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Androgen Dynamics in the Context of Children's Peer Relations: An Examination of the Links Between Testosterone and Peer Victimization

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Testosterone levels have been shown to decrease in the face of social defeat in several mammalian species. Among humans, the loss of social status has been studied primarily in the context of athletic competition, with winners having higher testosterone levels than losers. This study examined testosterone levels in relation to peer victimization (bullying) in a sample of 151 boys and girls aged 12–13. Statistically controlling for age and pubertal status, results indicated that on average verbally bullied girls produced less testosterone and verbally bullied boys produced more testosterone than their nonbullied counterparts. Similar trends were evident comparing social and physical bullying with testosterone. Sex differences are discussed in terms of empirically validated differences in coping styles, as girls tend to internalize, whereas boys tend to externalize, their abuse. Aggr. Behav. 35:103–113, 2009. © 2008 Wiley-Liss, Inc.

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INTRODUCTION

It is well established in nonhuman mammals that aggression is related in a number of ways to activity of the hypothalamic–pituitary–gonadal (HPG) axis [see Brain and Haug, 1992; Monaghan and Glickman, 1992]. Males are typically more aggressive than are females and have higher perinatal and circulating adult testosterone levels [see the review by van Goozen, 2005]. Castration of males is well known to reduce aggressiveness in several mammals [see the review by Albert et al., 1993]. In laboratory mice, chronic stress and social defeat can decrease HPG activity [Brain, 1972; Eleftheriou and Church, 1967; McKinney and Desjardins, 1973]. In rhesus monkeys, gonadal tone also increases with greater contact with females, and social dominance is associated with increased gonadal and reduced adrenocortical tone [Bernstein et al., 1983].

Although the nonprimate trends are much clearer than those among primates [see reviews by Albert et al., 1993; Archer, 1991], some evidence suggests interactions between HPG activity and aggression among humans [e.g., Olweus et al., 1980, 1988; Pajer et al., 2006; Tremblay et al., 1998; van Goozen et al., 1998], especially when dominance is considered vis-à-vis testosterone [see Mazur and Booth, 1998]. Mazur [1985] suggests that dominance and testosterone are reciprocally related, whereby individuals exhibiting dominance produce more testosterone (or maintain their already elevated levels) as compared with those exhibiting deference. Such a feedback loop has been demonstrated in male rhesus monkeys [Bernstein et al., 1983], where differential androgen levels appear to be more of a consequence than a cause of social dominance. Although alpha males in stable social groups consistently had the highest androgen levels, when transferred to new groups

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these same males were subordinated by other males and their circulating testosterone levels plummeted, suggesting that social defeat is a potent depressor of testosterone.

In humans, social status has been studied primarily in the context of athletic competition involving males. Booth et al. [1989] examined testosterone in six university male tennis players across several matches, finding increases in testosterone prior to the competition, whereas winners' levels exceeded those of losers after the match. Effects of winning on testosterone carried forward to subsequent matches, as winners had higher testosterone than did losers just before their next match [see also Mazur and Lamb, 1980]. Similar findings have also been obtained for male wrestling [Elias, 1981] and male judo [Suay et al., 1999]. Male hockey players have been observed to have significantly higher testosterone levels pregame when playing in their home venue as opposed to another team's venue [Carré et al., 2006]. Bernhardt et al. [1998] examined the testosterone levels of male Italian and Brazilian soccer fans before and after the 1994 World Cup final and found that testosterone rose for the winning Brazilian fans and decreased for the losing Italian fans. Similar findings were also obtained for fans watching a college basketball game between two rivals [Bernhardt et al., 1998]. Other studies have demonstrated hormone-status effects that extend beyond athletic competition. In a study of American male military officer candidates, Kreuz et al. [1972] found low levels of testosterone at the beginning of training, with normal levels returning shortly before graduation. Mazur and Lamb [1980] found an increase in testosterone in male medical students shortly after their degrees were conferred. Dabbs et al. [1998] found that trial lawyers had higher testosterone than nontrial lawyers.

