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Aggressive-antisocial boys develop into physically strong young men

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Abstract

Young men with superior upper-body strength typically show a greater proclivity for physical aggression. The traditional interpretation is that young men calibrate their attitudes and behaviors to their physical formidability. Physical strength is thus viewed as a causal antecedent of aggressive behavior. The present study is the first to examine this phenomenon within a developmental framework. We demonstrate that males' antisocial tendencies temporally precede their physical formidability. We capitalize on the fact that physical strength is a male secondary sex characteristic. In two longitudinal cohorts of children, we estimate adolescent change in upper-body strength using the “slope” parameter from a latent growth model. Boys, but not girls, with greater antisocial tendencies in childhood attained larger increases in physical strength between the ages of 11 and 17. These results support sexual selection theory, indicating an adaptive congruence between male-typical behavioral dispositions and subsequent physical masculinization during puberty.

Keywords

physical strength; aggression; antisocial behavior; adolescent development

Sexual dimorphism in upper-body strength far exceeds the disparity in overall body mass between men and women (Lassek & Gaulin, 2009). The presence of such a profound sex difference is indicative of different selection pressures in ancestral men and women. There are strong grounds to infer that men's greater physical strength was shaped by direct male-male competition for access to mates (Darwin, 1871; Puts, 2010; Sell, Hone, & Pound, 2012). Indeed, many of the traits that comprise the male suite of secondary sex characteristics (e.g., deep voice, jaw-augmenting facial hair, increases in stature and lean body mass) signal an enhanced capacity to physically intimidate one's rivals (Dixson & Vasey, 2012; Hodges-Simeon, Gurven, Puts, & Gaulin, 2014; Puts, Apicella, & Cardenas, 2012). A physical capacity to dominate others may be facilitated when complemented by psychological adaptations that foster greater willingness to engage in conflict. This implies a

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linkage between physical formidability and *behavioral* traits of competitiveness (e.g., aggression, boldness, self-centeredness, and low empathy).

An association between physically aggressive tendencies and physical strength is strikingly intuitive, given the well-established sex difference favoring males on both counts. There is considerable evidence that young men with superior upper-body strength exhibit greater aggressive propensities and are more experienced with physical fighting than their physically weaker male counterparts (Gallup, White, & Gallup, 2007; Sell, Tooby, & Cosmides, 2009). Furthermore, a mesomorphic somatotype – which is partly based on the perception of greater muscularity – characterizes male youth who are persistently delinquent (Glueck & Glueck, 1956).

There are several mechanisms that might account for the link between physical strength and aggression. The traditional interpretation is that somatic characteristics assume causal priority, inasmuch that physically formidable individuals receive greater positive reinforcement from engaging in confrontation (Glueck & Glueck, 1956; Raine et al., 1998; Sell et al., 2009). According to a “facultative calibration” view of personality (Lukaszewski & Roney, 2011), the tendency to engage in interpersonal conflict should be tailored to one's ability to inflict physical costs on others. Conversely, it is possible that aggressive individuals choose to invest in greater physical strength. This recognizes the fact that aggressive individuals often desire to enhance their physical formidability, whereas the facultative calibration hypothesis views aggressive tendencies as a reaction to one's physical formidability. A third possibility is that aggression and physical strength co-occur due to common biological factors that masculinize the brain and physique independently (i.e., the “neuroandrogenic hypothesis”; Ellis, Das, & Buker, 2008). Given that previous studies have been cross-sectional, it is difficult to weigh the relative merits of these competing hypotheses. A prospective longitudinal framework could help clarify the mechanism(s) at work. In particular, an unresolved question in past studies is whether muscular young men were already aggressive before they attained their current physical formidability.

The remarkable stability of aggression between childhood and adulthood suggests that aggressive men were likely to be aggressive as children (Huesmann, Eron, Lefkowitz, & Walder, 1984). Moreover, the developmental timing of sex differences in male-typical behavioral dispositions (e.g., physical aggression) unfolds differently from the emergence of male secondary sex characteristics (e.g., upper-body muscularity and deep voice). Males are already more aggressive and rule-breaking than females in early childhood – a period during which the sex difference in physical strength is modest or negligible (Butterfield et al., 2009; Molenaar et al., 2010). This suggests that the masculinizing effects of androgens on antisocial dispositions are realized well before puberty. Given that androgenic influences on secondary sex characteristics are not fully expressed until adolescence, we predict a temporal pattern in which male-typical behavioral traits in childhood presage greater development of physical strength following the onset of puberty.

