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Salivary testosterone and aggression, delinquency, and social dominance in a population-based longitudinal study of adolescent males

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Abstract

Testosterone (T) has been found to have a stimulating effect on aggressive behavior in a wide range of vertebrate species. There is also some evidence of a positive relationship in humans, albeit less consistently. In the present study we investigated the relationship between T and aggression, dominance and delinquency over time, covering a period from early adolescence to adulthood. From a large population-based sample (n = 1.161) a subgroup of 96 boys was selected whose behavior had been assessed repeatedly by different informants from age 12 to 21 years, and who had provided multiple T samples over these years of assessment. On the whole, a decrease in aggressive and delinquent behavior was observed in a period in which T rises dramatically. Boys who developed a criminal record, had higher T levels at age 16. In addition, positive associations were observed between T and proactive and reactive aggression and self-reported delinquent behavior. Over the pubertal years different forms of aggressive and delinquent behavior were positively related to T, which may indicate that specific positive links are dependent on the social setting in which this relationship is assessed.

Keywords: Testosterone; Aggression; Delinquency; Dominance; Pubertal development

Introduction

Testosterone (T), the most important male sex hormone, affects not only physical but also behavioral masculinization. For example, T has been found to increase aggressive behavior in a wide range of vertebrate species (Archer, 1988). Studies in male rodents show that competitive or intermale aggression increases at puberty, a time in which T levels dramatically rise. Also, administration of T results in an increase in aggression (Brain, 1979), whereas it is reduced by (chemical) castration (see Van Goozen et al., 1995 for results in humans).

In human adults, T has been found to be related to delinquency, drug abuse (Dabbs and Morris, 1990) and criminal violence (Dabbs et al., 1995; Ehrenkranz et al., 1974; Kreuz and Rose, 1972; Strong and Dabbs, 2000), as well as to conduct problems in childhood (Dabbs and Morris, 1990). However, Bain et al. (1987) found no difference in T between men charged for aggressive or non-aggressive crimes. It is clear, therefore, that in humans the evidence is at best suggestive of a positive relationship (Archer, 1991).

Much less information exists about the relationship between T and aggressive behavior in children and adolescents. Some studies found a positive relationship between T and physical and

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verbal aggression (Olweus et al., 1980, 1988), persistent externalizing behavior (Maras et al., 2003), and age-graded norm-violating behaviors (Udry, 1990) in youngsters. Scerbo and Kolko (1994) studied pre- and early adolescent clinical cases and found that T was related to increased staff-rated aggression. Likewise, disruptive boys approaching puberty seem to have higher T levels as compared to normal controls (Chance et al., 2000). Sánchez-Martín et al. (2000) found a positive relation between T and the frequency of engaging in aggressive interactions in four-year-old boys. However, there are also quite a few studies that have found no relationship between aggression and T in youngsters (Constantino et al., 1993; Halpern et al., 1994; Inoff-Germain et al., 1988; Mattsson et al., 1980; Susman et al., 1987; Van Goozen et al., 1998). One study found a relationship between T and disruptive behavior in girls, but not in boys (Granger et al., 2003). In another study (Schaal et al., 1996) boys with a history of high levels of physical aggression between ages 6 and 12 had lower T levels at age 13 than boys without such a history.

These mixed findings in studies on children and adolescents may be due to important methodological differences between the studies. First, some studies used clinical samples of children referred for disruptive behavior disorders (Chance et al., 2000; Constantino et al., 1993; Scerbo and Kolko, 1994; Van Goozen et al., 1998), while others used population-based samples (Olweus et al., 1980; Schaal et al., 1996; Udry, 1990). Second, studies differ not only in sample size but also in the number of samples taken for T analysis. Third, different instruments have been used to investigate this relationship and therefore a mixture of information on various forms of aggressive or dominant behaviors (disruptive, assertive, or physically aggressive behaviors) has been collected (Tremblay et al., 1998). Studies that assess aggression have generally not taken into account different types of aggression, e.g., whether it is reactive or proactive in nature, and it could well be that different types of aggression have different relationships with T. Reactive and proactive aggression have been observed in children and adolescents (Brendgen et al., 2001; Dodge et al., 1997; Pulkkinen and Tremblay, 1992; Vitaro et al., 1998). And finally, studies examining the T-aggression relationship in youngsters obviously differed in the ages of their participants, ranging from prepubertal to postpubertal, which could clearly affect the results. Schaal et al. (1996) found that boys who were persistently physically aggressive had lower T levels at age 13 than boys who were physically aggressive, but these same boys had higher T at age 16, and therefore a group by time interaction was observed (Tremblay et al., 1997).

