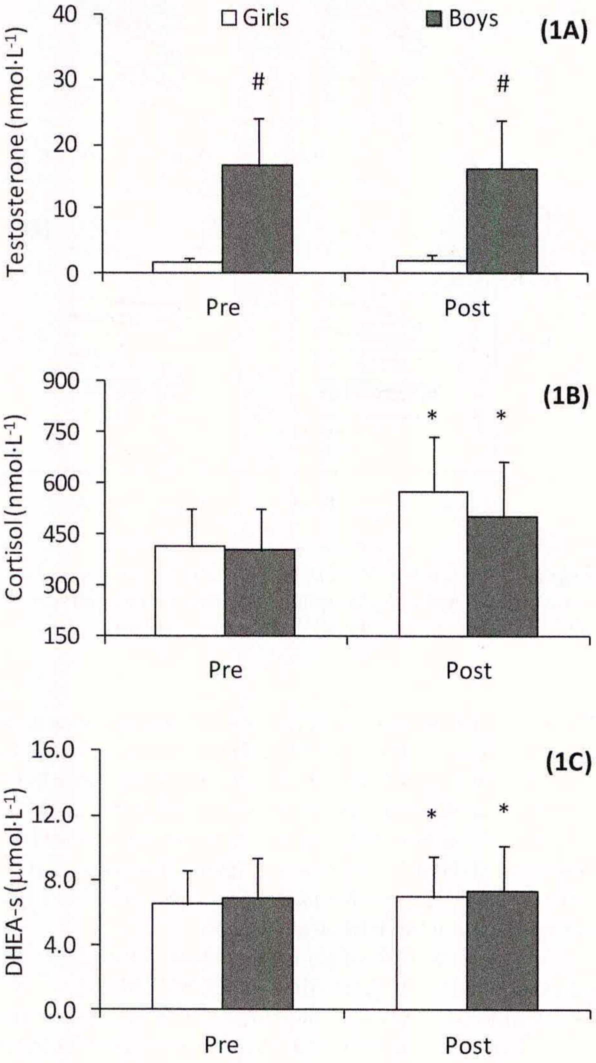

Figure 1 — Pre- and post-competition blood testosterone (1A), cortisol (1B) and dehydroepiandrosterone-sulfate (DHEA-s) (1C) concentrations in the adolescent boys and girls (means ± *SD*). Significant from pre-competition $^{*}p < .01$, Significant from girls $^{\#}p < .01$.

Discussion

The monitoring of young athletes across a weightlifting competition provided new insight regarding steroid hormone activity and links to physical performance. The