The present study uses a prospective longitudinal design to clarify the nature of the physical strength-aggression relationship. We examined multiple measures of aggressive-antisocial tendencies at approximately age 11. We also assessed hand-grip strength (HGS) at three

time points, namely ages 11, 14, and 17. HGS is highly correlated with other indices of muscular strength (Wind, Takken, Helders & Engelbert, 2010), and is thus an excellent measure of overall body strength. Latent growth models were fit to the HGS data in order to capture the pubertal change (slope) component of HGS development. Such a strategy allows us to determine whether antisocial tendencies are tied to preexisting levels or secondary sex development of physical strength. In particular, the emergence of an association between the slope factor and age-11 antisocial tendencies would demonstrate that individual differences in antisociality anticipate changes in HGS. According to sexual selection theory, sex differences in physical aggression emerge at a young age in order to prepare boys for future intrasexual competition (Archer, 2004). We therefore hypothesized that childhood antisociality would predict superior HGS development in males (but not females).

Method

Participants

We employed two large samples of twins from the 11-year-old cohorts of the Minnesota Twin Family Study (Iacono & McGue, 2002; Keyes et al., 2006). Individuals from these cohorts were recruited at approximately the age of 11, and subsequently invited for follow-up assessments at three-year intervals. The purpose of the Minnesota Twin Family Study is to investigate the antecedents of substance use disorders and related externalizing characteristics. A wide range of cognitive, somatic, personality, and clinical assessments were administered in order to address this research goal. Hand-grip strength was assessed during three laboratory visits corresponding to ages 11, 14, and 17. Mean ages were 11.78 ($SD = 0.43$), 14.84 ($SD = 0.51$), and 17.91 ($SD = 0.53$), respectively.

One sample ($n = 1527$) was recruited during the years 1990-1996, while the other sample ($n = 998$) was recruited approximately a decade later (1999-2006). We refer to these two samples as the “original cohort” and “newer cohort”, respectively. Most participants returned to the laboratory for their follow-up visits, with total in-person return rates of 83% and 71% at age 14 and 17, respectively. A major cause of attrition was that families relocated from the state of Minnesota, and thereby could only participate via phone assessment. Each cohort was subdivided into male and female groups. A large majority of participants (95%) were of European-American background.

A total of 2513 individuals possessed grip strength data at some point during the study. The vast majority (98.8%) were assessed for HGS at age 11. Furthermore, 2206 individuals (87.8%) possessed data at one or both of the two follow-up visits. Those who failed to return for laboratory visits were slightly (and non-significantly) weaker at age 11 than those who subsequently returned, Cohen's $d = -0.05$. Of those with HGS data, information about age-11 antisociality was available for all but eighteen individuals ($N = 2495$).

Measures and Procedure

Hand-grip strength (HGS)—At each assessment, HGS was measured a total of four times – twice from each hand – using Lafayette hand dynamometers (Models 78010 and 78011; Lafayette Instrument Company, Indiana, USA). Participants were instructed to

squeeze the dynamometer as hard as possible while standing upright and keeping their arms to the side in a neutral position. The maximum grip strength from these four trials was selected as our HGS variable (measured in kg-force units). We collected these data during day-long laboratory visits to the Minnesota Center for Twin and Family Research. These measurements were obtained during the course of a detailed anthropometric assessment. Additionally, physical stature and body mass were measured using a Detecto mechanical physician scale with height rod. Surveys of pubertal development were also administered during this time.

Pubertal development—Previous research has demonstrated that grip strength is related to biological maturity in males, even after controlling for height and weight (Jones, Hitchen, & Stratton, 2000). As such, it is possible that any emerging association between HGS and antisociality is confounded by pubertal status, given that early-maturing boys are at greater risk for delinquency (Cota-Robles, Neiss, & Rowe, 2002). At age 11, we administered a modified version of the Pubertal Development Scale (Petersen, Crockett, Richards, & Boxer, 1988). Participants reported their level of maturity using a four-point rating scale ranging from “not yet started changing/growing” to “growth is complete/finished changing”. Males were asked about voice changes, facial hair, underarm hair, and pubic hair. Female respondents reported on their growth spurt status, skin changes (pimples), body hair, and breast development. We averaged across the four characteristics to obtain a composite scale of pubertal development. This scale showed good internal consistency in females, Cronbach's $\alpha = .75$. Reliability was somewhat lower in males, Cronbach's $\alpha = .66$.

Pubertal development in boys was very positively skewed (and kurtotic). A plurality of boys showed a complete lack of pubertal development at age 11, with 44% responding “not yet started changing/growing” to all four items of the questionnaire. As a result, we subjected these scores to a log transformation as well as treating these data categorically using a median split. (Since results were essentially the same regardless of whether we conceived pubertal development as categorical or continuous, we only report results using the log-transformed scores.) In females, physical development scores were symmetrically distributed.