Studies in nonhuman primates also show a relatively strong association between testosterone and dominance (Mazur and Booth, 1998; Paikoff and Brooks-Gunn, 1990). Social dominance may or may not involve aggressive behavior and it has been suggested that a more direct relationship exists between T and dominance (Albert et al., 1993; Strong and Dabbs, 2000). This line of reasoning has been supported in humans (Schaal et al., 1996; Rowe et al., 2004; Archer, 2006), in which it was shown that testosterone levels were associated with social success rather than with physical aggression.

In the present study, we examined the relationship between testosterone, using multiple measurements of T in each year of assessment, and aggression, dominance, and delinquency, in a period covering early adolescence to adulthood. Puberty is a period in which T levels progressively rise from extremely low to mature levels, and it is also in most cultures a period of psychological development characterized by, among others, increases in antisocial and delinquent behavior (Moffitt, 1993; Weisfeld and Berger, 1983). One would therefore expect that a longitudinal study from late childhood to adolescence and adulthood could provide crucial data on the influence of T on aggression. To this end, we based our study partly on data reported by Schaal et al. (1996), but extended the measurement period to adulthood, and used a larger number of behavioral assessments. A first goal was to examine whether, in line with a rise in T, different types of aggressive, dominant, or delinquent behavior increased from early adolescence into adulthood. Secondly, we investigated whether physical aggression, social dominance and/or delinquent behavior, as shown from childhood to adulthood, had a positive relationship with (changing) T levels. We expected to find an overall increase in aggressive, dominant, and delinquent behavior, together with a rise in T, in our assessment period. Moreover, when examining T levels in separate years, we expected to find positive relationships between T and physical aggression, social dominance, and/or delinquent behavior.

Materials and methods

Participants

The participants involved in the present study (n = 96) were part of a longitudinal study that started in 1984, when teachers of kindergarten classes in 53 schools in an urban area in Montreal were asked to rate the behavior of each boy in their classroom (Tremblay et al., 1994). Eighty-seven percent of the teachers agreed to participate, and 1,161 boys were rated. To minimize social and cultural effects, the boys were recruited according to the following criteria; (1) attending school in low socioeconomic areas of Montreal; (2) born from Caucasian, French-speaking parents themselves born in Canada; and (3) living with parents having medium to low educational status. The sample was reduced to 1,037 boys after applying these criteria and eliminating those who declined to participate and those who could not be located (Tremblay et al., 1991, 1994, 1995).

Physically aggressive behavior was assessed at ages 6, 10, 11, and 12 years by means of the fighting subscale of the teacher form of the French Canadian version of the Social Behavior Questionnaire (SBQ; Tremblay et al., 1991). Physical aggression could be determined for 893 boys, after boys who withdrew from the longitudinal project (n = 116) and boys who had more than one missing value (n = 28) had been eliminated (see also Séguin et al., 1995, 1996). Stable highly aggressive boys were defined as those who fell above the 70th percentile at age 6 and on two or more assessment points on the physical aggression scale (19% of the sample). Nonaggressive boys had scores that fell below the 70th percentile at all assessment points (35% of the sample). Those who did not meet the above criteria were classified as unstable aggressive boys (46% of sample). Compared to another sample of boys (n = 882) representative of the whole province, physically aggressive behavior is over-represented in this urban community sample of low socioeconomic status (SES; Séguin et al., 1996).

For logistical reasons, we were able to invite approximately 200 13-year-old boys to come to the laboratory for various observational and experimental procedures. Several overlapping criteria were used to select this subsample. Exclusion criteria (for purposes not particular to this study) were applied as follows: 234 boys who could not be classified as stable anxious or stable

nonanxious were eliminated, as well as 326 boys who did not meet priority criteria such as (a) stability of physical aggression or nonaggression, (b) a history of going to the laboratory since age 6, or (c) a pattern of late onset physical aggressive or anxious behavior. Thus, some moderate or unstable anxious boys remained in the selected sample because they met some of these priority criteria (n = 138). Those who met priority criteria (b) or (c) but not (a) were classified as unstable aggressive boys. When all these criteria were applied, the selected sample consisted of 333 boys. At age 13, 203 of these boys agreed to come to the laboratory (Séguin et al., 1995, 1996). Only data of those participants were used in subsequent analyses when information on their T level was available when they had been 13, 16 and 21 years old. This resulted in a sample of 96 males. This subsample did not differ from the larger sample (n = 941) on a number of important characteristics such as SES and/or reactive or proactive aggression. We considered this subsample therefore to be representative of the sample at large.