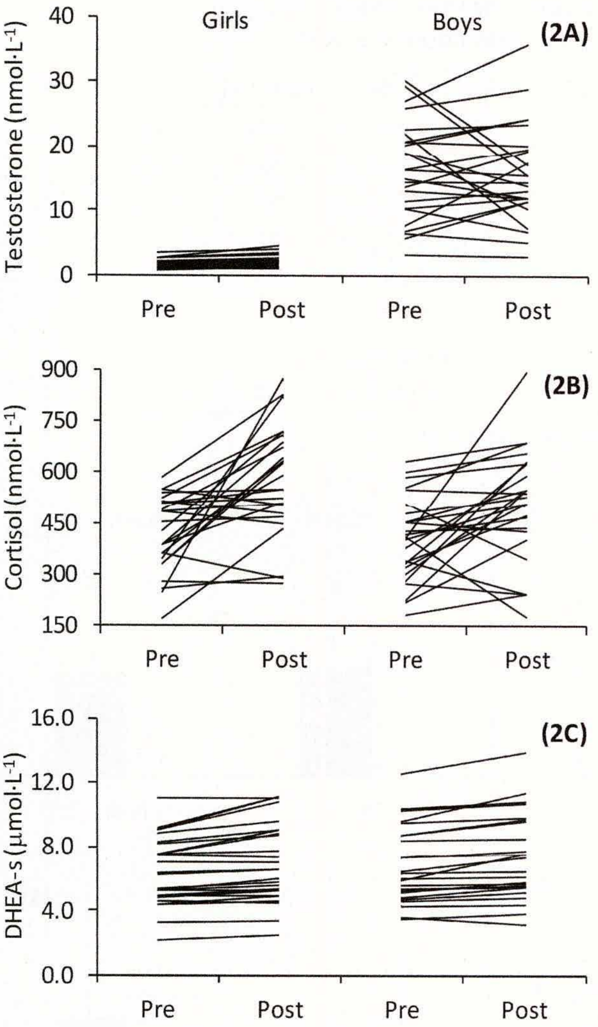

Figure 2 — Individual changes in blood testosterone (2A), cortisol (2B) and dehydroepiandrosterone-sulfate (DHEA-s) (2C) concentrations in the adolescent boys and girls.

boys and girls presented different BM, performance and hormonal (i.e., T, FT, FAI, SHBG) profiles in a competitive sport setting. The C and DHEA-s measures were both elevated across competition, whereas T did not change. We found no sex differences in hormone reactivity. Individual DHEA-s (boys) and T (girls) levels correlated with weightlifting performance, but these relationships depended upon the BM adjustments.

The boys were stronger than girls on all weightlifting outcomes and likely due to their larger BM (34,36), which infers more lean muscle and force-generating potential (40). The positive BM and performance correlations in this and other work (1,9) support this claim. Other factors contributing to superior weightlifting abilities among males include having a greater proportion of lean muscle (40) and, possibly, preferential hypertrophy of those muscle groups (e.g., quadriceps femoris) and fibers (e.g., Type IIA) required for weightlifting (19,22). The boys were also lifting 1.4 kg (snatch) and 1.7 kg (CJ) per unit of BM, similar to other junior weightlifters (18), and more than the girls (1.0 kg and 1.2 kg). This disparity in normalized performance indicates that other body-size independent factors (e.g., muscle fiber quality, neural inputs to muscle) are contributing to sex differences in muscle strength (40). Overall, the absolute (59%) and normalized (72%) strength ratios in this work are consistent with reports on adult Olympic weightlifters (5,7,39) and younger nonathletes (34,36).

The finding of sex differences in T, FT and SHBG (and thus FAI) concentrations are consistent with the literature (14,15,34), whereas the levels of C and DHEA-s are similar for both sexes (14). The blood hormone values in this study also lie within the wide reported range for boys (T = 0.5–30.2 nmol·L^{-1}, C = 215–662 nmol·L^{-1}, DHEA-s = 0.7–12.6 mmol·L^{-1}, SHBG = 10.1–73.8 nmol·L^{-1}) and girls (T = <0.5–4.1 nmol·L^{-1}, C = 223–662 nmol·L^{-1}, DHEA-s = 1.2–14.7 mmol·L^{-1}, SHBG = 14.7–91.2 nmol·L^{-1}) in a similar age bracket (14,15). The calculation of FT and the FAI produced a large range for boys (FT = 6.4–680 pmol·L^{-1}, FAI = 0.7–299) and girls (FT = 6.1–83.5 pmol·L^{-1}, FAI = 0.5–27.9), which is comparable to the current results. Our findings confirm the emergence of sexually dimorphic trends during pubertal development, whereby body size, muscle strength and anabolic hormones all increase dramatically, but more so for boys than girls (34–36).

The weightlifting competitions promoted a rise in athlete C (32%) and DHEA-s (8%) levels, similar to that observed in adult power-lifters (26,27). Studies on adult Olympic weightlifters also reported a large pre-event rise in C levels (> 100%) before an event (7,32). The C responses of young athletes in other sports (e.g., taekwondo, golf and tennis) are conceptually similar (2,3,17,24,25), although the timing and magnitude of the C changes varied with the type of sport played, whether it was practice or a real event, and the outcome achieved. Thus, exposure to various physical and psychological stressors on the day of competition appears to be driving the responses of these adrenal hormones. Conversely, T levels did not change across this study. This could reflect the low volume of exercise performed, long recovery periods and/or the training experience of subjects (4), along with individual variability in the T responses to competition (see Figure 2). Weightlifting studies on adults partly corroborate our findings (26,27,32), but we are unaware of any comparable data on adolescent athletes.