Aggressive-antisocial tendencies—We sought out measures of antisociality from our dataset that are continuously distributed and available at age 11. Two measures showed adequate sensitivity to individual differences: teacher ratings of antisocial personality features and self-reported aggression.

Teacher ratings of antisocial personality features: At age 11, participants nominated up to three teachers with whom they were acquainted at school. Rating forms were mailed to these nominees soon after the laboratory visit. A set of personality adjectives was included in the rating form. For each trait, teachers compared the participant to his/her classmates on a five-point rating scale: lowest 5%, lower 30%, middle 30%, higher 30%, or highest 5% of students in class. A mean of 2.20 rating forms were returned per participant (over 75% had at least two teacher ratings).

There were 28 sets of adjectives in the teacher rating form, of which we selected eight that tap into the broader construct of antisociality/low agreeableness (e.g., “tough, unforgiving, aggressive”). These items are listed in Appendix A. A composite index of antisocial personality was created by averaging these trait scores across all raters. Although the eight traits were selected on a rational rather than empirical basis, inter-trait correlations were moderate in magnitude for both sexes. Internal consistency was high, with Cronbach's alphas ranging from .85 to .90 across the four cohorts.

Self-reported aggression: Willingness to engage in physical aggression was assessed from a 40-item survey on opinions and attitudes, focusing on school and home life. The opinions-and-attitudes survey was introduced into the protocol in 1994, and thus the original cohort males (who began testing in 1990) lacked this particular survey. (A different instrument was used to measure aggression in these participants; see below). Seven items from the survey tapped into participants' views about aggression, and all specifically dealt with physical fighting (e.g., “If a person challenges you, you have to be ready to fight back”; see appendix B). Items were based on a four-point rating scale: (1) *Disagree a lot*, (2) *Disagree a little*, (3) *Agree a little*, and (4) *Agree a lot*. A summary score was created by averaging across the seven items. Attitudes about physical fighting showed good reliability; Cronbach's α ranged from .81 to .86 in the three cohorts for which the survey was available.

Original cohort males underwent a slightly different protocol at their intake assessment. Instead of providing ratings of their opinions and attitudes, they completed a self-report personality inventory. (None of the other cohorts received this inventory.) Participants were instructed to rank themselves on 34 personality facets/adjectives. For each adjective, they compared themselves to their same-age peers using a five-point rating scale: lowest 5%, lower 30%, middle 30%, higher 30%, or highest 5%.

The personality inventory contained three aggression-related adjectives: tough, aggressive, and conciliatory (reverse-scored). To ensure that respondents appropriately interpreted each adjective, we provided statements defining a high score and a low score. A high score on toughness was defined as, “you will sometimes pursue your own advantage even if someone else gets hurt; you seem to get a kick out of teasing or frightening others”. A high score on aggression was defined as, “you enjoy watching a good brawl; you sometimes like to get into fights and are ready to hit people when you're angry”. A low conciliatory score was defined as, “you are ready for a show-down or a fight when you think you've been criticized or taken advantage of”. Trait aggression was measured by averaging across these three items.

Statistical Analyses

Latent growth curve models were fit to the time series of HGS data in order to estimate adolescent change in strength (Meredith & Tisak, 1990). This model is appropriate given that both the mean and variance of HGS increased monotonically between ages 11 and 17 (see Isen, McGue, & Iacono, 2014). Two latent growth parameters are estimated: an intercept and slope. The intercept represents participants' initial HGS (assessed at age 11), whereas the slope is the amount of change occurring between the initial and final

assessments (i.e., between ages 11 and 17). Inter-individual variation in the slope is the main phenomenon of interest.

Interpretation of the slope is dependent on how one conceptualizes time. One can estimate time as a function of individuals' chronological age or as a fixed measurement wave. Due to the restricted age range at each assessment, we found it efficacious to regard the three measurement waves as time units. HGS was then residualized with respect to participants' chronological age at each assessment. Unstandardized residuals from the resultant regression equations were used as input in the latent growth curve models. (In order to retain information about mean level, we added the mean predicted HGS values to these residual scores.) Additionally, we regressed HGS on participants' height and weight in order to ensure that individual differences in body size were not confounding the results. (In practice, this correction had minimal impact on the structural relations between HGS and aggressive-antisocial tendencies.)

Figure 1 illustrates the parameters of the latent growth curve model. Slope loadings are fixed at 0 and 1 for the age-11 and age-17 HGS variables, respectively. This allows for easier interpretation of the slope mean, which is simply reduced to the difference in HGS between the beginning and end of the study. The factor loading of the age-14 time variable (denoted as τ) was freely estimated in each sample to allow for cohort- and sex-specific nonlinear growth. A potential correlation between individual differences in the intercept and slope (i.e., random effects) is represented by double-headed arrows in Figure 1. One might assume that individuals who are biologically precocious (and hence stronger) at age 11 should show less increase in HGS growth during their teens. If later-maturing peers eventually “catch up” in strength, then this would result in a negative intercept-slope correlation. However, the correlation is negligibly positive in both sexes (Isen et al., 2014).