Procedure and instruments

Initial examination of the data revealed that correlation coefficients (r) between annual scores for reactive and proactive aggression (as assessed at ages 12, 13, 14, and 15), and for toughness and leadership (as assessed at ages 13, 14, and 15) were relatively high (r varied from 0.21 to 0.67 for successive years), indicating a relatively high stability of individual aggression rank over time (see Table 1). Also, a relatively high r was found for scores on delinquency (as assessed at ages 13, 15, and 20; r varied from 0.30 to 0.41, see Table 2). Therefore, these behavioral measures were assumed to be more trait-like, and we decided to create high and low aggressive and delinquent subgroups based on the means calculated over these years. Moreover, because correlation coefficients between T levels at ages 13, 16, and 21 were low (r varied from 0.02 to 0.19, see Table 3), we decided not to calculate a mean T value over time, but to use annual T data instead.

Peer rating assessments at 13 to 15 years of age

During the laboratory visit, once a year at ages 13 to 15 years, ratings of toughness and leadership were obtained from individual interviews during which every subject from a peer group was asked to nominate the leader ('Who would you choose as leader?') and identify the toughest boy ('Who was the toughest?'). The interviews were done at approximately 10:30 AM, 3 h after the boys had been picked up at home and driven together (in groups of 3 to 5) to the laboratory in a van, had been assessed individually on personality, cognitive functioning, and had taken part in a competitive group task to provide an opportunity to observe social interaction. Each subject received a toughness and a leadership score ranging from 0 to 5 depending on the number of nominations he received (including self-nominations). Average scores were computed over ages 13 to 15, and we created a low tough (LT, n = 49) and a high tough (HT, n = 47) subgroup, using the median score. In a different analysis we created a low leader (LL, n = 49) and a high leader (HL, n = 47) subgroup. Thereafter, and following Schaal et al. (1996), these subgroups were combined, resulting in a low tough–low leader (LT–LL, n = 31), a low tough–high leader (LT–HL, n = 18), a high tough–low leader (HT–LL, n = 18), and a high tough–high leader (HT–HL, n = 29) subgroup.

Table 1
Correlation coefficients (r) between annual scores for reactive and proactive aggression (assessed at ages 12, 13, 14 and 15), and for toughness and leadership (assessed at ages 13, 14 and 15)

	Respective aggressive behavior		
	Age 13	Age 14	Age 15
Leadership			
Age 13	–	0.21 *	0.19
Age 14	–	–	0.46 **
Toughness			
Age 13	–	0.37 *	0.27 *
Age 14	–	–	0.42 *
Proactive aggression			
Age 12	0.58 **	0.51 **	0.25 *
Age 13	–	0.40 **	0.33 **
Age 14	–	–	0.51 **
Reactive aggression			
Age 12	0.56 **	0.46 **	0.32 **
Age 13	–	0.49 **	0.46 **
Age 14	–	–	0.67 **

* $P < 0.05$.
** $P < 0.01$.

Table 2
Correlation coefficients (r) for delinquency scores as assessed at ages 13, 15 and 20

	Age 15	Age 20
Delinquency		
Age 13	41 **	0.10
Age 15	–	0.30 **

* $P < 0.05$.
** $P < 0.01$.

