

FETAL TESTOSTERONE AND CRIMINALITY: TEST OF EVOLUTIONARY NEUROANDROGENIC THEORY*

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Evolutionary neuroandrogenic (ENA) theory asserts that criminality is a crude form of competitive behavior over resources, status, and mating opportunities. Theoretically, males have been selected for resource acquisitiveness as a result of female preferences for mates who are successful at resource provisioning. ENA theory also asserts that brain exposure to both prenatal and postpubertal androgens (particularly testosterone) promotes all forms of competitiveness, including those that victimize others. The present study was undertaken to test ENA theory by correlating 14 self-reported measures of offending with a biomarker for fetal testosterone exposure based on the ratio of the 2nd and 4th digits of the right hand (r2D:4D), in a nonrepresentative sample of 445. Both Spearman correlations and negative binomial regressions produced results that largely supported the hypothesized connection between offending and high prenatal androgen exposure, even when findings were analyzed separately by sex. Also, offending was significantly associated with r2D:4D for both males and females. Overall, this study supports the view that exposing the brain to high levels of testosterone and other androgens prenatally elevates the probability of offending later in life.

Although the biosocial perspective remains a minority approach to criminology (Cooper, Walsh, and Ellis, 2010), many biosocial theories have been offered in recent years (Wright, 2010; Wright and Cullen, 2012). Some are Darwinian in nature, arguing that various forms of criminality have evolved by natural selection—that is, sexual assault (McKibbin et al., 2008; Thornhill and Palmer, 2000), homicide (Buss, 2006; Daly and Wilson, 1988), child abuse (Jones, 1996; Lightcap, Kurland, and Burgess, 1982), genocide (Ghiglieri, 2000), and terrorism (Thayer and Hudson, 2010). Other biosocial theories focus on neurology or neurochemistry, arguing that one or more brain functioning patterns of offenders differ on average from what is typical of nonoffenders (DeLisi, 2011; Raine, 1997; Walsh and Beaver, 2009; Yang and Raine, 2009).

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EVOLUTIONARY NEUROANDROGENIC THEORY

A decade ago, a biosocial theory was proposed that contained both evolutionary and neurological elements (Ellis, 2003, 2005). The theory, called evolutionary neuroandrogenic (ENA) theory, depicts most criminality as being an expression of crude forms of competition for resources, status, and mating opportunities. As to why involvement in crime normally declines as individuals age beyond adolescence and young adulthood, ENA theory asserts that most people learn quickly that lawful (sophisticated) forms of competition are usually more effective in acquiring resources, status, and mating opportunities (and risk fewer ill consequences) than unlawful (crude) forms. Thus, individuals who have the greatest difficulties learning and engaging in long-term planning are those who take the longest time to transition from crude to sophisticated forms of competition.

At the heart of ENA theory are two propositions: First, males have been favored by natural selection for being unusually competitive regarding the acquisition of resources, status, and mating opportunities, which in turn results in their victimizing others more than females do. Second, androgens (male sex hormones) have evolved in ways that modify brain functioning to make individuals more competitive and likely to victimize others.

Beyond these two fundamental assertions, the theory becomes fairly complex in its explanations for *how* androgens influence brain functioning to promote competitive and victimizing behavior. Most of the pertinent variables in this regard are provided in figure 1 (Ellis, 2005, 2011). This diagram asserts that a wide array of androgen-promoted neurological, cognitive, learning, and emotional factors interact to impact the probability of criminal and associated behavior patterns.