As with any latent factor model, we estimated time-specific measurement error. This represents (residual) variance unexplained by the intercept and slope factors. The intercept parameter is reliable inasmuch that it accounts for a sufficient percentage of the age-11 HGS variance (Hertzog, Lindenberger, Ghisletta, & von Oertzen, 2006). Thus, it is desirable for residual variances to be small. However, we observed a substantial sex difference in the residual variance at age 11 (Isen et al., 2014). The intercept factor accounted for a larger proportion of the age-11 HGS variance in males than females (although the heritability was similarly high in both sexes). This might reduce statistical power to detect relationships between the intercept/slope parameters and antisociality in females. As a result, we performed follow-up analyses to examine whether girls' observed (raw) HGS values were related to any of the antisociality variables.

Estimation of the intercept and slope parameters was conducted using structural equation modeling in Mplus Version 6 (Muthen & Muthen, 2010). One of the major advantages of a latent growth modeling approach is that it can handle “missing” data from participants who lack certain data points. For example, some participants only underwent laboratory assessments at ages 11 and 14, whereas others were only assessed at ages 11 and 17. Imputation of the slope parameter is appropriate if the data are assumed to be “missing at random” (Little & Rubin, 2002). (In a non-elderly sample, it is implausible that physical

strength would be related to the reasons for missingness/attrition.) By using a full-information maximum likelihood approach, we can increase statistical power by accommodating the fullest number of participants. Moreover, estimation of a single slope parameter is more parsimonious than employing multiple difference scores to capture HGS change, and thus type-I error is minimized.

We segregated the two cohorts when performing most statistical analyses, as it affords us the opportunity for replication. This instills greater confidence in the validity of our conclusions. There were also practical reasons for separating the two cohorts (e.g., differences in the availability of survey information). For all statistical analyses, we accounted for the nonindependence of observations (i.e., clustered nature of twin data) by using a sandwich estimator in Mplus. This permits us to compute non-biased standard errors, which are otherwise too small when using standard (non-robust) maximum likelihood estimation. Finally, all antisocial facets were subjected to a Blom transformation in order to normalize the data (prior to conducting inferential analyses).

Results

Descriptive Statistics

Sample sizes and raw scores for pubertal development and each of the antisocial facets are listed in Table 1. These measures were obtained from participants during their intake (“age-11”) assessment. As expected, males received higher teacher ratings of antisocial personality and (in the case of the newer cohort) endorsed more aggressive attitudes. (Trait aggression was available only for original cohort males. In the interest of succinctness, we henceforth refer to trait aggression and aggressive attitudes under the common label “self-reported aggression”).

Correlations between teacher ratings and self-reported aggression ranged from $r = .15$ to $r = .28$ (all $ps < .001$) across the four samples, indicating that the two measures provide overlapping, but largely unique, information about antisociality. Pubertal development was not significantly associated with any of the antisociality measures in females, $ps > .05$. However, these relations were statistically significant in males, Pearson's r ranged from .09 to .19.

Descriptive statistics for body stature and mass are not reported here, as they are provided elsewhere (Isen et al., 2014). However, it should be noted that girls, due to their earlier growth spurt, are taller and heavier than boys at age 11. In order to obtain a measure of overall body size (i.e., bulk), we computed the product of height (in cm) and weight (in kg) at each assessment wave (see Raine et al., 1998). These values were then rank-normalized to adjust for positive skew. At age 11, girls possessed modestly larger body sizes than did boys (Cohen's $d = 0.20$). By middle adolescence, boys were bulkier than girls ($ds = 0.29$ and 0.88 at ages 14 and 17, respectively).

We next examined whether body size was related to aggression-antisociality. To reduce the number of statistical tests, we averaged self-reported aggression and teaching ratings (both rank-normalized) into a single score. Correlational analyses were performed between our

composite aggression-antisociality measure and body size at each age (conducted separately within the four sex/cohort groups). Out of a total of twelve statistical tests, only three correlations were statistically significant – all emerged in the newer cohort of males. Aggression-antisociality predicted greater body size at all ages in this cohort; Pearson's $r = 0.14$ ($p < .01$) at age 11, $r = .19$ ($p < .001$) at age 14, and $r = .21$ ($p < .001$) at age 17. Respective correlations in the original male cohort were non-positive (r s were $-.05$, $.00$, and $.00$), suggesting a cohort-by-body size interaction. Although the reasons for this discrepancy are unclear, it is noteworthy that the newer cohort participants (born around 1990) were consistently heavier than their male counterparts from the original cohort (born in the late 1970's), reflecting a secular increase in body mass. We regressed out the effects of body size when performing HGS analyses.