Assessments of reactive and proactive aggression from 12 to 15 years of age

In addition, when the boys were 12, 13, 14 and 15 years old, their teachers completed three reactive aggression, and three proactive aggression items (Dodge and Coie, 1987) The reactive items were "when teased or threatened he gets angry easily and strikes back"; "when accidentally hurt by a peer he assumes that the peer meant to do it and then overreacts with anger and fighting"; and "always claims that other children are to blame in a fight and feels that they started the whole trouble". The proactive items were "uses (or threatens to use) physical force in order to dominate other children"; "threatens or bullies others in order to get his way"; and "gets other children to gang up on a peer he does not like". The 3-unit response scale for these items ranged from 0 "does not apply", and 1 "applies sometimes", to 2 "applies often" (Brendgen et al., 2001). Cronbach's alphas, a model of internal consistency, which is based on the average inter-item correlation, varied from 0.82 to 0.86, which is highly consistent. For each year, a reactive and proactive aggression score was calculated by summing the scores of the three respective items, resulting in an annual reactive and proactive score ranging from 0 to 6. Five boys did not participate in the analyses, as they had missing values on reactive or proactive aggression in more than 2 years. Based on the average scores at ages 12 to 15 years, we created a low reactive aggressive (LRA, n = 47) and a high reactive aggressive (HRA, n = 44) subgroup, using the median score. In a different analysis we created a low proactive aggressive (LPA, n = 50) and a high proactive (HPA, n = 41) subgroup.

Assessments of delinquency at 13, 15, and 20 years of age

A 27-item delinquency questionnaire was administered to the boys when they were 13 and 15 years old (Tremblay et al., 1994). A revised and for this age group adjusted version was administered at age 20. This questionnaire was reduced to 23 items ([1] items are overlapping, and [2] items are added at age 20). The items, which were rated on a 4-point scale (never, once or twice, a number of times, very often), included: 'steal objects worth more than $10 in school[1]', 'steal from store[1]', 'take psychostimulants/hallucinogenics[2]', 'take opiates[2]', 'steal objects worth more than $100[1]', 'take money from home', 'keep object worth less than $19', 'keep objects worth between $10 and $100[1]', 'steal a bicycle[1]', 'steal a car[2]', 'sell stolen goods', 'enter without paying[1]', breaking and entering[1]', 'trespassing[1]', 'take marijuana[1]', 'take alcohol', 'get drunk', 'destroy school material[1]', 'destroy other material[1]', 'vandalism at

Table 3
Correlation coefficients (r) for annual T levels at ages 13, 16 and 21

	Age 16	Age 21
Testosterone		
Age 13	0.19	0.05
Age 16	–	0.02

* $P < 0.05$.
** $P < 0.01$.

school[1]', 'destroy objects at home', 'vandalism of cars[1]', 'set a fire[1]', 'strong-arm[1]', 'gang-fights[1]', 'use weapon in a fight', 'fist fight', 'force someone into sexual activity[2]', 'beat up someone[1]', 'carry a weapon[1]', 'throw objects at persons[1]'. Three boys did not participate in the analyses, as they had missing values in more than 1 year. The total number of items generate a total delinquency score (Cronbach's alphas at ages 13, 15, and 20 ranges from 0.82 to 0.93). The total scores were transformed into *Z* scores within each year to correct for variation in number of items. Next, average *Z* scores were calculated for ages 13 to 20, and based on these scores we created a low (LD, $n = 47$) and a high delinquency (HD, $n = 46$) subgroup, using the median score.

Assessments of conduct disorder (CD) and physical aggression at age 15

The Diagnostic Interview Schedule for Children (DISC-2.25) (Shaffer et al., 1991) was administered to the participants and their parents (mostly their mothers) when the boys were approximately 15 years old. A letter followed up by telephone contact served to solicit participation (Séguin et al., 1999). The DISC could not be administered to 5 of the participants, and 2 participants had only a child or a parent report. A participant was attributed to the CD subgroup when he met two or more of the thirteen CD criteria based on combined reports of parent and child. In this way, a CD subgroup consisting of 10 boys and a normal control (NC) subgroup of 81 boys were created.

Official criminal records as an adult

We created subgroups based on the information of whether boys did or did not have an official crime record as an adult (18 to 20 years of age). We have been given access to this information by The Royal Canadian Mounted Police (RCMP). We could not get criminal record information for 18 of the participants. A 'no official record' (NOR, $n = 71$) and an 'official record' (OR, $n = 7$) subgroup was composed.

Assessments of physical aggression trajectories from 6 to 15 years of age

The estimation of developmental trajectories for repeated measures of physical aggression from kindergarten to mid-adolescence is based on teacher reports. The boys' classroom teachers rated physical aggression in the spring of each year using the Social Behavior Questionnaire (Tremblay et al., 1991). This questionnaire was administered when the boys were aged 6, 10, 11, 12, 13, 14, and 15 years. Physical aggression was assessed with three items; "kicks, bites, hits"; "fights"; and "bullies or intimidates other children". The range of possible values of the physical aggression score was 0 through 6. The internal consistency scores (Cronbach's alphas) for the physical aggression scale ranged from 0.78 to 0.87 with a mean reliability score of 0.84 for assessments between 6 and 15 years.