We found no sex differences in the T, C and DHEA-s responses to competition. Some studies have reported different C responses for boys and girls, in terms of absolute concentrations and the timing of these responses across competition (3,25); however, interpretation of this work is limited by group size (n = 6–10) and the lack of other steroid measures. When examining hormone reactivity in a competitive setting, the nature of the sport played requires some consideration. Olympic weightlifting is a unique sport in that exercise volume and intensity are relatively consistent in a competition (i.e., 6 repetitions

Table 2 Pearson and Partial Correlations Between Body Mass, Pre-Competition Hormones, and Olympic Weightlifting Performance in the Adolescent Boys and Girls

		BM		Combined Total		
Sex	**Variables**	**Zero-order**	**Controlled for age**	**Zero-order**	**Controlled for age**	**Controlled for BM**
Boys	BM	NA	NA	**0.79**	**0.81**	NA
	T	0.13	0.12	0.07	0.06	-0.05
	C	-0.10	-0.17	0.06	-0.10	0.24
	DHEA-s	**0.49**	**0.50**	**0.46**	**0.51**	0.14
	SHBG	-0.17	-0.19	-0.05	-0.11	0.15
	FT	0.31	0.30	0.23	0.22	-0.02
	FAI	0.32	0.33	0.20	0.22	-0.11
Girls	BM	NA	NA	**0.60**	**0.59**	NA
	T	**0.54**	**0.54**	-0.02	-0.04	**-0.51**
	C	-0.17	-0.21	0.10	0.02	0.26
	DHEA-s	-0.02	-0.13	-0.06	-0.33	-0.06
	SHBG	-0.06	-0.02	-0.16	-0.07	-0.16
	FT	**0.44**	**0.43**	0.02	-0.03	-0.34
	FAI	0.28	0.25	0.10	0.01	-0.09

Note. BM = body mass, T = testosterone, C = cortisol, DHEA-s = dehydroepiandrosterone sulfate, SHBG = sex hormone binding globulin, FT = free testosterone, FAI = free androgen index. Significant correlations are highlighted in bold $p \leq .05$.

at maximal or near maximal loads); while in other sports they tend to be much more dynamic and unpredictable. Likewise, training for this sport primarily consists of the snatch and CJ exercises, so the competitive demands might be more homotypic and thus, less stressful than that experienced by other athletes who arguably use Olympic weightlifting to supplement sport-specific training. These factors could partly explain the similar hormone responses observed herein for boys and girls.

The weightlifting abilities of boys were positively related to DHEA-s and BM, consistent with data on young soccer players (1,11). However, the removal of the DHEA-s and performance relationship, after the BM adjustment, would suggest that this association is mediated by BM. Since DHEA-s acts as a precursor for other steroids, it could help to explain prior reports of hormonal (e.g., T, T/C ratio and FAI) relationships with physical performance in athletic or healthy boys (9,30,31,34) and equivalent training or longitudinal study results (18,21,29,33,36). Given these findings, it was somewhat surprising that no other significant associations were identified in the young males tested. This could be attributed to methodological differences, as none of the cited studies were conducted during competition, thereby potentially masking the identification of these relationships (7). Furthermore, the steroid effect might depend on other endocrine features (e.g., receptor interactions, cell type, hormone degradation, binding proteins), but their discussion is beyond this paper.

In contrast to boys, the weightlifting performance of girls was negatively related to pre-competition T levels and only after BM was controlled. This implies that BM is acting to suppress the relationship between these variables. Moreover, the nature of these interactions suggests that girls with low T tended to exhibit greater strength (controlled for BM) than high T subjects. The mechanisms underpinning these findings remain highly speculative, but could be ascribed to the T effect on aspects of body composition (e.g., visceral fat, breast tissue) (38) that do not contribute to force production and/or more fat localization in the lower body (8), which is important considering that the lower-limb musculature plays a greater role during the snatch and CJ exercises (40). Since T also contributes to nonuniform responses among females, in terms of body fat and muscle mass distribution (8,12), any link to performance might be better realized, or identified, once adjustments for individual BM are made. Our findings could explain the nonsignificant T relationships with competitive and training performance (not adjusted for BM) in adult female weightlifters (5,26,27).