Modeling of Hand-Grip Strength

Raw HGS values were symmetrically distributed at each time point in all four cohorts. (The median value was always the integer closest to the mean.) The HGS data were further residualized with respect to age, height, and weight in each sex separately. After adding the absolute HGS means to these unstandardized residuals, we submitted the data to latent growth modeling. For model identification purposes, the slope loadings of the age-11 and age-17 time-points were fixed at 0 and 1, respectively (see Figure 1). The middle time-point loading (which represents the proportion of growth occurring by age 14) was freely estimated in each cohort, ranging from 0.51 in males to 0.74 in females. Hence, HGS growth is relatively linear between the ages of 11 and 17 in males, whereas it clearly decelerates in females after age 14.

Parameter estimates of the intercept and slope factors are reported in Table 2. The intercept mean is modestly higher in males relative to females in both cohorts. As many as one-third (32-33%) of females are stronger than the average male at age 11. By age 17, only a single female (0.2% from the original cohort) was stronger than her average male peer. Males' HGS more than doubled between ages 11 and 17, while females' mean HGS increased by 40%. This is reflected in Table 2, where the average increase in strength (i.e., slope mean) is approximately 22 kg in males and 9 kg in females. Initial HGS levels failed to predict individual differences in HGS growth; the intercept-slope correlation was $r = .03$ in males and $r = .02$ in females.

Variances around the slope and intercept factors were substantially larger in males than females (see Table 2). The larger intercept variance in males stems from the fact that the latent growth model accounted for 87-98% of the observed age-11 HGS variance in boys, while only accounting for 66-68% of girls' HGS variance. (There was greater residual variance in females, perhaps because their HGS values did not display the same monotonic linear increase as found in males; for a minority of females, HGS slightly decreased between ages 14 and 17.) On the other hand, males' excess variance around the slope is non-spurious, as it reflects the fact that the sex difference in HGS variance becomes more marked as children advance through adolescence (Isen et al., 2014). Males' variance around the slope was approximately fourfold that of females.

Relations with Antisociality

Next, the intercept and slope factors were regressed on age-11 antisocial facets. Standardized regression coefficients in males are presented in Table 3. Boys with greater self-reported aggression and higher teacher ratings showed enhanced gains in physical strength during adolescence, but were not consistently stronger than their peers at age 11. As can be seen in Table 3, this phenomenon is apparent in both the original and newer male cohorts. Individual differences in the slope (but not intercept) were positively associated with every antisocial facet, particularly the aggression-antisociality composite. Although there was some evidence that the intercept (i.e., age-11 HGS) was related to teacher ratings, this effect was confined to the newer cohort.

The incremental utility of employing different methods of assessing antisociality (i.e., self-reported aggression versus teacher ratings) was borne out in a multiple regression framework. In both cohorts, the two antisocial facets were uniquely associated with HGS slope, β s > 0.13 , p s $< .05$. The core of these findings is represented in Figure 2 using median splits. Participants who scored in the top 50% of teacher ratings and the top 50% of self-reported aggression were formed into a high-antisocial group. Those who scored in the bottom half of both variables were defined as low-antisocial. (Individuals scoring above the median on one variable, but below the median on the other, were not placed into a group). As Figure 2 demonstrates, these groups differ only modestly with respect to their observed HGS at age 11; Cohen's $d = 0.12$ (when pooled across cohorts). Six years later, however, these groups differ markedly with respect to their age-17 HGS (pooled $d = 0.50$).

The present pattern of results cannot be due to the confounding influences of age, weight, and height, as these were already partialled out of HGS. However, it is possible that precocious biological maturity contributes to greater antisocial propensities as well as accelerated HGS development in boys. This concern was unwarranted, as pubertal development was only related to the HGS intercept; pubertal status was unrelated to individual differences in the slope (see Table 3). When we included pubertal development and teacher ratings as joint covariates in a multiple regression model, the relationship between the HGS intercept and teacher ratings was reduced to non-significance in the newer cohort, $\beta = 0.11$, $p = .08$. Similar reduction was observed with respect to aggression-antisociality when including pubertal development as a covariate, $\beta = 0.10$, $p = .06$.