Nagin and Tremblay (1999, 2001) identified four distinct groups when they estimated the developmental trajectories of physical aggression for the total Montréal sample with a semiparametric, group-based method. When applied to our sub-sample, the criteria led to the following four groups: a low physical aggression trajectory group (LOW, $n = 21$), a moderate physical aggression trajectory group (MOD, $n = 37$), a high physical aggression trajectory group ($n = 35$), and a chronic physical aggression trajectory group ($n = 3$). Because the latter group was so small, we combined the high and chronic trajectory groups into one high physical aggression trajectory group (HIGH, $n = 38$).

Assessments of pubertal status at 13 and 16 years of age

Pubertal status was self-assessed at ages 13 and 16 using the Pubertal Development Scale (Petersen et al., 1988). This scale of pubertal status assessment integrates self-report of growth spurt, body and facial hair development, and skin and voice changes on 4-point scales. Pubertal status could not be assessed for 10 of the participants. Classification into one of the five pubertal status categories (pre-, early, mid-, late, and postpubertal) is based on the level of development of the three most salient indices of pubertal change (i.e., body hair, facial hair, and voice alterations. Because most boys were either in the early pubertal or midpubertal status categories at age 13, and in the midpubertal or late pubertal status categories at age 16, we decided to transform this variable into a dichotomous variable.

Testosterone measurements

T levels were assayed from multiple saliva samples collected during a visit to the laboratory in 1991 (at approximately 8:30 AM, 10:00 AM, 11:30 AM, and 3:30 PM), in 1994 (at approximately 9:25 AM, 10:30 AM, 12:00 AM, and 2:00 PM), and in 1999 (at approximately 9:00 AM, 10:00 AM, and 11:00 AM). Since correlation coefficients between individual samples of T over 1 day were highly correlated (Spearman's rho's varied from 0.68** to 0.86**), a mean level of T was calculated for each year, leading to more reliable values. Participants were requested to donate saliva into sterile vials, which were immediately frozen (−20°C) until radioimmunoassay. The assays were performed blindly. The procedure was a variant of that established by Vittek et al. (1984) with T-assay kits purchased from ICN Biomedicals Inc. (Montreal). Once centrifuged, 500 μL of saliva was pipetted and extracted with 2 mL of ether. One milliliter of the organic phase was taken and evaporated to dryness. The residue was incubated at 37°C for 120 min with 50 μL of steroid dilutent. After incubation, 100 μL of sex-hormone-binding-globulin inhibitor, 400 μL of ^{125}I-testosterone, and 400 μL of anti-T were added and incubated overnight. A separation antibody was then added and allowed to incubate for 90 min at 37°C. After 15 min of centrifugation, the supernatant was discarded and the tube was counted in a gamma counter. Precision of the analytical procedure was improved by extraction of the standard curve. Intraassay and interassay coefficients of variation were 6.3% and 12.3%, respectively. Regarding the specificity of the assay, no significant cross-reactions of the antibody were measured, except for 5-α-dihydrotestosterone (3.4%). In 1999, we used a commercially available radioimmunoassay kit (Coat-A-Count Total Testosterone Determinations in Saliva; Diagnostic Products Corp., Los Angeles, California); this DPC kit protocol does no require ether extractions.

The intraassay coefficients of variation were 13.92% and 6.66% respectively at 43.29 pg/ml and 154.92 pg/ml. The interassay coefficients of variation were 19.95% and 10.81% respectively at 43.29 pg/ml and 154.92 pg/ml. Regarding the specificity of the assay, very little crossreactivity was measured, except for dihydrotestosterone, which was less than 5%. The titration of T from saliva was preferred to any other way of obtaining similar data for practical and theoretical reasons. Its application being unobtrusive, it does not interfere with stress-elicited alterations of T. In addition, the handling of saliva is uncomplicated in comparison with the handling of blood or urine. Salivary T level, being highly correlated with the unbound fraction of circulating T, is assumed to be a precise indicant of the behaviorally active fraction of T (Riad-Fahmy et al., 1982; Wang et al., 1981).