Studies examining the effects of status loss in relation to testosterone in females are few in number and tend to focus on contrived competition that occurs in the context of athletic sporting matches or competitive tasks in laboratory settings. These few studies have shown that the hormone-status effect seen in males is not typically replicated with females. For example, although Bateup et al. [2002] did find a pregame anticipatory rise in testosterone among female rugby players, the postgame levels were the same among losers and winners. Kivlighan et al. [2005] examined the testosterone levels in males and females before and after a rowing ergometer competition and found that the pattern of results was "complex," varying by the level of competence, the type of hormone examined, the specific phase of the event, and gender. As one example, novice women's testosterone levels declined in anticipation of the competition. Mazur et al. [1997] examined sex differences in testosterone in response to playing a video game against a same-sex competitor and found that females' testosterone levels generally decreased as the experiment progressed.

This study was designed to examine androgen dynamics in the context of children's peer relations, where real-world bids for social status occur on a frequent basis [for a review, see Vaillancourt et al., 2008c]. Indeed, obvious social hierarchies are found among preschool children [Charlesworth and LaFreniere, 1983; Hawley, 2002; McGrew, 1972; Strayer and Strayer, 1976], children [Pickert and Wall, 1981; Weisfeld et al., 1980], and adolescents [Coleman, 1961; Savin-Williams, 1979, 1980; Thrasher, 1927; Whyte, 1943]. These hierarchies are often achieved and maintained through aggressive means [e.g., Adler and Adler, 1995, 1998; Hawley, 2003; Merten, 1997; Ostrov and Keating, 2004; Vaillancourt et al., 2003]. These aggressive means are used more frequently at the beginning of new group formations (e.g., school transitions) when individuals are insecure about their social standings and/or are vying for higher status [Pellegrini and Bartini, 2000; Pellegrini and Long, 2002; Pepler et al., 2006]. Children and adolescents are acutely aware of their social standing in the peer group [e.g., Adler and Adler, 1998; Savin-Williams, 1979], actively compete for hegemony [Vaillancourt and Hymel, 2004, 2006], and are psychologically and physiologically affected by it [Vaillancourt et al., 2008a].

In children's peer groups, nonorganized, naturally occurring competitions for status often take the form of bullying [Adler and Adler, 1995, 1998; Hawley, 2003; Merten, 1997; Ostrov and Keating, 2004; Vaillancourt et al., 2003]. Bullying, or peer victimization, is characterized by three critical components: intentionality, repetition, and power imbalance [Olweus, 1999]. Thus, an occasional fight between two equals is not bullying; rather bullying is a repeated unfair fight initiated by one or more persons with more power than the victim. Power can be achieved through a number of avenues, including strength, size, number in a group, and social popularity [for a review, see Vaillancourt et al., 2008c]. Children who bully often have high status in their peer group, which is maintained through aggressive means [Vaillancourt et al., 2003], whereas children who are victimized by their peers often have low status [for a review, see Rubin et al., 2006]. According to Björkqvist [2001], bullying has "interesting parallels with animal models of social defeat" (p 439) in terms of the power differential that is present between the victim and the aggressor and the stress that is associated with the abuse.

This study examines the link between salivary testosterone and peer victimization in boys *and* girls. We examine these links in early adolescence (ages 12–13), which represents a time when peer relations are the most important and salient aspect of children's school experiences [Adler and Adler, 1995; Gavin and Furman, 1989] and when peer victimization has been shown to peak [Nansel et al., 2001; Pepler et al., 2006]. If trends observed in adult males of other mammalian species hold, and if competition as seen in bullying reflects the trends seen in human males during sporting competitions, then it might be predicted that males who are victimized by their peers would have lower testosterone levels than those who are not. With respect to girls, the formulation of a directional hypothesis is complicated by the fact that few studies have examined testosterone in relation to dominance or competition among females [Bateup et al., 2002; Cashdan, 1995; Dabbs and Hargrove, 1997; Pajer et al., 2006; van Anders and Watson, 2007], and none to our knowledge have examined testosterone in relation to adolescent girls' and boys' experiences with bullying or social defeat. As well, testosterone in females is mostly derived from dehydroepiandrosterone (DHEA) from the adrenals and accordingly the secretion pattern may be different in females than it is in males [Parker, 1991].