In contrast to the data in males, all associations between the growth factors and antisocial facets were non-significant in females (see Table 4). Moreover, pubertal development was unrelated to the HGS intercept. Because overall body size may convey important information about females' competitiveness, we also fit the latent growth model to raw HGS data (i.e., without adjusting for body weight and height); none of the antisociality covariates were significantly related to the intercept and slope parameters. This pattern of statistical non-significance persisted when examining antisociality with respect to observed HGS values at each assessment, with or without adjustment for body size (Pearson's r s $< .10$, p s $> .07$).

An important question arises whether sex moderates the association between antisociality and HGS development. Such an effect cannot feasibly be demonstrated in a multi-group

latent growth model due to the vastly higher mean and variance of males' HGS slope. The results in Tables 3-4 represent standardized regression coefficients in order to render the effect sizes comparable across sex/cohort. Thus, these coefficients do not convey the raw impact of antisociality on HGS development. When viewing the unstandardized regression of HGS slope on the composite aggression-antisociality measure, the sex difference was greatly magnified. In males, each 1-SD unit increase in aggression-antisociality roughly predicted 1-2 kilograms of excess HGS gain during adolescence; $b = 1.28$ (95% CI: 0.67, 1.90) and $b = 1.98$ (95% CI: 1.17, 2.80) in the original and newer cohorts, respectively. By contrast, the unstandardized coefficients in the respective female cohorts were much lower, 0.23 (95% CI: -0.34, 0.81) and 0.52 (95% CI: -0.08, 1.12). Although the confidence intervals slightly overlapped between the male and female original cohorts, no overlap was evident for the newer cohorts.

Discussion

The present study uses longitudinal data to address a provocative question: Why are physically strong males more aggressive than their physically weaker peers? This is framed within the broader goal of understanding the developmental processes by which male-typical behavioral traits complement masculine physical characteristics. We employed latent growth models of HGS to exploit the fact that puberty profoundly alters males' physical strength. In two large samples of male youth, aggressive-antisocial tendencies were positively related to the pubertal change ("slope") component of physical strength. To our knowledge, this is the first study to demonstrate that individual differences in behavior/personality are linked to inter-individual development of a secondary sex characteristic. As expected, there was no relationship between HGS and antisociality in females.

Sex-specific associations between aggressive propensities and upper-body strength are well-established in the literature (e.g., Gallup et al., 2007; Sell et al., 2009). Previous studies have generally relied on cross-sectional designs, rendering interpretation of the developmental mechanism(s) more difficult. Sell et al. (2009, 2012) interpret their findings through the lens of facultative calibration theory, in which males adaptively tailor their aggressive behavior and attitudes to their physical formidability. Since physically formidable individuals possess an enhanced ability to inflict physical costs on others, it would seem intuitive that physical strength facilitates the adoption of coercive tactics.

While the facultative calibration perspective is theoretically viable, it does not offer a complete picture of the ontogeny of aggression (nor was it advocated as such). For example, it remains silent on important developmental considerations. Male toddlers already demonstrate greater risk-taking and aggressive propensities than female toddlers (Archer, 2009). It appears that neuroendocrine mechanisms are responsible for sexual dimorphism in physical aggression early in ontogeny, long before the emergence of sexual dimorphism in physical strength. Moreover, patterns of aggressive/antisocial behavior can be considered trait-like, as they show moderate stability from early childhood to adolescence (van Beijsterveldt, Bartels, Hudziak, & Boomsma, 2003).

The facultative calibration hypothesis of physical aggression cannot account for the present pattern of results. In particular, this hypothesis would not anticipate our finding that aggressive-antisocial propensities in childhood predict greater increases in physical strength during adolescence. The fact that age-11 aggression in boys was associated with the slope (pubertal change) component of HGS, but not to contemporaneously measured HGS, challenges the notion that physical strength is a causal antecedent of physical aggression.

Alternatively, joint hormonal mediation may be responsible for both muscular strength and aggressive-antisocial traits. Androgen exposure is known to affect both brain functioning and somatic development (Ellis et al., 2008), indicating that male-typical behavioral traits and muscular strength might arise together indirectly (i.e., through a pleiotropic mechanism), rather than one directly causing the other. This is supported by observations that fetal testosterone exerts organizational influences on grip strength and physical aggression in young men (Bailey & Hurd, 2005; Butovskaya, Fedenok, Burkova, & Manning, 2013; Hone & McCullough, 2012). However, the hormonal mechanism(s) responsible for the present findings are not necessarily prenatal or even gonadal.