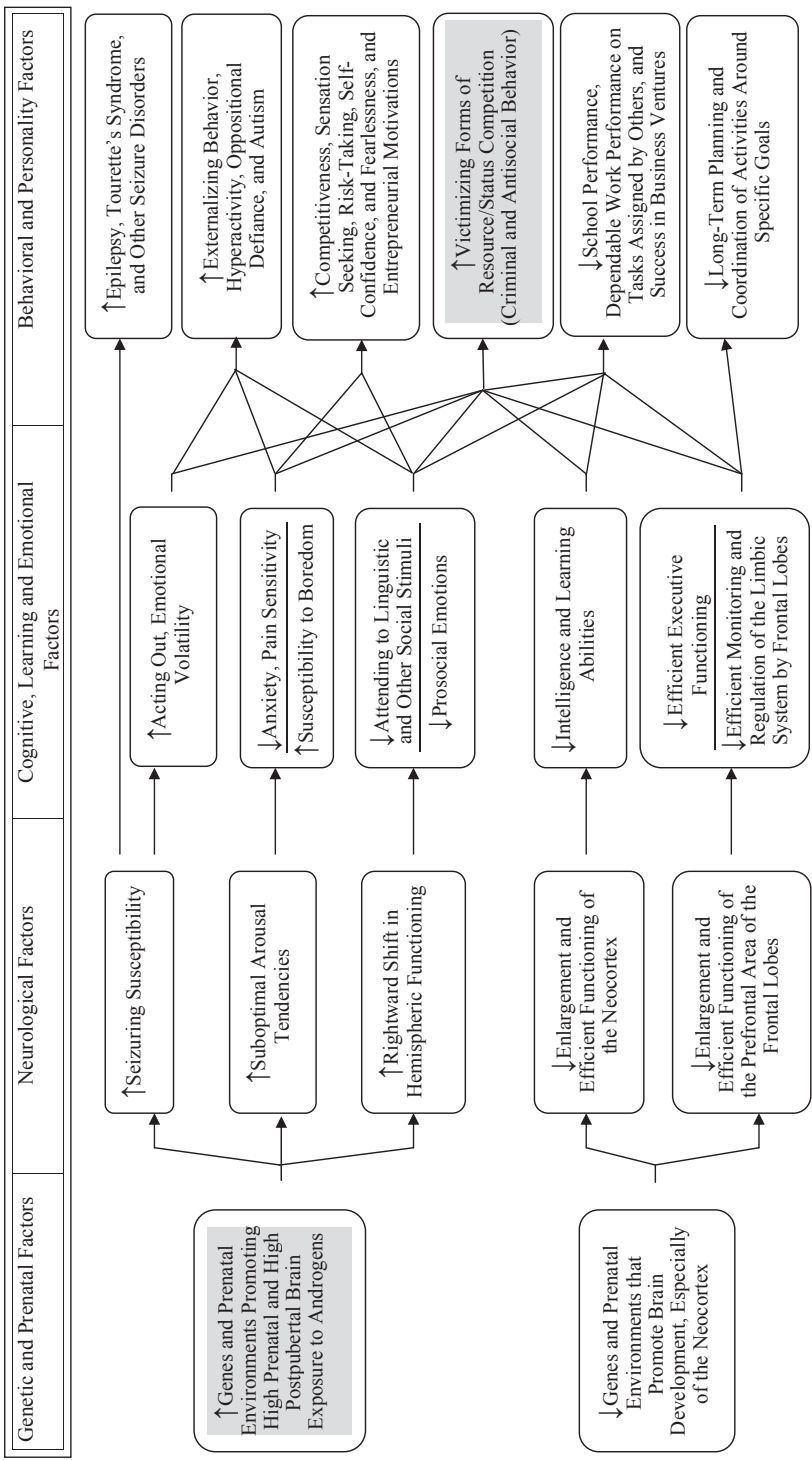
According to figure 1, androgens alter three brain functioning patterns during fetal development. However, these patterns tend not to be fully activated until the onset of puberty. These three patterns interact with other brain centers affecting foresight and planning ability (shown in the lower portion of figure 1). According to ENA theory, these neurological patterns function in ways that shape each individual's probability of engaging in delinquency and crime.

The labyrinth of causal connections hypothesized in figure 1 have a limited bearing on the present study. In fact, only two cells shown in figure 1—those that are shaded—are directly pertinent to the hypothesis that the current study will test. The shaded cell in the upper left of the diagram identifies high exposure to perinatal androgens as a key independent variable, and the shaded cell in the middle right-hand column specifies criminality as the dependent variable. In other words, although ENA theory argues that the connection between prenatal androgens and criminality involves a complex set of intervening variables, it still unmistakably predicts that exposure to prenatal androgens is central to elevating the probability of criminal behavior later in life. This hypothesis will be tested in this study.

MEASURING PRENATAL ANDROGEN EXPOSURE

To test the hypothesis that prenatal androgens promote criminality, one must have some measure of the presence of androgens during fetal development. Because ENA theory asserts that prenatal and postpubertal androgens both contribute to criminal behavior

Figure 1. Graphic Representation of ENA Theory of Criminal and Antisocial Behavior (Excluding the Evolutionary Portion)



NOTE: The only association examined in the current study was between prenatal androgen exposure (shown in the shaded cell to the left) and criminal behavior (shown in the shaded cell to the right).
Source: Ellis 2005: 296.

(as shown in figure 1), one might simply infer prenatal androgen exposure by measuring postpubertal levels. In this regard, numerous studies have revealed significant positive correlations between offending and *postpubertal* levels of testosterone, although some failures to replicate have been reported (reviewed by Ellis, Beaver, and Wright, 2009: 208–10). However, this is not a very good test of the hypothesis that *prenatal* androgens promote criminality because research has shown that there is actually little-to-no correlation between prenatal androgen levels and postpubertal levels, at least when comparisons are made *within* each sex (Hönekopp et al., 2007).

Unfortunately, direct measurement of prenatal androgens is difficult. Concentrations of testosterone in the amniotic fluid can be measured, but doing so carries some risks to fetuses and is done only with medical justification (van de Beek et al., 2004). Levels of androgens can be assessed at birth from umbilical cord blood, but these levels seem to be only modestly indicative of fetal exposure (Mori and Shiota, 1994; van de Beek et al., 2004). Furthermore, carrying out a study in which umbilical cord blood androgens were correlated with involvement in delinquency and crime would require following a sizable sample of individuals for two or more decades.

In the late 1990s, research began pointing toward a surprising indirect measure of prenatal androgen exposure. It involved observing a physical trait known as the 2D:4D finger length ratio (Hönekopp et al., 2007; Manning et al., 1998). As a rule, people with the lowest finger ratios seem to have been exposed to the highest levels of prenatal androgens. The term—abbreviated as 2D:4D—refers to the relative lengths of the second and fourth digits of the hand, with several studies indicating that the right hand provides a more reliable indicator of prenatal androgen exposure than does the left hand (Brown et al., 2002; Grimbos et al., 2010; Hönekopp and Watson, 2010; Kastlunger et al., 2010; Williams, Greenhalgh, and Manning, 2003). Parenthetically, a study of rats in which testosterone was injected into some mothers while pregnant but not in control mothers suggests that the right paw provided a more reliable measure of prenatal androgen exposure than did the left paw (Talarovicová, Krsková, and Blazeková, 2009). Throughout the remainder of this report, we will refer to the 2D:4D ratio on the right hand as r2D:4D because most studies, including the current study, are based on this hand.

