UP School of Economics
Discussion Papers

Discussion Paper No. 2012-03 January 2012

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by

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Classification: SOCIAL SCIENCES – Economic Sciences

Keywords: academic performance, female achievement, 2D4D ratio

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Abstract

Exposure to prenatal androgens affects both future behavior and life choices. However, there is still relatively limited evidence on its effects on academic performance. Moreover, the predicted effect of exposure to prenatal testosterone (T) - which is inversely correlated with the relative length of the second to fourth finger lengths (2D:4D) - would seem to have ambiguous effects on academic achievement since traits like confidence, aggressiveness, or risk-taking are not uniformly positive for success in school. We provide the first evidence of a non-linear relationship between 2D:4D and academic achievement using samples from Moscow and Manila. We find that there is a quadratic relationship between high T exposure and markers of achievement such as grades or test scores and that the optimum digit ratio for women in our sample is lower (indicating higher prenatal T) than the average. The results for men are generally insignificant for Moscow but significant for Manila showing similar non-linear effects. Our work is thus unusual in that it draws from a large sample of nearly a thousand university students in Moscow and over a hundred from Manila for whom we also have extensive information on high school test scores, family background and other potential correlates of achievement. Our work is also the first to have a large cross country comparison that includes two groups with very different ethnic compositions.

Introduction

Performance in schooling is known to be dependent on cognitive ability, family background, and social status, but it is also heavily influenced by biological and psychological traits independent of or even orthogonal to standard notions of cognitive ability. These include aggressiveness or self-confidence, conscientiousness, and/or willingness to take risks.

Some of these characteristics may derive partly from prenatal exposure to androgenic steroids. An extensive body of existing research has shown the links between this prenatal exposure and increased circulating testosterone. This in turn has been tied to various measures of performance in ways consistent with greater testosterone exposure. The most common marker for measuring prenatal androgens is the second-to-fourth finger digit length ratio (henceforth 2D:4D) with relatively longer fourth fingers (lower 2D:4D) indicating higher fetal androgens (See Manning, 2002 for a literature review). Previous work has shown links between digit ratios and success in competitive sports, preference for risk, and success in high frequency financial trading (e.g. Honekopp et al. 2006 and Manning et al. 2007 for sports; Apicella et al. 2008, Sapienza et al. 2009, and Ronay and Von Hippel 2010 and Stenstrom et al. 2011 for risk; and Coates et al 2009 on financial trading).

There is also some limited work on the relationship between 2D:4D and academic performance but the findings are still mixed and often based on quite limited samples. Romano (2006) found that adult males' 2D:4D ratios positively predicted examination grades while females' marks were uncorrelated with these ratios. Brosnan (2008) studied British school children's digit ratios andtheir correlations with their numeracy and literacy.Digit ratios were not found to be significant for the group as a whole but there were sex based differences whereby lower digit ratios predicted numeracy for boys and higher digit ratios predicted higher literary SAT scores for girls though in both cases the effects were small. Similarly, Bull et al. (2010) found no correlated differences among children for numerical or visual-spatial tasks.

Brosnan et al.'s 2011 study considered a small group of computer science students to see if prenatal testosterone exposure was related to performance and computer-anxiety however they found few differences and no sex-related differences in grades. However, lower computer anxiety was associated with lower 2D:4D ratios.

The diverse findings across existing work on 2D:4D suggests that there may be strongly sex differentiated effects; further, the unreliable findings across studies could be driven by nonlinearity in the relationship between testosterone and later outcomes. Some characteristics associated with high testosterone could plausibly have non-linear effects on performance – some aggressiveness, for instance, may be beneficial, but too much may lead to destructive behavior (e.g. Kornhuber et al. 2011 shows low digit ratios correlated with increased tendency

to alcohol dependency). Across samples of students that truncate at different portions of the testosterone distribution, regression estimates would find positive relationships in some samples and negative relationships in others. Surprisingly, formal tests of nonlinear specifications are absent in the literature.

In addition, low 2D:4D ratios may be correlated with important omitted factors. Consider the fact that prenatal androgen exposure may also be correlated to nutrition in the womb in which case the effects of low 2D:4Dwould be a joint product of the nutritional and hormonal components of the prenatal environment. By controlling for proxies of prenatal environment, we can investigate whether the 2D:4D relationship falls to statistical insignificance after controlling for prenatal environment proxies.

Sapienza, et al. 2009 were among the first to highlight potential nonlinearities as confounding the effects of prenatal testosterone exposure that may result in insignificant linear estimations but did not directly test for non-linear effects themselves.