METHODS

Participants

The participants were recruited from school settings and newspaper advertisements. Before being formally enrolled into the study, a telephone interview was conducted with the potential participants and their parents to see if they qualified for the study. Specifically, the participants were excluded into the study if they: (1) had a history of childhood maltreatment (physical, sexual, emotional abuse, and/or neglect), (2) had a diagnosed psychiatric condition or significant psychological issue, (3) lived in a changeable home situation (i.e., foster care), (4) were currently using psychotropic medication or oral contraceptives, (5) smoked, and, importantly, (6) had a history of aggression directed toward peers and/or family members. These exclusion criteria were exercised in order to minimize potential confounds. On the basis of this telephone interview, 7 participants were excluded from the study and an additional 16 parents declined consent for their children at the screening phase. Two female participants who were enrolled in the study were subsequently excluded because they reported being abused by a caregiver. These cases were reported to the child protective agency and the participants' data were excluded from analyses as indicated in the child assent and parental consent forms.

The final sample was thus composed of 151 (80 boys and 71 girls) predominantly Caucasian middle-income children with mean age of 12 years and 7 months (SD = .76 for boys and .72 for girls). Income status was derived by matching postal codes to average family income using Canadian Census Data (2000; X = \$76,907, SD = \$24,478).

All the participants provided informed assent and their parents provided informed consent for this study, which received ethical clearance from the authors' university research ethics committee. The cross-sectional data presented in this study are part of a larger ongoing longitudinal study on children's peer relations.

Procedures and Measures

All data, including testosterone measures, were collected at the end of October and beginning of November (weeks 43 and 44) in 2005. The start of the school year was chosen because studies have shown that bullying increases at the beginning of new group formations [e.g., Pellegrini and Bartini, 2000; Pellegrini and Long, 2002; Pepler et al., 2006].

Saliva collection. Following procedures described in Vaillancourt et al. [2008a], trained research assistants (RAs) went to the homes of the participants and taught them and at least one parent how to collect the saliva samples. Detailed instructions were also left with the participants and parent(s) and a telephone reminder was made on the Sunday before the Monday collection. The participants were instructed not to eat during the 2-hr period prior to providing the passive drool sample and to chew on a piece of Wrigley's Extra™ Peppermint sugar-free gum (Toronto, Canada) just before providing the sample. As a way of standardizing the time of day the samples were provided, the participants were asked to produce their samples 20 min after waking (between 07:00 and 08:00 hr) and at 21:00 hr on Monday and Thursday evening. Saturday morning and evening samples were also collected, again 20 mins after waking (between 09:00 and 10:00 hr) and at 21:00 hr. The participants were instructed to store their samples in their home freezers (−20°C) until collected by the RAs the following week.

The participants completed a food and time log, indicating the exact time at which they produced their sample and the food they had eaten 2 hr prior to their saliva collection. They also indicated if anything stressful had occurred on the day of testosterone collection. The participants indicated in their logs good compliance with the instructions such as no eating 2 hr prior to providing samples and producing samples 20 min after waking.

Bullying. Information about participants' experiences with bullying was obtained using an empirically validated self-report questionnaire [Vaillancourt et al., 2008a] that was adapted from Olweus [1986]. In this survey the participants were first asked to read a standard definition of bullying, which differentiates peer victimization from teasing [Olweus, 1999]. They were then asked to indicate the extent to which they had been bullied physically, verbally, and socially *at school* since the start of the school year along a 5-point scale including 0 "not at all," 1 "once or a few times," 2 "2 or 3 times a month (every month)," 3 "every week," and 4 "many times a week."

The participants were asked about their experiences with all three forms of bullying because researchers have demonstrated sex difference in children's experiences with bullying. Specifically, although boys and girls seem to be equally bullied verbally, boys tend to be bullied physically more than do girls, who in turn tend to be bullied socially (peer group exclusion, rumor spreading) more than do boys [e.g., Rivers and Smith, 1994]. For each type of bullying, the following behavioral examples were provided: *physical bullying* ("hit, kicked, slapped, spat on or otherwise physically hurt"), *verbal bullying* ("said mean things to you, called you names, verbally threatened you"), and *social bullying* ("left you out on purpose, refused to play with you, said bad things behind your back, got other students to not like you"). In keeping with recommendations by Solberg and Olweus [2003], three groups were formed on the basis of bullying frequency: (1) never (= "not at all"), (2) occasionally (= "once or a few times"), (3) frequently (= "every month," "every week," and "many times a week").