It needs to be emphasized that despite its value in estimating prenatal androgen exposure, r2D:4D is far from a perfect indicator (Hell and Päßler, 2011; Lippa, 2003; Manning, 2008). Nonetheless, the few studies that have used more direct methods for assessing prenatal androgen exposure have found r2D:4D to be a modest correlate of this exposure (although estradiol, a biochemical postcursor of testosterone, also seems to affect the finger length ratio) (Lutchmaya et al., 2004; McIntyre et al., 2005; van Anders, Vernon, and Wilbur, 2006). Another clear indication that a low r2D:4D ratio is associated with heightened prenatal exposure to androgens comes from finding that males have lower r2D:4D ratios than do females (Hönekopp and Watson, 2010; McIntyre, 2006; van Anders, Vernon, and Wilbur, 2006).

As to why such a biomarker as 2D:4D would exist, a recent study of mice provided at least a partial answer. It revealed that the fourth digit on the right forepaw is unusually dense with androgen receptors. When androgen receptors in newborn male pups were experimentally inhibited with an anti-androgen drug, the fourth digit grew less relative to the second digit, thus, producing a higher (i.e., feminized) 2D:4D ratio (Zheng and Cohn, 2011).

EVIDENCE THAT PRENATAL ANDROGEN EXPOSURE PROMOTES CRIMINALITY

Empirical evidence bearing on the possibility that prenatal androgens are associated with 2D:4D as ENA theory hypothesizes is currently limited to four studies. As we will summarize, three of the four studies have provided findings supporting theoretical expectations.

Based on a sample of 77 males, one study reported that males with the lowest r2D:4D finger ratios had more moving traffic violations than did males as a whole (Schwerdtfeger, Heims, and Heer, 2010). Another study compared the r2D:4D ratios of 44 males who have at least one criminal conviction with 46 males who have no convictions. It concluded that the convicted males had significantly lower r2D:4D ratios (Hanoch, Gummerum, and Rolison, 2012). However, a study comparing the r2D:4D ratios of 44 male convicts with 66 males who did not have a conviction history found no significant differences between these two groups (Anderson, 2012). Each of these three studies was based on samples of 100 or fewer individuals, all of whom were males.

The only study conducted so far based on a large sample of both males and females was one conducted among more than 3,000 college students from the United States and Malaysia (Ellis and Hoskin, 2013). In this study, the r2D:4D measure was self-reported. Although other studies have used a variety of self-reported 2D:4D measures, such methods are less reliable than studies that use direct physical measurement by trained researchers (Caswell and Manning, 2009; Hönekopp, 2011; Manning et al., 2010). In Ellis and Hoskin's (2013) study, respondents were asked to estimate on a five-point scale whether the second finger was much longer, slightly longer, essentially the same, slightly shorter, or much shorter than the fourth finger on their right hand. Despite this crude method of measurement used, numerous significant inverse correlations between r2D:4D and criminality within both males and females from both countries were found, possibly a result of the study's large sample size. Nevertheless, the imprecision in how r2D:4D was measured leaves the findings inconclusive.

THIS STUDY

The present study was undertaken to provide a more definitive test of the possibility that criminality is associated with the r2D:4D finger ratio. Following ENA theory, the specific hypothesis to be investigated is that individuals with relatively low second to fourth digit ratios on the right hand (indicating high prenatal androgen exposure) will exhibit greater involvement in criminal behavior than those with relatively high ratios. Theoretically, this pattern should hold for both males and females. As explained in more detail in the next section, we used a precise physical measure of r2D:4D rather than one based on self-report.

METHODS

Respondents consisted of 190 (43 percent) males and 255 (57 percent) females. The sample was a combination of undergraduate college students in criminology classes at a public university in Texas and other volunteers who were at least 18 years of age who were recruited by these students. Because there was considerable age dispersion in the

current sample (18 to 76 years of age), age was statistically controlled throughout the main analyses. The racial and ethnic composition of the entire sample was 53 percent Hispanic, 40 percent non-Hispanic White, and 7 percent African American.

Participants were assured that the original data collected would be 1) kept in a secure place, 2) identified by number and not by respondent name, 3) examined by research personnel only, and 4) destroyed as soon as the information was coded and entered into an electronic file.