Adrenal androgens are particularly relevant because they dramatically rise during middle childhood, and are thought to influence sexually selected behaviors without grossly affecting morphology. Del Giudice, Angeleri, and Manera (2009) refer to this juvenile phase (adrenarche) as a period in which boys can hone their inter-peer competitiveness without developing the physical masculinization that would otherwise elicit rivalry from adolescent/adult men. There is evidence that aggressive-antisocial boys have elevated levels of adrenal androgens even while possessing normal concentrations of testosterone (van Goozen et al., 1998, 2000). In adults, adrenal androgens (particularly dehydroepiandrosterone) are important precursors to testosterone synthesis (Labrie et al., 2005) which, in turn, is important for the growth/maintenance of muscle mass. Thus, individual differences in adrenal androgen functioning may underlie the temporally lagged relationship between preadolescent antisociality and adult physical strength.

Given our lack of hormonal measures, we cannot conclude that androgen exposure organizes both aggressive propensities and pubertal increases in strength. Our results are not incompatible with the interpretation that antisocial boys engage in activities that facilitate greater development of strength. It is possible that aggressive boys in the present sample were more likely to participate in violent, physically strenuous activities (such as martial arts and hunting), which could have fostered a greater increase in their HGS.

The present study offers several novel contributions to our understanding of the intersection between personality and somatic development. It appears that males' physical strength is related to broad facets of the antisocial spectrum rather than aggression specifically. Teacher ratings of risk-taking, rule-breaking, and low empathy predicted subsequent HGS growth during adolescence. Given that these male-typical traits facilitate competition, it is likely that they are part of the same adaptive complex as physical aggression.

Major strengths of the study include the large sample size and extensive range of antisociality measures. Statistical findings were both robust and replicable. That is, the

association between HGS slope and antisociality was robust to differences in rating method (i.e., teacher ratings vs. self-reported attitudes) and were replicable (i.e., consistent across two cohorts of participants). Future studies may profit from using a wider array of physical strength measures (rather than relying on HGS only). It will also be beneficial to assess children at younger ages, well before the onset of puberty.

Concluding Remarks

Pubertal development is a salient and ubiquitous phenomenon in humans, but the functional role of secondary sex characteristics is often underappreciated. Features such as a low-deep voice, facial hair, and greater musculature may have rendered males more attractive to potential mates and/or more intimidating to same-sex rivals during the course of evolutionary history (Darwin, 1871). Investigators have recently garnered encouraging evidence that these secondary sex characteristics serve as aggressive display features in inter-male competition (Dixson & Vasey, 2012; Hodges-Simeon et al., 2014). This implies that physical aggression and male secondary sex development have coevolved as part of an adaptive complex (Archer, 2009). Our results cohere with sexual selection theory, and suggest that aggressive-antisocial dispositions in childhood may serve as preparation for future male-male competition in young adulthood, when physical strength is at its peak.

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Appendix A

Teacher-rated Antisocial Personality Features

1. Tough, unforgiving, aggressive
2. Thrill-seeking, risk-taking
3. Values a good reputation, respects authority (reversed)
4. Truthful, trustworthy (reversed)
5. Law abiding (reversed)
6. Nurturant, helpful, concerned about others (reversed)
7. Superficial, shallow
8. Manipulative

Appendix B

Attitudes about Physical Aggression

1. If a person challenges you, you have to be ready to fight back.
2. If another kid cut in front of me in line, I'd probably push him or her out of the way.

3. If a friend got into a fight, I'd be ready to jump in so that she or he could win.
4. I want to be known as a good fighter, someone the other kids are afraid of.
5. If I didn't like someone, I might try to hurt him or her just for the heck of it.
6. If someone bigger than me was bothering me, I might try and get some friends together to beat him or her up.
7. If someone calls you a name, that is reason enough to fight.

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Fig. 1. Path diagram of a latent growth model. Rectangles represent observed hand-grip strengths at the age-11, age-14, and age-17 assessments. Circles denote latent variables, and triangles represent the grand means of the intercept and slope parameters. Residual variances (RV) are time-specific, and represent variation unexplained by the growth model.

Fig. 2.

Median split of male participants into high and low groups of antisociality at age 11. Observed hand-grip strength values are plotted at age 11 (bottom panel) and age 17 (top panel). The ranges of values on the y-axis (14-24 kg and 38-48 kg in the two panels, respectively) are deliberately truncated in order to allow for adequate resolution of the error bars, which represent 95% confidence intervals. Please note that grip strength approximately doubled between ages 11 and 17.