Pubertal status. Pubertal development was assessed using the self-report Pubertal Development Scale (PDS) developed by Petersen et al. [1988]. This measure asks girls and boys to rate their development along a scale from 1 to 4. Girls are asked about pubic hair growth, breast development, and menstruation, and boys are asked about pubic hair growth, changes to their voice, and facial hair growth. Body hair growth, breast development, and voice changes were coded as "has not started to grow/change" = 0, "has barely started to grow/change" = 3.33, "is definitely under way" = 6.67, and "seems complete" = 10. Menstruation was coded as 10 for yes (has begun to menstruate) and 0 for no (has not begun to menstruate).

Validation of the PDS has demonstrated that self-reports of physical maturation correlated well with physicians' Tanner stage ratings [Brooks-Gunn et al., 1987].

Testosterone assays. Enzyme immunoassay procedures were developed by modifying methods previously reported and validated [Muir et al., 2001; Munro and Stabenfeldt, 1985]. All saliva samples were transported on ice and stored at −20°C prior to assays. Saliva was centrifuged at 3,000 × *g* for 15 min and only the supernatant was assayed. Testosterone standards were obtained from Steraloids, Inc., Newport, RI. Antibodies to testosterone (R156/7) and the corresponding horseradish peroxidase conjugates were obtained from C. Munro of the Clinical Endocrinology Laboratory at the University of California, Davis. Cross-reactivities for anti-testosterone are: testosterone 100%, 5α-dihydrotestosterone 57.4%, androstenedione 0.27%, androsterone, DHEA, cholesterol, 17β-estradiol, progesterone, and pregnenolone <0.05% [Munro and Stabenfeldt, 1985]. The assay was carried out on NUNC Maxisorb plates (Rochester, NY) that were first coated with 50 μL of antibody stock diluted at 1:10,000 in a coating buffer (50 mmol/L bicarbonate buffer pH 9.6) and stored for 12–14 hr at 4°C. Wash solution (.15 mol/L NaCl solution containing .5 mL of Tween 20 per liter) was added to each well to rinse away any unbound antibody, and then 50 μL phosphate buffer per well was added. The plates were incubated at room temperature for 30 min for testosterone before adding standards, samples, or controls. Fifty microliters of testosterone horseradish peroxidase was added to each well, with 50 μL of standard, sample, or control. The plates were incubated for 2 hr at room temperature. Next, the plates were washed and 100 μL of a substrate solution of citrate buffer, H_2O_2, and 2,2′-azino-bis (3-ethylbenzthiazoline-6-sulfonic acid) was added to each well and the plates were covered and incubated while shaking at room temperature for 30 min. The plates were then read with a single filter at 405 nm on the microplate reader (Titertek multiskan MCC/340 Helsinki, Finland). Blank absorbance was subtracted from each reading to account for nonspecific binding.

Optical densities were obtained, standard curves were generated, a regression line was fit, and samples were interpolated into the equation. Intraplate variation was 6.5%, whereas interplate variation was 6.8%.

RESULTS

Table I presents the number of children who have been bullied since the start of the school year by frequency (never, occasionally, and frequently), type of abuse (physical, verbal, and social), and sex . Sex differences in experience with different types of peer victimization were examined using χ^2 tests of association. A statistically significant result was obtained for physical aggression, $\chi^2(2, N = 150) = 15.11$, $P < .0001$. An examination of the standardized residuals indicated that more boys ($n = 39$) than girls ($n = 14$) reported being bullied physically on an occasional basis. There were significant bivariate correlations between physical and verbal peer victimization, $r = .46$, $P < .001$, physical and social peer victimization, $r = .29$, $P < .001$, and verbal and social peer victimization, $r = .46$, $P < .001$.

The mean puberty score was 5.23 (SD = 2.44), and there was a statistically significant difference in pubertal status between girls and boys, $F = 21.69$, $P < .001$. The mean puberty score for girls was 6.15 (SD = 2.51) and for boys was 4.40 (SD = 2.06). Pubertal status was not found to be related to experiences with peer victimization nor was it related to testosterone levels.

The distributions of the testosterone measures were skewed and very peaked and three statistical outliers (girls) were found. The testosterone data were therefore log-transformed for all analyses and the three outliers were omitted. Note that the three outliers' scores on bullying, pubertal status, and age were not outside the normal distribution. The pretransformation skewness and kurtosis scores were 2.80 (SE = .08) and 11.65 (SE = .17), respectively, whereas the posttransformation scores were −.12 (SE = .08) for skewness and 0.002 (SE = .17) for kurtosis. The morning and evening mean log(testosterone) values, standard deviations, and correlation coefficients are presented in Table II. Although there were no statistically significant mean difference in log(testosterone) by sex for any of the samples, boys did typically have higher scores than girls despite being less physically mature (see multilevel modeling description below). The correlations (log scores) between samples ranged from 0.38 to 0.57 for girls and 0.48 to 0.69 for boys.