MEASURES OF CRIMINALITY

The questionnaire was four pages in length and covered a wide variety of topics, only a few of which were analyzed for the present study. Aside from basic demographic information, the variables herein used from the questionnaire involved an inventory of 14 self-reported offenses. Respondents were asked to report how many times during their lives (if any) they had committed each of these offenses:

1. Serious assault or beating (needing medical treatment)
2. Minor assault or beatings (not needing medical treatment)
3. Sexual assault (including attempted sexual assault, molesting, rape)
4. Domestic or courtship violence
5. Reckless driving (e.g., road bullying)
6. Illegal car racing
7. Serious theft or robbery (including motor vehicle theft)
8. Minor theft or robbery (including shoplifting, purse snatching, and pick pocketing)
9. Serious damage to property (major vandalism and arson)
10. Minor property damage (minor vandalism such as breaking windows in houses or cars)
11. Bribery, fraud, or other finance-related offenses
12. Distribution of illegal drugs (excluding alcohol)
13. Use of illegal drugs (excluding alcohol)
14. Illegal gambling

The number of times respondents stated they had committed each offense was recorded unless it exceeded 10; in which case, 10 was recorded. Also, the total types of crimes committed—a measure of criminal versatility—was computed by assigning each case a score of 1 for each category of crime with at least one reported offense (and assigning a 0 for no offenses), and then summing across the 14 crime categories.

MEASURING R2D:4D

To measure each respondent's r2D:4D ratio, we used a desktop printer and scanner with a 600 × 600 dpi scanner resolution. The respondent's right hand was placed palm down on the glass and was held flat to make certain that fingers were equally extended and to ensure that the scanner captured a clear picture of the entire right hand. GNU Image Manipulation Program (GIMP 2.8) software was used to measure digitally the length of the fingers. For both the second and the fourth digits, mouse-controlled calipers were placed on the basal crease of the finger and extended to the tip of the finger so that the lengths were measured in number of pixels rounded to one decimal place. The length of

the second digit divided by the length of the fourth digit was recorded as the r2D:4D ratio. Similar methodology has been used by numerous other researchers (e.g., Allaway et al., 2009; Coolican and Peters, 2003; Fink, Manning, and Neave, 2004; Rahman and Wilson, 2003; Roney and Maestripieri, 2004; van Anders, Vernon, and Wilbur, 2006).

If the two fingers are approximately of equal length ($r2D:4D \approx 1$) or if the index finger is longer ($r2D:4D > 1$), then low fetal testosterone (and high fetal estrogen) is indicated. If the ring finger is noticeably longer than the index finger ($r2D:4D < 1$), then the testosterone levels were high (and estrogen was low) prenatally. For reliability purposes, the r2D:4D ratio was measured on two different occasions, 3 months apart, by a person who was unaware of which scan belonged to which questionnaire. Intraobserver reliability was .89, a coefficient comparable with other studies and indicative of strong reliability (Allaway et al., 2009).

ADDITIONAL VARIABLES MEASURED

As a closing item on the questionnaire, respondents were asked the following question: "How carefully did you read and try to honestly answer the questions in this questionnaire?" Response choices ranged from 0 ("not at all honest") to 10 ("extremely honest"). The typical respondent reported a high level of honesty and care when answering questions. On average, the females in the sample stated they had been slightly more honest (mean = 9.37) than males (mean = 9.14), although the difference fell slightly short of being statistically significant ($t = -1.84, p = .07$).

Other variables that were obtained from the questionnaires were those of sex, age, and race/ethnicity. The proportionality of race/ethnicity in the sample was as follows: 7 percent Black, 53 percent Hispanic, and 40 percent non-Hispanic White. The gender, age, race/ethnicity, and honesty measures were included in the multivariate regression analysis.

DATA ANALYSES

Preliminary analysis revealed that all crime measures except for total crime types were highly skewed and overdispersed (see table 1). The Spearman rho is helpful with skewed measures because it reflects similarity of rank ordering, and thus, it was used rather than the Pearson correlation. The statistical technique adopted for the multivariate analyses was negative binomial regression. This type of regression is appropriate for models that use count data for dependent variables that have many incidences of zero offending and a great deal of dispersion among those who did report committing one or more offenses (Hilbe, 2011; Kremelberg, 2011). The measure of r2D:4D was standardized to a mean of zero and standard deviation of 1 for the negative binomial analysis to provide a more interpretable metric for the results.

RESULTS

Table 1 displays the range of responses, means, and standard deviations for each variable separately by sex. In addition, the sex difference between means for each variable was assessed for statistical significance with a *t* test. The most frequently reported offenses for both sexes were illegal car racing, reckless driving, and illegal drug use.

Table 1. Descriptive Statistics—Continuous Variables ($n = 255$ Females, 190 Males; $N = 445$)

Variable	Range	Males		Females		t Score	Significance
		Mean	(SD)	Mean	(SD)		
Serious assault	0–10	.20	(.93)	.15	(.94)	.66	.508
Minor assault	0–10	.86	(2.13)	.35	(1.46)	2.84	.005
Sexual assault	0–10	.05	(.23)	.02	(.12)	2.29	.022
Domestic assault	0–10	.12	(.57)	.10	(.67)	.36	.716
Serious theft	0–10	.07	(.23)	.05	(.23)	.58	.565
Minor theft	0–10	.77	(1.91)	.51	(1.70)	1.54	.125
Financial crime	0–10	.13	(.80)	.05	(.22)	1.35	.180
Serious property damage	0–10	.25	(1.19)	.06	(.31)	2.21	.028
Minor property damage	0–10	.77	(2.06)	.30	(1.25)	2.80	.006
Illegal car racing	0–10	3.24	(4.32)	.69	(2.17)	7.66	.000
Reckless driving	0–10	1.87	(3.24)	.69	(2.02)	4.43	.000
Drug dealing	0–10	.88	(2.47)	(1.77)	(1.77)	2.19	.029
Illegal drug use	0–10	2.74	(4.00)	1.73	(3.48)	2.80	.005
Illegal gambling	0–10	1.42	(3.14)	.18	(1.16)	5.21	.000
Total number of offense categories	0–14	2.76	(2.68)	1.42	(2.09)	5.87	.000
r2D:4D ratio	.85–1.04	.94	(.03)	.96	(.03)	–8.25	.000
Age	18–76	31.88	(12.73)	31.73	(12.66)	–.12	.903
Honesty measure	1–10	9.14	(1.36)	9.37	(1.20)	–1.84	.067

ABBREVIATION: SD = standard deviation.