There are some considerations when interpreting these results. For instance, no data were taken to discriminate body composition and stature (e.g., fat, muscle, height), while steroid profiling is limited by a lack of morning samples and control data. Plasma volume shifts add to these complexities, such that hemoconcentration could produce an artificial rise in hormones (23). However, we expected only small plasma volumes shifts due to the nature of an Olympic weightlifting competition, whereby the duration of muscle activity is very short (i.e., s) and coupled with long rest periods. The lack of Tanner scores to assess pubertal development is another limitation, although this study was not designed to examine pubertal status and the small group sizes/age spread would prevent any meaningful inferences. Still, the hormonal measures taken do correlate with Tanner scores (10,11,41) and we anticipated that pubertal stage would be directly proportional to subject age and BM (9,11,34). As a technically-demanding sport, the training experience of each participant might also regulate both hormone secretion and weightlifting performance under competitive stress.

In conclusion, the boys were bigger and stronger with a more anabolic profile than girls, thereby confirming those sex differences that emerge during puberty across a weightlifting competition. The DHEA-s (boys) and T (girls) measures correlated with weightlifting performance, but BM appeared to be acting as a mediating (boys) or suppressing (girls) variable in these relationships. Our findings confirm and add new insight regarding the hormonal contribution to competitive performance in young athletes.

Acknowledgments

This project was funded by the Ministry of Sport and Tourism of the Republic of Poland, as part of a nationwide talent identification programme.

References

1. Baldari C, Di Luigi L, Emerenziani GP, Gallotta MC, Sgro P, Guidetti L. Is explosive performance influenced by androgen concentrations in young male soccer players. *Br J Sports Med.* 2009; 43(3):191–194. PubMed doi:10.1136/bjsm.2007.040386
2. Capranica L, Lupo C, Cortis C, Chiodo S, Cibelli G, Tessitore A. Salivary cortisol and alpha-amylase reactivity to taekwondo competition in children. *Eur J Appl Physiol.* 2012; 112(2):647–652. PubMed doi:10.1007/s00421-011-2023-z
3. Chiodo S, Tessitore A, Cortis C, et al. Stress-related hormonal and psychological changes to official youth Taekwondo competitions. *Scand J Med Sci Sports.* 2011; 21(1):111–119. PubMed doi:10.1111/j.1600-0838.2009.01046.x
4. Crewther BT, Keogh J, Cronin J, Cook C. Possible stimuli for strength and power adaptation: acute hormonal responses. *Sports Med.* 2006; 36(3):215–238. PubMed doi:10.2165/00007256-200636030-00004
5. Crewther BT, Cook C. Relationships between salivary testosterone and cortisol concentrations and resistance training performance in Olympic weightlifters. *J Sports Med Phys Fit.* 2010; 50(3):371–375. PubMed
6. Crewther BT, Cook C, Cardinale M, Weatherby RP, Lowe T. Two emerging concepts for elite athletes: The short-term effects of testosterone and cortisol on the neuromuscular system and the dose-response training role of these endogenous hormones. *Sports Med.* 2011; 41(2):103–123. PubMed doi:10.2165/11539170-000000000-00000