The degree of correlation between testosterone measurements both within and between individuals

TABLE I. Number of Children by Type and Frequency of Peer Victimization and by Sex

	Physical peer victimization	Verbal peer victimization	Social peer victimization
Girls			
Never	54	25	32
Occasionally	14	36	26
Frequently	3	10	13
Boys			
Never	36	22	46
Occasionally	39	37	28
Frequently	5	21	6

TABLE II. Means, Standard Deviations, and Intercorrelations by Sex for Testosterone and log(testosterone)

	1	2	3	4	5
Girls					
1. Monday a.m.					
M = 148.27 (SD = 1.28)					
[M = 4.73 (SD = 0.76)]					
2. Monday p.m.	0.46*				
M = 135.55 (SD = 1.30)	[0.52]				
[M = 4.55 (SD = 0.87)]					
3. Thursday a.m.	0.56	0.60			
M = 147.03 (SD = 1.12)	[0.55]	[0.60]			
[M = 4.67 (SD = 0.89)]					
4. Thursday p.m.	0.57	0.44	0.57		
M = 137.70 (SD = 1.42)	[0.50]	[0.52]	[0.48]		
[M = 4.54 (SD = 0.87)]					
5. Saturday a.m.	0.58	0.47	0.47	0.37	
M = 123.53 (SD = 1.01)	[0.56]	[0.45]	[0.42]	[0.52]	
[M = 4.52 (SD = 0.80)]					
6. Saturday p.m.	0.71	0.61	0.61	0.74	0.58
M = 138.76 (SD = 1.17)	[0.48]	[0.52]	[0.38]	[0.57]	[0.57]
[M = 4.63 (SD = 0.81)]					
Boys					
1. Monday a.m.					
M = 162.61 (SD = 1.32)					
[M = 4.77 (SD = 0.83)]					
2. Monday p.m.	0.46				
M = 195.37 (SD = 2.45)	[0.51]				
[M = 4.73 (SD = 1.02)]					
3. Thursday a.m.	0.60	0.45			
M = 156.99 (SD = 1.30)	[0.69]	[0.58]			
[M = 4.73 (SD = 0.85)]					
4. Thursday p.m.	0.55	0.58	0.57		
M = 152.82 (SD = 1.90)	[0.58]	[0.53]	[0.60]		
[M = 4.50 (SD = 1.02)]					
5. Saturday a.m.	0.52	0.41	0.58	0.55	
M = 160.85 (SD = 1.32)	[0.53]	[0.41]	[0.57]	[0.64]	
[M = 4.76 (SD = 0.83)]					
6. Saturday p.m.	0.44	0.41	0.66	.058	0.61
M = 146.89 (SD = 1.36)	[0.48]	[0.51]	[0.64]	[0.50]	[0.61]
[M = 4.63 (SD = 0.87)]					

*All correlations are statistically significant at $P < .0001$ (two-tailed). Log-transformed values are in [brackets] and testosterone is measured in pg/mL.

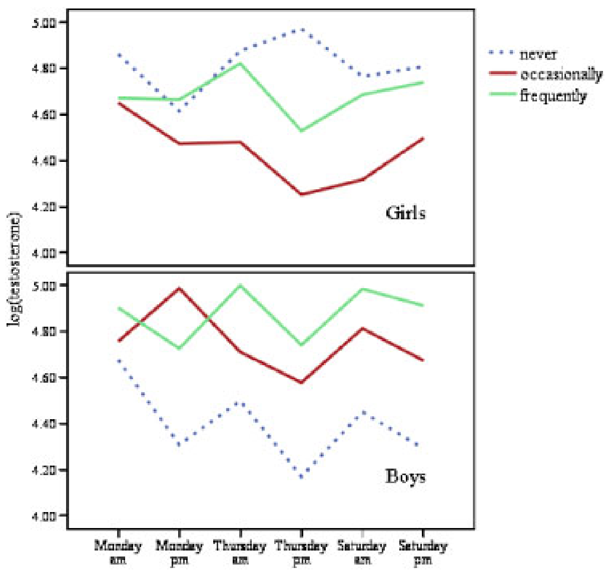

Fig. 1. Mean log(testosterone) by frequency of verbal peer victimization.

was calculated using intraclass correlation coefficients [Hruschka et al., 2005]. Results indicate that on average, the correlation between days for a person was about 0.52. However, the variability between participants for testosterone was high even after controlling for individual diurnal variation. We found that most of the variability (53%) was between rather than within children.