As expected, the means for males were higher than for females for all 14 categories of crime as well as for the diversity of crimes committed. Nevertheless, the differences were not statistically significant for the following five specific crime categories: serious assault, domestic assault, serious theft, minor theft, and financial crime. Although the absence of a sex difference for minor theft and perhaps financial crime was not surprising, it was unexpected for violent crimes like serious and sexual assault.

All categories of crime show striking variation; standard deviations are greater than their corresponding means in all cases except for the total number of offense categories for the male sample. Many participants have never committed any one of the 14 types of crime, whereas a small minority has engaged in each of the crime types numerous times.

Regarding the r2D:4D digit ratio, the mean is significantly higher for females than for males. In fact, the t score for the sex difference in r2D:4D ($t = -8.25$) was higher than the t score for any of the sex differences in offending rates. Such a pattern conforms to findings from numerous prior studies (e.g., Hönekopp and Watson, 2010; McIntyre, 2006; van Anders, Vernon, and Wilbur, 2006), presumably reflecting the fact that nearly all females are exposed to lower levels of prenatal testosterone than nearly all males.

Correlations between finger ratio and self-reported offending are displayed in table 2. As theoretically predicted, all crime types are significantly and negatively associated with r2D:4D for the total sample. When the analyses were performed separately according to sex, all correlations remain negative, although two coefficients for the male sample—sexual assault and drug dealing—were no longer significant. All correlations for the female sample were statistically significant.

The magnitude of the relationships for most of the crime categories is in the moderate range. However, regarding the total crime category (as a measure of offending diversity or versatility) at the bottom of table 2, substantial inverse correlations were found

Table 2. Spearman Rank Correlations Between r2D:4D and Self-Reported Offending for 14 Offense Types for Males, Females, and the Total Sample

Offense Types	Total Sample (<i>N</i> = 445)	Males (<i>n</i> = 190)	Females (<i>n</i> = 255)
Serious assault	-.255**	-.189**	-.298**
Minor assault	-.284**	-.175*	-.299**
Sexual assault	-.198**	-.129	-.288**
Domestic assault	-.164**	-.179*	-.140*
Serious theft	-.278**	-.245**	-.310**
Minor theft	-.258**	-.271**	-.217**
Serious property damage	-.217**	-.207*	-.195**
Minor property damage	-.242**	-.221*	-.198**
Illegal car racing	-.264**	-.250**	-.123*
Reckless driving	-.309**	-.285**	-.222**
Bribery and fraud (financial crime)	-.239**	-.190**	-.283**
Drug dealing	-.180**	-.062	-.225**
Illegal drug use	-.244**	-.178*	-.200**
Illegal gambling	-.298**	-.284**	-.188**
Total types of crime	-.439**	-.420**	-.446**

* $p < .05$; ** $p < .01$ (two-tailed test).

(i.e., $-.420$ for males and $-.446$ for females). This observation indicates that as exposure to prenatal androgens increases, an individual's likelihood of committing a wide diversity of offenses increases considerably.

A summary of our negative binomial regression modeling is shown in table 3, with the more detailed coefficients for each control variable for all 14 types of offenses presented in the online supporting information.¹ Regarding basic interpretation, negative coefficients indicate that higher prenatal androgen exposure is associated with higher probabilities of offending (as theoretically predicted). Negative binomial regression coefficients should be interpreted as the expected log count change in the dependent variable that is associated with a one-unit change in the independent variable (Hilbe, 2011). As mentioned previously, the raw digit ratio scores were standardized to facilitate the interpretation of the negative binomial regression results.

Table 3 shows the negative binomial regression coefficient for each of the 14 offenses investigated for 1) the total sample, 2) males only, and 3) females only. When males and females are analyzed together (the total sample), table 3 demonstrates that the associations between r2D:4D and offending are statistically significant for all 14 crime categories. In all cases, the direction is negative (low r2D:4D ratios are associated with higher offending rates).

When the sample is divided according to sex, the pattern remains, although some coefficients become statistically nonsignificant. For the male sample, all digit ratio coefficients are negative, but only eight of them reached statistical significance. Those that were not significant were serious, minor, and sexual assault and all three types of victimless crime (illicit drug use, drug dealing, and illegal gambling). Among females, r2D:4D is negatively

1. Additional supporting information can be found in the listing for this article in the Wiley Online Library at <http://onlinelibrary.wiley.com/doi/10.1111/crim.2015.53.issue-1/issuetoc>.