7. Crewther BT, Heke T, Keogh JWL. The effects of training volume and competition on the salivary cortisol concentrations of Olympic weightlifters. *J Strength Cond Res.* 2011; 25(1):10–15. PubMed doi:10.1519/JSC.0b013e3181fb47f5
8. de Ridder CM, Thijssen JH, Bruning PF, Van den Brande JL, Zonderland ML, Erich WB. Body fat mass, body fat distribution, and pubertal development: a longitudinal study of physical and hormonal sexual maturation of girls. *J Clin Endocrinol Metab.* 1992; 75(2):442–446. PubMed
9. Delgado A, Allemandou A, Peres G. Changes in the characteristics of anaerobic exercise in the upper limb during puberty in boys. *Eur J Appl Physiol Occup Physiol.* 1993; 66(4):376–380. PubMed doi:10.1007/BF00237786
10. Di Luigi L, Baldari C, Gallotta MC, et al. Salivary steroids at rest and after a training load in young male athletes: relationship with chronological age and pubertal development. *Int J Sports Med.* 2006; 27(9):709–717. PubMed doi:10.1055/s-2005-872931
11. Di Luigi L, Guidetti L, Baldari C, et al. Cortisol, dehydroepiandrosterone sulphate and dehydroepiandrosterone sulphate/cortisol ratio responses to physical stress in males are influenced by pubertal development. *J Endocrinol Invest.* 2006; 29(9):796–804. PubMed doi:10.1007/BF03347373
12. Douchi T, Yoshimitsu N, Nagata Y. Relationships among serum testosterone levels, body fat and muscle mass distribution in women with polycystic ovary syndrome. *Endocr J.* 2001; 48(6):685–689. PubMed doi:10.1507/endocrj.48.685
13. Elliott KJ, Cable NT, Reilly T, Diver MJ. Effect of menstrual cycle phase on the concentration of bioavailable 17-beta oestradiol and testosterone and muscle strength. *Clin Sci.* 2003; 105(6):663–669. PubMed doi:10.1042/CS20020360
14. Elmlinger MW, Kühnel W, Ranke MB. Reference ranges for serum concentrations of lutropin (LH), follitropin (FSH), estradiol (E2), prolactin, progesterone, sex hormone-binding globulin (SHBG), dehydroepiandrosterone sulfate (DHEAS), cortisol and ferritin in neonates, children and young adults. *Clin Chem Lab Med.* 2002; 40(11):1151–1160. PubMed doi:10.1515/cclm.2002.202
15. Elmlinger MW, Kühnel W, Wormstall H, Döller PC. Reference intervals for testosterone, androstenedione and SHBG levels in healthy females and males from birth until old age. *Clin Lab.* 2005; 51(11):625–632. PubMed
16. Enea C, Boisseau N, Ottavy M, et al. Effects of menstrual cycle, oral contraception, and training on exercise-induced changes in circulating DHEA-sulphate and testosterone in young women. *Eur J Appl Physiol.* 2009; 106(3):365–373. PubMed doi:10.1007/s00421-009-1017-6
17. Fernandez-Fernandez J, Boullosa DA, Sanz-Rivas D, Abreu L, Filaire E, Mendez-Villanueva A. Psychophysiological stress responses during training and competition in young female competitive tennis players. *Int J Sports Med.* 2015; 36(1):22–28. PubMed
18. Fry AC, Kraemer WJ, Stone MH, Koziris LP, Thrush JT, Fleck SJ. Relationships between serum testosterone, cortisol, and weightlifting performance. *J Strength Cond Res.* 2000; 14(3):338–343. doi:10.1519/1533-4287(2000)014<0338:RBSTCA>2.0.CO;2
19. Fry AC, Schilling BK, Staron RS, Hagerman FC, Hikida RS, Thrush JT. Muscle fiber characteristics and