Because the testosterone data were nested within time and person, we statistically examined time of day (morning and evening), day of week (Monday, Thursday, and Saturday), sex (girls = 0 and boys = 1), age, pubertal status, and bullying (never, occasionally, and frequently) effects on testosterone using multilevel regression modeling [MLwiN; Rasbash et al., 2001] to control for dependency across measurements [Hruschka et al., 2005].

Using this analytic approach, we found that log(testosterone) levels were higher in the morning (coded as 0) than in the evening (coded as 1; $b = -.21$, SE = .10, $P = .04$), older children had higher levels of testosterone than younger children ($b = -.02$, SE = .01, $P = .03$), and boys were slightly more elevated than girls on testosterone, although this later finding did not reach statistical significance ($b = .06$, SE = .14, ns) until we controlled for the interaction[1] between sex and bullying ($b = -.51$, SE = .14, $P < .01$; described below).

[1]The β coefficient for males is negative because we have controlled for the effects of occasional abuse, frequent abuse, male∗occasional abuse, and male∗frequent abuse. This means that the male effect is also dependent on the level or frequency of abuse.

When we examined log(testosterone) in relation to peer victimization, we found that the children who were bullied occasionally in a verbal manner had lower level of testosterone than those who were not bullied verbally ($b = -.45$, SE = .18, $P = .01$), controlling for age, sex, pubertal status, and time and day of sampling. Furthermore, modeling the interaction between participants' sex and the regularity of being verbally bullied (controlling for pubertal status, age, and time and day of sampling) revealed that for girls, occasional and frequent exposure to verbal bullying was associated with lower testosterone ($b = -.77$, SE = .25, $P < .01$). For boys, the pattern was the opposite; verbally bullied boys had higher testosterone levels than their nonbullied counterparts ($b = .67$, SE = .33, $P = .04$). Figure 1 shows the mean log(testosterone) by frequency of verbal peer victimization. With respect to social and physical bullying, although the overall pattern of results were similar (i.e., higher testosterone for bullied boys than for bullied girls), these differences were not statistically significant.

DISCUSSION

The purpose of this study was to examine the relationship between peer victimization and testosterone levels in a community sample of children aged 12 and 13 years. Consistent with the social defeat model in animals and status loss in human athletic competition, we expected that bullied children would have lower levels of testosterone than their nonbullied peers. Results indicated that on average verbally bullied girls did indeed have lower testosterone levels than did their nonbullied peers, after controlling for pubertal status, age, and time and day of sampling. For boys the pattern was the opposite, as verbally bullied boys had *higher* testosterone than did their nonbullied counterparts (again controlling for pubertal status, age, and time and day of sampling). Similar trends were evident comparing social and physical bullying with testosterone, although these relations were not statistically significant.

We also found that morning testosterone levels were higher than evening levels, older children had higher levels of testosterone than younger children, and boys had higher levels of testosterone than did girls, consistent with previously published reports [e.g., Booth et al., 2003; Dabbs, 1990]. However, boys' testosterone levels only exceeded those of girls when the interaction between sex and experience with victimization was controlled statistically, highlighting the fact that testosterone–behavior relationships are dynamic and thus require analytic techniques that model their association beyond simple linear effects. Indeed, recent studies are increasingly pointing to the need to consider factors that moderate the testosterone–behavior relationship, in particular the role of sex [see Granger et al., 2003; Updegraff et al., 2006].

Placement of these findings in the context of the literature is complicated by the fact that there are very few studies examining androgen dynamics in girls as well as boys, as studies in childhood and adolescence have tended to focus on the relation of testosterone to aggression in males [e.g., Olweus et al., 1980, 1988; Tremblay et al., 1998]. In fact, according to Granger et al. [2004], there is "precious little information available to familiarize investigators with the effects of gender, age or pubertal development on individual differences in salivary testosterone" (p 1235). Furthermore, no study to date has examined testosterone levels in relation to oppression and abuse in childhood, despite well-articulated and empirically validated models of social defeat in both the animal and human literatures [see Björkqvist, 2001].