Table 3. Negative Binomial Regression Model Using r2D:4D Digit Ratio, Sex, Age, Race/Ethnicity, and Honesty as Predictors—Only r2D4D Coefficients Are Shown

Dependent Variable	Total Sample (<i>N</i> = 445)		Male Sample (<i>n</i> = 190)		Female Sample (<i>n</i> = 255)	
	<i>b</i>	(SE)	<i>b</i>	(SE)	<i>b</i>	(SE)
Assault						
Serious	-1.52***	(.32)	-.78	(.63)	-3.37***	(.88)
Minor	-1.31***	(.32)	-.40	(.50)	-1.27**	(.47)
Domestic	-.73*	(.30)	-.75*	(.44)	-.50	(.43)
Sexual	-2.56***	(.61)	-1.65	(1.16)	-3.10***	(.79)
Theft						
Serious	-2.19***	(.41)	-1.69**	(.56)	-2.91***	(.77)
Minor	-1.17***	(.28)	-1.11**	(.35)	-1.40***	(.48)
Fraud	-2.68***	(.58)	-2.88**	(.89)	-2.97***	(.81)
Property Damage						
Serious	-.47**	(.18)	-1.81*	(.77)	-1.92**	(.66)
Minor	-.13**	(.05)	-1.13*	(.45)	-1.26**	(.45)
Illegal Car Racing	-.03*	(.02)	-.70*	(.30)	-.81	(.65)
Reckless Driving	-1.28***	(.26)	-1.30***	(.33)	-1.21**	(.42)
Drug Dealing	-.58*	(.23)	-.25	(.48)	-2.17**	(.65)
Illegal Drug Use	-.87***	(.23)	-.22	(.28)	-1.52***	(.43)
Illegal Gambling	-1.09**	(.37)	-.60	(.34)	-4.43*	(2.11)

ABBREVIATION: SE = standard error.

* $p < .05$; ** $p < .01$; *** $p < .001$ (two-tailed test).

and significantly associated with 12 of the 14 crime categories; the only exceptions were domestic assault and illegal racing.

A more detailed negative binomial regression analysis for the offending diversity measure is presented in table 4. This table clearly shows that having low r2D:4D finger ratios are associated with elevated involvement in a diversity of crimes. The associations were strong for the sample as a whole (NBR = $-.98$) as well as for males (NBR = $-.69$) and especially for females (NBR = -1.42) when analyzed separately. Following Paternoster et al. (1998), we conducted a significance test of the difference between the coefficients for males and females. The effect for the female sample is significantly larger ($z = 3.17$). Overall, having a more male-typical digit ratio (i.e., low r2D:4D) is associated with a greater diversity of crimes. This finding is true of the whole sample and for each sex, with the effect being somewhat stronger for women than for men.

Turning to the control variables other than sex (i.e., age, race/ethnicity, and self-reported honesty), table 4 shows that they are far less important than the r2D:4D variable (regardless of whether analysis is performed separately by sex). Specifically, years of age had no significant bearing on the r2D:4D–offending diversity relationships. In the case of race/ethnicity, the only significant impact was for Hispanic females to report relatively low involvement in a diversity of offenses compared with White females. Finally, the honesty item had one significant effect on the r2D:4D–offending diversity relationships. Specifically, males who professed being the most honest admitted to having committed a greater diversity of offenses than males who gave low ratings to their honesty in answering the questionnaire.

Table 4. Negative Binomial Regression Model Using r2D:4D Digit Ratio, Sex, Age, Race/Ethnicity, and Honesty as Predictors of the Total Categories of Crime Committed

Predictors	Total Sample (N = 445)		Males (n = 190)		Females (n = 255)	
	<i>b</i>	(SE)	<i>b</i>	(SE)	<i>b</i>	(SE)
r2D:4D ratio	−.98***	(.11)	−.69***	(.13)	−1.42***	(.19)
Male	.39***	(.11)	—		—	
Age	.04	(.03)	.03	(.03)	.08	(.05)
Age-squared/10	−.01	(.00)	.00	(.00)	−.01*	(.00)
Black	.04	(.21)	−.11	(.30)	−.18	(.32)
Hispanic	−.04	(.12)	.22	(.14)	−.44*	(.20)
Honesty	.02	(.04)	.11*	(.06)	−.08	(.07)
α^a	.60		.39		0.92	
Intercept	−.07	(.63)	−.78***	(.80)	−.46	(1.02)
Model χ^2	126.63***		37.19***		63.87***	
d.f.	7		6		6	
N	466		200		266	

NOTE: Standard errors are presented in parentheses.
ABBREVIATION: d.f. = degrees of freedom.
^aThese values reflect the residual variance in true crime counts, which is dispersion beyond that expected from a simple Poisson process.
* $p < .05$; *** $p < .001$ (two-tailed test).

Again, the overall conclusion to draw from table 4 is that r2D:4D is by far the most important factor used in the current study to account for variations in offending diversity. Age, race/ethnicity, and honesty had little-to-no bearing on offending diversity, and the effects of sex were modest for the sample as a whole (which was of course totally eliminated when males and females were analyzed separately). Finally, it is interesting to note that the link between r2D:4D and offending diversity was considerably higher for females (NBR = −1.42) than for males (NBR = −.69; for gender difference in coefficients, $z = 3.17$, $p < .01$), suggesting that androgens could be even more pertinent to female variations in criminality than to male variation.