performance correlates of male Olympic-style weightlifters. *J Strength Cond Res.* 2003; 17(4):746–754. PubMed

20. Hackney AC, Viru A. Research methodology: endocrinologic measurements in exercise science and sports medicine. *J Athl Train.* 2008; 43(6):631–639. PubMed doi:10.4085/1062-6050-43.6.631
21. Hansen S, Bangsbo J, Twisk J, Klausen K. Development of muscle strength in relation to training level and testosterone in young male soccer players. *J Appl Physiol.* 1999; 87(3):1141–1147. PubMed
22. Kanehisa H, Funato K, Kuno S, Fukunaga TSK. Growth trend of the quadriceps femoris muscle in junior Olympic weight lifters: an 18-month follow-up survey. *Eur J Appl Physiol.* 2003; 89(3-4):238–242. PubMed doi:10.1007/s00421-003-0802-x
23. Kargotich S, Goodman C, Keast D, Morton AR. The influence of exercise-induced plasma volume changes on the interpretation of biochemical parameters used for monitoring exercise, training and sport. *Sports Med.* 1998; 26(2):101–117. PubMed doi:10.2165/00007256-199826020-00004
24. Kim KJ, Chung JW, Park SK, Shin JT. Psychophysiological stress response during competition between elite and non-elite Korean golfers. *Int J Sports Med.* 2009; 30(7):503–508. PubMed doi:10.1055/s-0029-1202338
25. Kim KJ, Park S, Kim KH, Jun TW, Park DH, Kim KB. Salivary cortisol and immunoglobulin A responses during golf competition vs. practice in elite male and female junior golfers. *J Strength Cond Res.* 2010; 24(3):852–858. PubMed doi:10.1519/JSC.0b013e3181c7c394
26. Le Panse B, Vibarel-Rebot N, Parage G, et al. Cortisol, DHEA, and testosterone concentrations in saliva in response to an international powerlifting competition. *Stress.* 2010; 13(6):528–532. PubMed doi:10.3109/10253891003743440
27. Le Panse B, Labsy Z, Baillot A, et al. Changes in steroid hormones during an international powerlifting competition. *Steroids.* 2012; 77(13):1339–1344. PubMed doi:10.1016/j.steroids.2012.07.015
28. McGuigan MR, Kane MK. Reliability of performance of elite Olympic weightlifters. *J Strength Cond Res.* 2004; 18(3):650–653. PubMed
29. Mero A, Jaakkola L, Komi PV. Serum hormones and physical performance capacity in young boy athletes during a 1-year training period. *Eur J Appl Physiol Occup Physiol.* 1990; 60(1):32–37. PubMed doi:10.1007/BF00572182
30. Mero A, Kauhanen H, Peltola E, Vuorimaa T, Komi PV. Physiological performance capacity in different prepubescent athletic groups. *J Sports Med Phys Fit.* 1990; 30(1):57–66. PubMed
31. Moreira A, Mortatti A, Aoki M, Arruda A, Freitas C, Carling C. Role of free testosterone in interpreting physical performance in elite young Brazilian soccer players. *Pediatr Exerc Sci.* 2013; 25(2):186–197. PubMed doi:10.1123/pes.25.2.186
32. Passelergue P, Robert A, Lac G. Salivary cortisol and testosterone variations during an official and a simulated weight-lifting competition. *Int J Sports Med.* 1995; 16(5):298–303. PubMed doi:10.1055/s-2007-973009
33. Passelergue PA, Lac G. Salivary hormonal responses and performance changes during 15 weeks of mixed aerobic and weight training in elite junior wrestlers. *J Strength Cond Res.* 2012; 26(11):3049–3058. PubMed doi:10.1519/JSC.0b013e3182473e3d
34. Ramos E, Frontera WR, Llopart A, Feliciano D. Muscle strength and hormonal levels in adolescents: Gender related differences. *Int J Sports Med.* 1998; 19(8):526–531. PubMed doi:10.1055/s-2007-971955
35. Rogol AD, Roemmich JN, Clark PA. Growth at puberty. *J Adolesc Health.* 2002; 31(Supplement 6):192–200. PubMed doi:10.1016/S1054-139X(02)00485-8
36. Round JM, Jones DA, Honour JW, Nevill AM. Hormonal factors in the development of differences in strength between boys and girls during adolescence: a longitudinal study. *Ann Hum Biol.* 1999; 26(1):49–62. PubMed doi:10.1080/030144699282976
37. Sartorius G, Ly LP, Sikaris K, McLachlan R, Handelsman DJ. Predictive accuracy and sources of variability in calculated free testosterone estimates. *Ann Clin Biochem.* 2009; 46(Pt 2):137–143. PubMed doi:10.1258/acb.2008.008171
38. Solorzano CM, McCartney CR. Obesity and the pubertal transition in girls and boys. *Reproduction.* 2010; 140(3):399–410. PubMed doi:10.1530/REP-10-0119
39. Stone MH, Sands WA, Pierce KC, Carlock J, Cardinale M, Newton RU. Relationship of maximum strength to weightlifting performance. *Med Sci Sports Exerc.* 2005; 37(6):1037–1043. PubMed
40. Storey A, Smith HK. Unique aspects of competitive weightlifting: performance, training and physiology. *Sports Med.* 2012; 42(9):769–790. PubMed doi:10.1007/BF03262294
41. Tsolakis C, Xekouki P, Kaloupsis S, et al. The influence of exercise on growth hormone and testosterone in prepubertal and early-pubertal boys. *Hormones.* 2003; 2(2):103–112. PubMed doi:10.14310/horm.2002.1189