Accordingly, testosterone is best known for its dynamics in male adulthood and its link to aggression/dominance and not victimization [Archer, 1991; Mazur and Booth, 1998]. Nevertheless, testosterone is also measurable, albeit at substantially lower levels, in adult females and in children and youth [e.g., Bateup et al., 2002; Cashdan, 1995; Dabbs and Hargrove, 1997]. It is not surprising that patterns in females and children might be at variance with those established for adult males, where there is lower gonadal tone in subordinated adult nonhuman mammals [Bernstein et al., 1983; Eleftheriou and Church, 1967; McKinney and Desjardins, 1973] and diminished testosterone in losers of competitions in adult human sports [e.g., Booth et al., 1989; Carré et al., 2006; Elias, 1981; Mazur and Lamb, 1980]. Boys in our sample actually showed lower testosterone when they were *not* bullied. There is perhaps even less basis upon which to make predictions about dynamics in females. In a study by Bateup et al. [2002], adult women's testosterone levels were measured during college rugby competition; although testosterone increased in anticipation of the matches and postgame levels were higher than pregame levels, testosterone level during the game was unrelated to winning or losing.

There have been few studies that have examined testosterone dynamics in early adolescence and again none have examined it in relation to peer victimization. For example, Strong and Dabbs [2000] examined salivary testosterone in a relatively small sample of young children aged 3–12, finding that testosterone was associated with low sociability, but only in prepubertal children. Rowe et al. [2004] studied blot-spot levels of testosterone in a representative sample of 789 9-, 11-, and 13-year-old boys in North Carolina. As expected, there was a developmental rise in testosterone levels. Testosterone was related positively to nonaggressive conduct disorders in boys with deviant peers, and to leadership in boys with nondeviant peers, but it did not significantly correlate with aggressive conduct disorders. At a much younger age, Sánchez-Martín et al. [2000] related testosterone levels to free play social behavior in male and female preschool children. There was a positive correlation in boys between testosterone and both giving and receiving aggression in the context of serious aggression, but this relationship did not extend to playful aggression.

Some of the observed chronic dynamics of adult circulating levels of testosterone in relationship to social dominance in animal studies may be attributable to indirect causation, mediated by contact with females. Males may become dominant by defeating other males through aggression and threat gestures, and one reward of this is greater access to females. This dynamic is observed in rhesus monkeys [Bernstein et al., 1983] and mice [deCatanzaro and Ngan, 1983], and contact with females has been shown to increase adult males' gonadal tone [Batty, 1978; Bernstein et al., 1983; deCatanzaro et al., 2006; Macrides et al., 1975]. It is possible that such dynamics apply to adolescents, but for children aged 12–13 it seems unlikely. At this age, children are just beginning to develop sexual attraction to others, dating is relatively infrequent, and children's preference for peers is still relatively sex-segregated [e.g., Carver et al., 2003; Maccoby, 1988]. Still, there may be some influence of other females on boys' testosterone levels, as Updegraff et al. [2006] found a positive association between testosterone and competence with peers among adolescent boys who had close relationship with their mothers and sisters.

As the gonads in early adolescents are relatively undeveloped, emitting relatively low levels of steroids, it is possible that androgen dynamics of this study are largely of adrenocortical origin [cf. Vaillancourt et al., 2008a; see also Blanchard et al., 1993; Hermans et al., 2008]. Variations in testosterone levels could be more reflective of stress and less reflective of sexuality or other adult dynamics, which might explain why the bullied boys in our sample showed higher rather than lower levels of testosterone than their nonbullied peers. Whether variations in testosterone in early adolescents or females of any age are functional in regulating behavioral or physiological processes is not clear. Because androgens are part of the biosynthetic chain of steroids in the adrenal glands and ovaries, acting as precursors to some estrogens, their dynamics do not necessarily reflect functional processes [Levy and Lightman, 1997; Temple and Liddle, 1970].