Our work takes advantage of detailed data on academic performance from two universities to study therelationshipbetween student achievement and digit ratios. The first is a large sample of several hundred students drawn from four different departments (economics, political science, law, and management) of the Higher School of Economics in Moscow, one of the leading universities in Russia. The second is composed of students from the University of the Philippines School of Economics.

Results

In both Russia and the Philippines, we could find no consistent pattern of results using linear regressions but in most gender separated estimates found several statistically significant results when using both linear and quadratic terms. This suggests that nonlinearities in the relationship are a neglected area in the existing 2D:4D literature.

Our findings from the Higher School of Economics (Moscow) suggest that (left hand) digit ratios significantly affect academic performance of females, but not males. In particular, women with slightly lower digit ratios (i.e. higher prenatal testosterone exposure) than average tend to perform better in school. This estimate of an “optimum” amount of prenatal testosterone exposureis calculated from the significant coefficients on the nonlinear regression.Table 1 shows that women’s left hand 2D:4D ratios have a statistically significant quadratic relationship with high school honors and math scores. Note that in both cases the quadratic term is the opposite sign from the linear term. This suggests that there is an optimal 2D:4D ratio associated with each outcome measure.

Table 1: 2d4d and Female pre-college achievements

	Dependent variable				
	HS Honors	**Olympiad**	**Full Scholarship**	**Math Score**	**Russian Score**
Left Ratio	53.10* (31.55)	2.51 (27.38)	26.38 (28.18)	2553.95**^ (1226.18)	-629.61 (1001.22)
Left Ratio^2	-26.20* (14.89)	-0.94 (13.79)	-13.18 (14.20)	-1289.44**^ (615.88)	302.32 (502.89)
R^2	1.2%	0.3%	0.2%	3.4%^	1.4%
P(F-test)	7.5%	57%	61%	10.5%	39.0%
$Beta_i$=0					
L^{Max}	1.013			0.990	

Note: Estimated through via OLS; Honors, Olympiad, and Scholarship are dummy dependent variables; results unchanged if estimated via probit. Observations where 2d4d measure is greater than +/- 3 sigma omitted. L^{Max} is the value of left digit ratio that maximizes the dependent variable, equal to $Beta^{Left}/(2*Beta^{LeftSquared})$; only reported when digit ratio coefficients are statistically significant. * denotes 10% statistical significance; ** denotes 5%. ^ denotes that results are statistically significant at 5% level if all observations are included.

In the case of Math scores, the optimum 2D:4D ratio for women, L_{max}, is significantly lower than average (i.e. more "masculine" women). High school honors seems to suggest the opposite with the optimal 2D:4D occurring at higher than average 2D:4D ratios.

Table 2 gives us the correlates of females' left hand 2D:4D measures and their performance at the Higher School of Economics; the HSE's preferred performance measure is the "cumulative rating." Students are ranked according to a cumulative measure which is a weighted mix of GPA in different subjects multiplied by a factor that is dependent on the length and relative importance of the course. This cumulative rating is used to rank all students and is also a determinant in selecting students eligible for upper class scholarships and awards.

The Left Hand 2D:4D measures have a quadratic relationship with cumulative rating similar to that in Table 1. Just as with the Math exam scores, the optimal female 2D:4D is lower than that of the average (i.e. more "masculinized" women). For students majoring in Law (Faculty 3), the quadratic relationship reverses: extreme 2D:4D predicts better performance. However, the Law faculty coefficients when summed with the all-HSE coefficients are small, less than 1/3 the size of the all-HSE coefficients.

Table 2: 2d4d and Female cumulative rating

	No department interaction	Department interaction included
Left	**18404.95***	**39603.66****
	(9957.65)	(19772.89)
L*Faculty 2		**-12060.76**
		(26295.77)
L*Faculty 3		**-52815.62***
		(28978.92)
L*Faculty 4		**-26426.87**
		(32302.85)
$Left^2$	**-9494.58***	**-20216.88****
	(5017.17)	(9921.87)
L^2*Faculty 2		**6152.08**
		(13244.46)
L^2*Faculty 3		**26971.09***
		(14545.06)
L^2*Faculty 4		**13404.32**
		(16274.81)
L^{Max}	**0.969**	**0.979**
Right	**4119.36**	
	(9017.37)	
$Right^2$	**-2134.64**	
	(4531.72)	

Note: Estimated through via OLS. Observations where 2D:4D measure is greater than +/- 3 sigma omitted. L^{Max} is the value of left digit ratio that maximizes the dependent variable, equal to $Beta^{Left}/(2*Beta^{LeftSquared})$; only reported when digit ratio coefficients are statistically significant. * denotes 10% statistical significance; ** denotes 5%.