T trajectory groups

Based on their T levels in 1991, 1994, and 1999, participants were divided into a low (LT), a moderate (MT), or a high (HT) testosterone group. For someone to be assigned to the LT group he had to have T values in the lower 33% of at least two of the 3 years of assessment. In a similar way, boys were classified as belonging to the MT or HT group. In this way, 15 boys were classified as LT, 26 as MT, and 18 boys as HT.

Statistical analyses

In order to examine whether aggressive and delinquent behaviors, as well as T levels, changed over time, analyses of variance (ANOVAs) with repeated measures were used. Moreover, Pearson correlations between T levels and pubertal stage were calculated. In case of high positive correlations pubertal stage was entered as covariate in further analyses. AN(C)OVA's with group as independent and T level at ages 13, 16, and 21 as dependent variable were conducted to find out whether there were differences in salivary T between low and high aggression groups. Values are expressed as means (±SD). In case of significant group differences between more than two groups, post hoc Bonferroni tests for multiple comparisons were conducted. When scores or groups were unevenly distributed non-parametric tests were used. Single isolated outlier values, with an outlier defined as an individual value more than 2.5 SDs above the mean value of the group, were replaced by the group averages. In addition, an ANOVA with T trajectory groups as between subject factor and aggression scores as dependent variables was used to examine whether T trajectory groups differed in their dominant, aggressive, or delinquent behavior scores. In case the dependent variables were dichotomous, we conducted a Pearson chi-square test.

Finally, a continuous variable stepwise approach using multiple regressions was applied to establish whether the various assessments of aggressive and delinquent behavior from childhood to adulthood had a predictive relationship with T at age 21. With respect to the teacher reported reactive and proactive aggression scores, correlations were calculated between these scores, and on the

basis of these results, proactive and/or reactive aggression scores were entered in the regression analysis. Continuous scores for proactive- and reactive aggression (mean scores over ages 12 to 15), for toughness and leadership (mean scores over ages 13 to 15), and for delinquency (mean scores over ages 13, 15, and 20), dummy scores for CD group and crime record group, and the probability score of being in the high physical aggression trajectory group (see Nagin and Tremblay, 1999, 2001) were used as predictors, whereas T level at age 21 was entered as dependent variable.

Results

Behavioral and T changes in the pubertal period

Figs. 1 and 2 show the patterns of mean T levels at ages 13, 16, and 21 (Fig. 1) and behavioral assessments from early adolescence to adulthood (Fig. 2). As expected, T levels increased significantly in this time period ($F(2,94) = 160.4$, $P < 0.01$). However, contrary to expectation, significant main effects of time were found reflecting an overall decrease in scores on teacher rated proactive- ($F(3,66) = 4.6$, $P < 0.01$) and reactive aggression ($F(3,66) = 10.7$, $P < 0.01$). With respect to self-reported delinquency we also found a significant curve linear effect of time ($F(2,74) = 46.4$, $P < 0.01$).

T levels in aggressive, dominant, and delinquent subgroups

Next, separate AN(C)OVAs were conducted to find out whether there was a relationship between T and aggressive, dominant, and/or delinquent behavior at ages 13, 16, and 21 years (see Table 4).

At age 13, T correlated moderately strong with pubertal status ($r = .30$, $P < 0.01$), but at age 16, the size of the correlation was much lower ($r = 0.12$, ns). Pubertal status at age 13 was therefore entered as a covariate in the analyses for that particular year. When examining the differences between high and low aggression, dominance, or delinquency subgroups in T level at age 13, we did not find any significant differences (see Table 4).

At age 16, boys with an official crime record were found to have significantly higher T levels compared to boys without such a record (Mann–Whitney U test; $Z = -2.14$, $P = 0.03$). Moreover, at age 16, T was higher in high proactive aggressive (HPA) boys than in low proactive aggressive (LPA) boys (Mean ± SD: LPA = 38.3 ± 19.0 pg/ml, HPA = 53.4 ± 22.6 pg/ml, $F(1,89) = 11.89$, $P < 0.01$), and higher in the high reactive aggressive (HRA) subgroup than in the low reactive aggressive (LRA) subgroup (Mean ± SD: LPA = 39.5 ± 19.3 pg/ml, HPA = 51.1 ± 23.1 pg/ml, $F(1,89) = 6.83$, $P = 0.01$). No T differences were found at age 16 between high and low dominant groups, high and low physically aggressive groups, groups with and without CD, or between self-reported delinquent subgroups (see Table 4).