In this study, bullied boys produced more testosterone and bullied girls produced less testosterone than did their nonbullied peers (see Fig. 1). There are at least two possible causal explanations for the observed differences between bullied and nonbullied children in testosterone. One possibility is that testosterone rises (as seen in boys) or falls (as seen in girls) in response to being victimized by peers, with this sex difference attributable to differential response to the abuse. Several studies have demonstrated that girls are more concerned about the evaluation of their peers and report more stress associated with peers than do boys [for a review, see Rose and Rudolph, 2006]. Moreover, girls also cope with bullying differently, tending to internalize their abuse through depression, anxiety, and lower self-esteem, whereas boys tend to externalize their abuse by becoming aggressive and disruptive [e.g., Hoglund, 2007]. Perhaps abused boys in this study had higher testosterone levels than nonbullied boys because they responded to their abuse by lashing out, whereas abused girls had lower testosterone levels than nonbullied girls because they internalized the rejection. This hypothesis is consistent with Taylor et al.'s [2000] theory that women use a "tend-and-befriend" strategy when confronted with a challenge, whereas men use a "flight-or-fight" strategy. Although we excluded aggressive children in this study, it is still possible that some responded aggressively to peer abuse. It is also possible that some children viewed the abuse as a challenge. If so, then the pattern of findings regarding boys is consistent with the literature reviewed above concerning dominance in sports. Future studies should examine closely the way in which peer victimization is perceived by the victim, especially in light of Wingfield et al.'s [1987] challenge hypothesis, which predicts that testosterone influences social behavior only when status is threatened [Newman et al., 2005, p 205].

An alternative possibility is that girls with lower adrenocortical and/or ovarian androgen output are more prone to being victimized in early adolescence than other peers. Similarly, it remains possible that boys who have higher levels of testosterone, or who are slightly more mature in gonadal development than their peers at this age, are somewhat more prone to being victimized [e.g., Haynie and Piquero, 2006]. Differentiating among these possibilities would require further study, for example, examining acute dynamics of testosterone's response to discrete social events and conducting longitudinal studies of transitions in children's steroids as they undergo more chronic social changes.

It is noteworthy that pubertal status in this study was not found to be related to testosterone levels although increased age was related to higher levels of testosterone. This may be related to the restricted age range of our sample. There is a time lag between testosterone surge and physical development that occurs at puberty. An individual can have a surge in testosterone and yet the physical signs associated with this shift might not yet be present, especially in boys [Styne, 2007]. If we had sampled older adolescents (14–18 year olds), a correlation between pubertal status and testosterone levels would probably have been found, particularly among boys.

As mentioned above, although the assumption is that peer victimization is related to changes in testosterone, this causal statement cannot be proven in this cross-sectional study. Another limitation of this study is that we were unable to assess the moderating role of sex in relation to frequent physical peer victimization and testosterone, because only three girls and five boys were bullied in this manner. It has been consistently demonstrated that physical aggression decreases with age and is rather atypical by early adolescence [see Tremblay and Nagin, 2005] and therefore it is not surprising that so few children report being chronically bullied in a physical manner. It would be valuable to replicate this study with a larger sample that takes into account frequency and form of bullying [see Vaillancourt et al., 2008a]. Another potential limitation of this study is that we did not assess participants' body mass index or percentage of body fat, both of which have been linked to pubertal timing and higher testosterone levels in humans [Frisch, 1972, 1984]. As well, there is a robust literature examining the prevalence of weight-based teasing and bullying, demonstrating that overweight and obese children are highly victimized by their peers [for a review, see Puhl and Latner, 2007]. Finally, because the collection of saliva was not witnessed by anyone from our research team, it is possible that instructions were not followed as closely as the participants indicated.

Notwithstanding the above limitations, this study is the first to our knowledge to examine the relation of peer victimization and testosterone in children. It helps underscore the importance of examining androgen dynamics in males *and* females as the pattern of associations appears to be markedly different. Indeed, researchers examining testosterone–behavior relationships need to consider the moderating role of sex carefully, as sex has been shown to be an important qualifying variable in several other recent studies [e.g., Granger et al., 2003; Updegraff et al., 2006] as well as this study. Finally, the implications of these findings for health and well-being ought to be considered in light of evidence linking sex hormones to immune responses in animals and humans [for a review, see Bouman et al., 2005]. It is interesting to note that there is a robust link between poor health and peer victimization [for a review, see Vaillancourt et al., 2008b]. Results of this study may help explain some of the mechanisms associated with this relationship.

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