The mean digit ratio for HSE women is 0.994, with a standard deviation of 0.036. Thus, the cumulative rating-maximizing value of 2D:4D is at least 1/3 of a standard deviation below the female mean. Outliers had no substantial influence on mean female 2D:4D.

The analogous regressions for men are insignificant for both tables; the mean male digit ratio was 0.983 with a standard deviation of 0.034.

Our second sample is from the University of the Philippines School of Economics. Using their current weighted averages in math subjects (MWA) and in economics subjects (EWA) as proxies for academic performance, we similarly find evidence of non-linear effects of digit ratios on grades for the full sample and for women when using the left hand measures of digit ratios, but not for men. As before the first order effect is positive but the second order is negative.

Table 3. University of the Philippines Grades vs. Digit Ratios (Full Sample)

Explanatory Variables	EWA	EWA	MWA	MWA
Left_2d4d	-.1812909 *(2.022483)*	29.02162 *(69.38512)*	1.961129 *(2.291595)*	128.5681** *(61.79653)*
Left_2d4d_sq		-15.19247 *(36.19287)*		-65.79793** *(32.51104)*
Constant	2.730208 *(1.946463)*	-11.28725 *(33.24952)*	.5488981 *(2.192795)*	-60.28354 *(29.35258)*
R squared	0.0001	0.0014	0.0062	0.0241
N	126	126	128	128
Lmax				0.9771

***significant at 1%
** significant at 5%
*significant at 10%

Table 3 shows the relationship between measured left hand 2D:4D ratios for the full Manila sample against EWA and against MWA. For Math Weighted Averages, the quadratic term is significant and negative.Table 4 shows this relationship broken down by gender and we also calculate an L_{max},which is the implied optimal 2D:4D ratio for each outcome measure and subsample.

Table 4. University of the Philippines Grades vs. Digit Ratios (Broken down by Gender)

Explanatory Variables	Female EWA	Male EWA	Female MWA	Male MWA
Left_2d4d	5.0673 *(79.25639)*	141.4977 *(123.9198)*	106.7099 **(61.11701)*	25.08376 *(154.4484)*
Left_2d4d_sq	-2.01464 *(41.38703)*	-72.47587 *(65.34986)*	- 54.61548**(32.18902)*	-10.06622 *(80.87946)*
Constant	-.6044195 *(37.94243)*	-66.23435 *(58.7171)*	-49.77428 *(28.99413)*	-12.13422 *(73.70529)*
R squared	0.0035	0.0420	0.0194	0.0410
N	72	49	74	49
Lmax			0.9769	

***significant at 1%
** significant at 5%
*significant at 10%

Average Left_2d4d: 0.963 (full sample); 0.956 (males); 0.967 (females)

This threshold or optimum point L_{max} occurs at around 0.977 for MWA of females, which is above the Manila mean female ratio of 0.967. Thus, unlike in Moscow for the average Manila

female, women with slightly less testosterone exposureachieve the highest math grades. But recall that female 2D:4D reveals higher average testosterone exposure for the Manila sample than for Moscow. Thus, comparing *across* the Manila and Moscow female subsamples, the results suggest that testosterone is more beneficial in increasing math grades for female Manila students than in raising cumulative grades for female Moscow students. Thus, our female Manila $L_{max,}$ feminized by Manila standards, reveals higher testosterone exposure than by Moscow standards.

Unlike the Moscow results, we also find significant results for the right hand side 2D4D regressions in Manila that have different effects than for measures of left hand 2D4D. For the full sample we find the right hand side digit ratios to be insignificant in linear form and significant for both economics and math weighted grades when using a quadratic specification. The same is true when breaking out the results by gender.