Table 1
Descriptive Statistics of Pubertal Development (PD) and Antisocial Facets in Males and Females

Variable	Male <i>N</i>	<i>M</i> ± <i>SD</i>	Range	Female <i>N</i>	<i>M</i> ± <i>SD</i>	Range
<i>Original Cohort</i>						
Age	757	11.7 ± 0.4	10.7 – 12.8	770	11.7 ± 0.5	10.8 – 12.6
PD	705	1.30 ± 0.37	1 – 3.25	744	2.22 ± 0.59	1 – 4
Teacher Ratings	734	2.19 ± 0.72	1 – 4.83	718	1.75 ± 0.47	1 – 3.96
Trait Aggression	613	2.56 ± 0.82	1 – 5	0		
Attitudes	0			699	1.44 ± 0.44	1 – 3.43
<i>Newer Cohort</i>						
Age	478	11.9 ± 0.4	10.9 – 12.9	520	11.9 ± 0.4	11.0 – 13.0
PD	461	1.48 ± 0.46	1 – 3.50	497	2.30 ± 0.67	1 – 4
Teacher Ratings	410	2.04 ± 0.63	1 – 4.38	433	1.81 ± 0.51	1 – 3.84
Attitudes	468	1.81 ± 0.65	1 – 4	512	1.48 ± 0.49	1 – 3.86

Notes. Teacher ratings = teacher report of antisocial personality features; Attitudes = self-reported endorsement of physically aggressive attitudes.

Table 2
Latent Growth Model Parameters of Grip Strength Development in Adolescence

Parameter	Males		Females	
Original Cohort				
	Mean	Variance	Mean	Variance
Intercept	22.22 ± 0.17	11.98 ± 1.13	21.57 ± 0.13	5.61 ± 0.60
Slope	22.74 ± 0.31	17.60 ± 3.91	8.71 ± 0.21	4.79 ± 1.05
Newer Cohort				
	Mean	Variance	Mean	Variance
Intercept	20.98 ± 0.20	11.50 ± 1.31	19.71 ± 0.17	6.15 ± 0.75
Slope	21.36 ± 0.39	32.45 ± 5.23	8.82 ± 0.25	8.15 ± 1.53

Notes. Grip strength values (in kg-force units) were adjusted for age, height, and weight. Standard errors are presented after the plus-minus signs. The intercept is an estimate of the initial (age-11) grip strength. The slope represents the change in grip strength between ages 11 and 17. Means are fixed (constant) values in a given sample, while variances reflect the extent of interindividual differences in initial strength (intercept) and subsequent growth (slope).

Table 3
Regression of Latent Growth Factors on Age-11 Predictors in Males

Predictors	Intercept		Slope	
	<i>Beta</i>	<i>95% CI</i>	<i>Beta</i>	<i>95% CI</i>
Original Cohort				
Teacher Ratings	0.04	[-0.08, 0.15]	0.28***	[0.15, 0.41]
Self-reported Aggression	0.01	[-0.06, 0.08]	0.18**	[0.05, 0.31]
Aggression-Antisociality	0.05	[-0.05, 0.14]	0.27***	[0.14, 0.41]
Pubertal Development	0.10*	[0.01, 0.19]	0.04	[-0.09, 0.16]
Newer Cohort				
Teacher Ratings	0.15*	[0.04, 0.26]	0.23***	[0.11, 0.36]
Self-reported Aggression	0.08	[-0.02, 0.18]	0.21**	[0.08, 0.33]
Aggression-Antisociality	0.14*	[0.04, 0.23]	0.28***	[0.16, 0.40]
Pubertal Development	0.16**	[0.07, 0.25]	0.06	[-0.06, 0.18]

Notes. Intercept represents individual differences in age-11 grip strength, while slope represents growth between ages 11 and 17. Regression coefficients (betas) are standardized. Aggression-antisociality is the average score of teaching ratings and self-reported aggression.

*
p < .05,

**
p < .01,

p < .001

Table 4
Regression of Latent Growth Factors on Age-11 Predictors in Females

Predictors	Intercept		Slope	
	<i>beta</i>	<i>95% CI</i>	<i>Beta</i>	<i>95% CI</i>
Original Cohort				
Teacher Ratings	0.02	[-0.11, 0.15]	0.03	[-0.13, 0.19]
Self-reported Aggression	-0.03	[-0.12, 0.06]	0.06	[-0.11, 0.22]
Aggression-Antisociality	0.00	[-0.10, 0.10]	0.07	[-0.10, 0.24]
Pubertal Development	0.09	[-0.01, 0.19]	-0.12	[-0.28, 0.04]
Newer Cohort				
Teacher Ratings	-0.03	[-0.18, 0.12]	0.07	[-0.10, 0.23]
Self-reported Aggression	0.01	[-0.08, 0.10]	0.09	[-0.04, 0.22]
Aggression-Antisociality	-0.01	[-0.13, 0.13]	0.13	[-0.02, 0.27]
Pubertal Development	-0.02	[-0.16, 0.12]	-0.11	[-0.26, 0.05]

Notes. Intercept represents individual differences in age-11 grip strength, while slope represents growth between ages 11 and 17. Regression coefficients (betas) are standardized. Aggression-antisociality is the average score of teaching ratings and self-reported aggression.