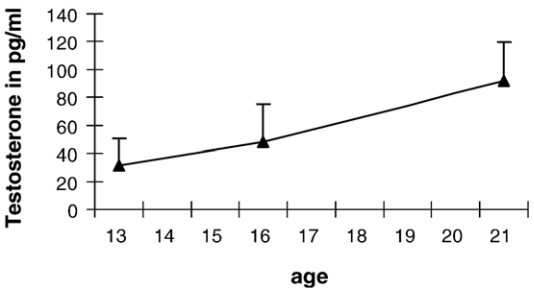

Fig. 1. Mean daily T at ages 13, 16 and 21 years.

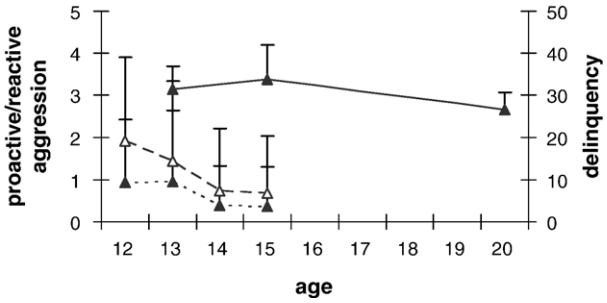

Fig. 2. Changes in scores for proactive (- -▲- -) and reactive (- - -△- - -) aggression and delinquent behavior (—▲—) from early adolescence to adulthood.

At age 21, high delinquent males (HD, $n = 46$) had higher T levels than low delinquent males (LD, $n = 47$; $F(1,91) = 11.1$, $P < 0.01$). No meaningful differences in T were found between the other aggressive, dominant, or delinquent subgroups.

T trajectories

Additional analyses were conducted to examine whether T trajectory groups differed in scores for aggressive, dominant, and/or delinquent behavior. We found that of the 5 boys who had a criminal record no one belonged to the LT group, one belonged to the MT group, and the remaining four boys belonged to the HT group (Pearson chi-square = 6.21, $P = 0.05$).

Finally, a (linear) stepwise multiple regression analysis identified the behavioral assessment that best predicted T at age 21 when controlling for each of the other assessments. Although a high correlation was found between the mean reactive and proactive aggression scores ($r = 0.79$, $P < 0.01$) this score was not sufficiently high enough (the criterion being $r > 0.90$) to treat these variables as essentially the same. Both variables were therefore entered into the analysis. It turned out that the mean Z score on self-reported delinquency between ages 13 and 20 years best predicted T level at age 21, accounting for 5.5% of the variance (with Beta = 0.24, $F(1,69) = 4.02$, $P = 0.05$). Once the delinquency score had been entered into the equation, the other delinquency, dominance, or aggression variables did not add significantly to the prediction.

Discussion

So far, very few studies (Drigotas and Udry, 1993; Granger et al., 2003; Tremblay et al., 1997) have examined the aggression–testosterone (T) relationship by taking repeated samples of T over time and by assessing this relationship longitudinally with a multi method/multi informant procedure. In the present study, we first aimed to explore whether aggressive and/or delinquent behaviors increased from early adolescence to adulthood due to the concurrently rising levels of T. Secondly, we investigated whether physical aggression, social dominance and/or delinquent behavior, as observed from childhood to adulthood, had a

Table 4
Differences in T between aggressive, dominant, and delinquent subgroups, assessed at ages 13, 16 and 21 years, using AN(C)OVAs

	Age 13 (ANCOVA)			Age 16 (ANOVA)			Age 21 (ANOVA)		
	df	*F*	*P*	*df*	*F*	*P*	*df*	*F*	*P*
Independent variables									
Toughness	1,83	0.59	0.45	1,94	0.06	0.81	1,94	0.04	0.84
Leadership	1,83	3.50	0.07	1,94	0.46	0.50	1,94	0.29	0.59
Proactive aggression	1,80	0.33	0.57	1,89	11.89	0.00	1,89	0.17	0.68
Reactive aggression	1,80	0.01	0.94	1,89	6.83	0.01	1,89	0.01	0.95
Aggression trajectory	2,82	0.11	0.89	2,93	2.16	0.12	2,93	1.16	0.32
Delinquency	1,83	0.09	0.76	1,91	0.34	0.56	1,91	11.11	0.00
Interactions									
Toughness × leadership	3,81	1.00	0.40	3,92	0.26	0.85	3,92	0.30	0.82