Because the ages of respondents in our sample varied a great deal and respondents were asked about *lifetime* offending, there was some concern that our findings might be partially a result of participants’ age. To assess this possibility, we not only controlled for age but also reanalyzed the data only among the respondents who were between 18 and 30 years of age. The pattern of results was very similar to that for the full sample. In particular, the link between digit ratios and the measure of crime versatility remained negative and significant for the total younger subsample (NBR = −.87 [.14], $p < .001$, $n = 265$), as well as for males (NBR = −.59 [.20], $p < .01$, $n = 110$) and females (−1.10 [.22], $p < .001$, $n = 155$) in the younger subsample.

DISCUSSION

ENA theory rests heavily on lines of evidence that evolution has shaped the functioning of the human brain so that males can at least partially accommodate female preferences

for mates who are loyal and reliable provisioners of resources (Geary, 2010; Miller, 2011). These female preferences in turn are thought to have evolved because females with such preferences have a reproductive advantage over females who use other criteria for choosing mates (Buss and Schmitt, 1993; Ryan, 1998).

According to ENA theory, as a result of females choosing mates who are competent at resource provisioning, sex hormones such as testosterone have evolved tendencies to promote competitive and status-striving behavior among males. However, because competitive, status-striving behavior often can victimize others, thereby provoking retaliation from victims (or their relatives), learning to strive for resources and status in ways that minimize retaliation is important. As civilizations have evolved, the urges that victims have to avoid being victimized has given rise to written criminal statutes, which in turn has brought about the criminal justice system as an enforcer of those statutes (Conley, 1991).

To explain most forms of criminality (including delinquency), ENA theory asserts that the motivation to compete for resources and status (and for mating opportunities) is largely hardwired into the brain and that androgens play a central role in guiding this process (Ellis, 2005). Studies have shown that androgens help to organize several areas of the brain (Kimura, 1992), particularly in the arousal control centers (Daitzman et al., 1978) and the neocortex (Wisniewski, 1998; Witelson, 1991).

Androgens also seem to impact at least two important neurotransmitter systems. These are the dopaminergic system (Hull et al., 1998; Ngun et al., 2011) and the serotonergic system (van Goozen and Fairchild, 2006). Studies have suggested that the combined effects of these systems result in greater male tendencies to be competitive, impulsive, self-directed, and willing to take risks (Christiansen, 1998; Davies, 2014; Smith, Chein, and Steinberg, 2013; Trent and Davies, 2012). Sex differences in these competitive, impulsive, self-directed, and risk-taking tendencies often are noticeable soon after birth but normally become accentuated after the onset of puberty when androgen levels surge, particularly among males (Collaer and Hines, 1995; Hull et al., 1998; Manning et al., 2014).

Another important factor in sexually differentiating the brain—always to varying degrees rather than in an either/or fashion—involves the prevalence of androgen receptors (Ngun et al., 2011). These receptors, located in neurons as well as cells more generally, are programmed by genetic codes called “CAG repeats” located on the X chromosome (Allen et al., 1992; Zitzmann and Nieschlag, 2003). To the extent that androgen receptors are present, many male-typical traits are promoted, including ones of a neurological (and thereby behavioral) nature (Azurmendi et al., 2006; Kimura, 1992; La Spada et al., 1991; Sato et al., 2004).

As noted, ENA theory asserts that the motivation for resource acquisition and mating opportunities are largely unlearned. However, the ability to recognize the most effective *techniques* for making these acquisitions interacts heavily with learning ability and the ability to plan (figure 1). Consequently, as puberty commences, individuals with the most highly androgenized brains usually exhibit “crude” forms of resource competition and efforts to mate. Within a few years, most of these individuals develop increasingly “sophisticated” forms of resource procuring and mating techniques that are within legal boundaries. In contrast, males who are slow to develop “sophisticated” forms of competition for resources and mates are those who exhibit the greatest difficulties learning and planning (Ellis, 2005, 2011). These latter individuals are most likely to exhibit long-term criminal careers.

MAIN RESEARCH FINDINGS

As noted earlier, ENA theory's central theme is that prenatal brain exposure to androgens has evolved so as to promote competitiveness over resources, status, and mating opportunities in males, with the stipulation that criminality tends to be crude expressions of this competitiveness. Males should therefore be more involved in crime than females, as considerable research has documented (reviewed by Ellis, Beaver, and Wright, 2009: 11–7). ENA theory's prediction of universal sex differences in offending contrasts with the more prevalent view that sex differences in offending result from social learning (Akers and Jensen, 2006; Burton et al., 1998; LaGrange and Silverman, 1999; Shekarkhar and Gibson, 2011; Steffensmeier and Allan, 1996).

In addition to explaining sex differences in criminality in terms of sex differences in brain exposure to androgens, ENA theory leads to the hypothesis that even *within each gender* elevated prenatal androgens should positively correlate with criminality. In other words, if 1) gender differences in criminal behavior are substantially influenced by prenatal androgens and 2) variability exists *within* both sexes regarding prenatal androgen exposure—as evidence has suggested (Collaer and Hines, 1995)—then prenatal androgens and criminality should remain correlated even *within* each sex.