positive relationship with (changing) T levels. To that end, we examined a population-based sample of boys ($n = 96$) who were followed from kindergarten up to age 21. As expected, T levels increased significantly during pubertal development. However, contrary to prediction we found that in the same period, boys did not display an increase in either teacher-rated aggressive behavior or self-reported delinquency; we even observed a decreasing pattern in these types of behavior. These findings are in line with earlier results (Susman et al., 1987; Halpern et al., 1994), in which T levels were found to rise with pubertal stage and age, but no significant positive relationship was found between aggression and age. These results clearly pose problems for accounts of an activational influence of T on aggressive behavior. Thus, the evidence for a direct, activating or stimulating effect of T on aggression during adolescence remains therefore at best controversial (Eichelman, 1992; Reiss and Roth, 1993).

However, a further and closer examination of the data showed that at different annual time points there were clear and positive associations between T, on the one hand, and aggressive, and/or delinquent behavior, on the other. We found that boys who turned out to have an official crime record as an adult (so-called criminals-to-be), had higher T levels at age 16, compared to boys without such a record. Moreover, we found that high proactive and high reactive aggressive boys also had higher T levels at age 16 than the low aggressive subgroups. At age 21, T levels were higher in boys who were highly delinquent from age 13 to age 20, compared to the low delinquent subgroup. In a linear stepwise regression analysis, we also showed that the mean self-reported delinquency score from ages 13 to 20 was the only and therefore best predictor of T level at age 21. In contrast to earlier findings by Schaal et al. (1996), no relationship was found between T at age 13 and either nominations of toughness or leadership. At age 13, boys may have strong social constraints which restrain them from showing aggression. This in contrast to age 16, when social constraints might become weaker, possibly leading to a stronger T-aggression relationship. The antisocial behavior has been found to decline again after boys get more serious (e.g., with work and relationships) (Moffitt, 1993). This would indicate that the stronger relationship during puberty might rather be related to social ('maturity gap') than to biological factors. However, it is also surprising that no relation was found between aggression and T at age 13 given that the Schaal et al. study and the present one at least in part shared the same data set. An important difference between these two studies, however, is that we decided to use in the present statistical analyses the mean T level as calculated over several samples collected on 1 day, whereas Schaal et al. (1996) examined the pattern of T concentration over the day. In addition, from a further set of analyses in which we created T trajectory groups, it became clear that the boys who consistently have the highest levels of T over the years are the ones who later have an elevated risk of becoming delinquent convicts. Thus, although there is some positive association between T and aggressive or delinquent behavior over the years of assessment, different variables turn out to have a significantly positive relation with T at different ages, while it is the general impression that T is most closely related to delinquent behavior. At present, it is not clear why this is the case. One explanation is that we used a sample that was restricted to boys from low socioeconomic families. SES is known to correlate inversely with externalizing problems, such that lower SES boys show higher average levels of aggression (e.g., Nagin and Tremblay, 2001). Thus, the present sample is composed of adolescents who could be expected to be at the higher end of the continuum of externalizing behavior, and this restriction of variance may influence the likelihood of detecting relations among the variables. In addition, Mazur and Booth (1998) suggested that dependent on the social setting T could be related to dominance, aggressive behavior, or delinquent behavior, such as norm breaking. Within settings in which the behavior of subordinates is required to conform to rigid norms or laws (e.g., such as in schools), high T in dominant boys could encourage types of behavior which are regarded as rebellious, antisocial, or even criminal (Mazur and Booth, 1998). We examined in our study boys over a period of important physical, emotional and social change and thus depending on the precise timing of the measurements and the circumstances of the boys T could be related to different types of dominant, aggressive or delinquent behavior.

Limitations

The present study also had some methodological limitations. First, the population-based sample was limited to

young Caucasian males from lower socioeconomic areas in a large North American city. It will be important to replicate these results with other population-based samples. Second, it is clear that future studies even more than we did now need to assess dominance, delinquency and aggression in ways that are comparable (Tremblay, 2000, 2003). Third, future studies could examine assessments of proactive and reactive aggression from different sources of information. And finally, although we examined the aggression-T link longitudinally by measuring T as well as aggressive, dominant, and delinquent behavior repeatedly over time, future studies should assess T, aggressive behavior, and measures of social context simultaneously.

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