We used negative binomial regression to refine the results of our more basic correlational analysis, with r2D:4D, sex, age, race/ethnicity, and an honesty-in-answering-the-questionnaire item entered into the prediction equations as control variables. Tables 3 and 4 show that the r2D:4D digit ratio was a strong predictor of involvement in criminal behavior, and in all cases, the relationship was negative (as theoretically predicted). These findings confirm the hypothesis that low digit ratios (indicating greater prenatal exposure to androgens) are associated with increased probabilities of offending.

UNIQUENESS OF THIS STUDY

Although most of the methodology used in this study resembled those reported recently by Ellis and Hoskin (2013), there were two notable differences. First and foremost, rather than relying on self-reported r2D:4D based on a simple 5-point scale, the present study used a more reliable objective measure of r2D:4D. This measure has become recognized as the gold standard measure of the relative lengths of the second and fourth digits with well-established interrater reliability (e.g., Brown et al., 2002; Grimbos et al., 2010; Hönekopp and Watson, 2010; Kastlunger et al., 2010; Williams, Greenhalgh, and Manning, 2003). Furthermore, at least one study has shown that the measure is indeed indicative of varying prenatal testosterone exposure (Lutchmaya et al., 2004).

Second, although both the Ellis and Hoskin (2013) study and the present one indicated that low r2D:4D ratios (indicating higher prenatal exposure to androgens) were associated with self-reported offending, most of findings from the present study were substantially stronger. This result can be explained by noting that in this study a more reliable physical measure of r2D:4D was used.

As noted in the introduction, three studies have investigated the association between r2D:4D and officially measured criminality of traffic violation. In this regard, Schwerdtfeger, Heims, and Heer (2010) found an association of $-.36$ between males having been convicted of a moving traffic violation and r2D:4D, and Hanoch et al. (2012) reported that for male offenders versus male nonoffenders more generally, the association with r2D:4D was $-.24$. The magnitude of these associations is similar to the within-male findings from

the present study. Nevertheless, a third study of official involvement in crime by Anderson (2012) found no significant differences between males who had been convicted and those who had not been. Obviously, more research is warranted, but the overall pattern of findings so far is pointing toward confirmation of the hypothesis that prenatal androgens have an impact on criminal behavior.

LIMITATIONS

The present study has at least five notable limitations. First, the study was based on a convenience/snowball sample of university students in Texas majoring in criminology and friends and family members they recruited for participation in the study. Consequently, the sample is disproportionately young, middle class, southern, and Hispanic, which limits the generalizability of our findings and underscores the need for replication.

Second, for some offenses in which sex differences were expected (e.g., serious assault, domestic assault, and serious theft), none were identified. We believe that this was most likely because of the failure of our sample to include sufficient numbers of individuals who were involved in serious criminality. An additional consideration is that only 43 percent of the sample were males, which further diminished the chances of seriously criminal individuals having been included in our sample.

Third, the r2D:4D digit ratio has been shown to be a proxy, albeit not very precise, for prenatal androgen exposure (Hell and Päßler, 2011; Lippa, 2003). Also, one should bear in mind that factors other than androgens affect digit growth (McIntyre et al., 2005; Voracek, Manning, and Dressler, 2007). Furthermore, the availability of androgens in the body's extremities when a growth spurt occurs in the fourth digit cannot be considered anything but roughly associated with androgen levels *inside the nervous system* during critical periods of fetal development (McIntyre, 2006; Talarovicová, Krsková, and Blazeková, 2009). Also, it is worth noting that self-reported offending provides only a rough gage of people's varying tendencies to violate criminal statutes (Moffitt and Silva, 1988; Thornberry and Krohn, 2000). As a result of these limitations in estimating brain exposure to androgens (as the independent variable) and offending behavior (as the dependent variable), one can assume that the present findings only provide minimal estimates of the extent to which prenatal brain exposure to androgens affects later involvement in crime.

Fourth, although numerous statistically significant r2D:4D–criminality relationships were herein documented, and the magnitude of most of these statistical relationships were modest to moderate, using the r2D:4D ratio for individual-level preoffending diagnostics or for parole screenings would be inadvisable. We consider the present study's findings as mainly being of interest because they provide a clear test of the theoretical deduction that prenatal androgens are influencing brain functioning patterns in ways that affect people's tendencies to commit crime.

Fifth, many hypotheses can be derived from ENA theory, only one of which was tested by the present study. As illustrated in figure 1, our study focused on determining whether a positive correlation exists between perinatal androgens (shaded cell to the left) and criminality (shaded cell to the right). So central is this hypothesis to ENA theory that failing to confirm it would certainly have put the entire theory into question. Nonetheless, our having found that prenatal androgens are associated with criminality does not mean that the rest of the theory is true. Prenatal androgens could be affecting criminal behavior through pathways that differ substantially from those depicted in figure 1.

CONCLUSION

At the heart to ENA theory is the assertion that prenatal brain exposure to testosterone and other androgens contributes to criminality. Evidence bearing on this hypothesis involved correlating a biomarker for prenatal androgens known as r2D:4D with self-reported offending. Overall, the hypothesis that low r2D:4D ratios would be positively correlated with offending was supported even when the data were examined for males and females separately, thereby eliminating the possibility that sex differences in both r2D:4D and offending were confounding the correlations. Nevertheless, further replications are in order. Also, because ENA theory is complex with numerous component variables, many other aspects of ENA theory are in need of empirical scrutiny.

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