Table 5. University of the Philippines Grades vs. Digit Ratios (Full Sample)

Explanatory Variables	**EWA**	**EWA**	**MWA**	**MWA**
Right_2d4d	.1366252 (*1.733344*)	-79.8321**(*33.74905*)	1.52002 (*2.055222*)	-119.317***(*35.17666*)
Right_2d4d_sq		40.4379**(*17.01367*)		61.1047***(*17.7885*)
Constant	2.421145 (*1.708066*)	41.89644 (*16.7436*)	.9403909 (*2.018278*)	60.5903(*17.3952*)
R squared	0.0001	0.0243	0.0050	0.0425
N	126	126	128	128
Rmin		0.9871		0.9763

*** significant at 1%
** significant at 5%
* significant at 10%

Tables 5 and 6 present us with a J shaped pattern in which those with very low 2D4D ratios (high testosterone) have marginally higher grades than the average but from the estimated minimum of the grade distribution, the effect is strongly positive (i.e. higher grades are associated with higher 2D4D ratios or lower prenatal testosterone exposure). In fact, the calculated 'Rmin' of the J curve (at which grades are lowest) for the full, male, and female samples are generally below the mean right hand ratios which suggest that for the average student, grades are increasing in 2D4D (or decreasing in T). Thus, while the specific quantitative results differ between the left hand and right hand regressions, the qualitative result still seem consistent – recall that for the average (female) student, MWA is also increasing in left hand 2D4D.

Table 6. University of the Philippines Grades vs. Digit Ratios (Broken down by Gender)

Explanatory Variables	Female EWA	Male EWA	Female MWA	Male MWA
Right_2d4d	-113.175* *(63.2498)*	-177.025*** *(58.926)*	-94.94635* *(52.11924)*	-197.3734* *(113.4082)*
Right_2d4d_sq	57.595* *(30.7889)*	94.147*** *(30.9599)*	49.38609* *(25.66164)*	103.215* *(60.00437)*
Constant	57.595 *(32.4385)*	85.75541 *(27.99191)*	47.79268 *(26.43247)*	96.85394 *(53.49913)*
R squared	0.0625	0.0996	0.0685	0.0442
N	72	49	74	49
Rmin	0.9825	0.9402	0.9613	0.9561

***significant at 1%

** significant at 5%

* significant at 10%

Theoretical Discussion

Most of the existing literature on digit ratios have looked at the correlation between increased androgen exposure (high testosterone, low 2D:4D) and risk taking or aggressiveness. A more recent literature focuses more specifically on success in school or work (cf. Coates et al. 2009 on successful bond traders). Our theory focuses on the latter, particularly on measures of success in school.

Note that a low ratio can indicate both 'success-promoting' (SP) and 'success-inhibiting' (SI) traits. This is because while some assertiveness may be beneficial, too much may be destructive. Also, the presence of one SP trait might be confounded by an associated SI trait. For instance, high risk-taking may be associated with low patience. If the SI influence of prenatal androgen gradually increases in importance as androgen exposure rises, while the SP effect remains relatively constant with increased androgen, then the result will be a nonlinear effect. In the most general form, an outcome of interest W, can be expressed as

$$W = F[SP(T,X), SI(T,Y)]$$

Where T denotes prenatal androgen exposure, and X and Y denote other (possibly overlapping) factors that may influence the outcome of interest.Because of the combined effect of T,X, and Y on SP and SI traits, and the possible interaction between these traits, the net effect of T on Wmay be negative or positive and may change signs as T rises. That is, $\frac{\partial W}{\partial T} >< 0$, and $\frac{\partial^2 W}{\partial T^2} \neq 0$.Furthermore,the 2nd cross partial derivatives$\frac{\partial^2 W}{\partial T \partial X}$and $\frac{\partial^2 W}{\partial T \partial Y}$ may have nonzero values: a person's sensitivity to T might be due to confounding physiological factors that make up X and

Y, e.g. the presence of other hormones, metabolic processes, etc.Thus, that the second partial derivatives are non-zero means thatW is non-linear in T.

Empirical Discussion

Most of the existing literature has tended to find weak or inconsistent effects of prenatal testosterone exposure as measured by 2D4D ratios. Sapienza et al. 2009 highlighted the lack of significance in their regression estimates of risk aversion on student 2D4D ratios. However, their 2D4D estimates were mostly insignificant though the gender dummies were themselves significant. Their more direct measures of current testosterone did show weak but significant effects on risk aversion although this only became clearer when the authors segregated their sample into low and high testosterone men and women. They note the potential role of nonlinearities to justify this partition (p. 15269) but include no tests using higher order functional forms.

Our work is the first paper to highlight the important role of nonlinearities in considering the effects of prenatal testosterone exposure on gender differences in academic performances. Our findings suggest that existing studies which presuppose a simple linear relationship are substantially flawed and cannot be relied upon to adequately assess the true effects of prenatal testosterone on most outcome variables. However, the lack of certainty regarding the physiological channels through which prenatal hormone exposure affects attitudes to risk, confidence, or aggressiveness mean that it is difficult to specify exactly how the nonlinear relation might manifest itself in various outcome variables. The presence of inconsistent results in previous literature and the difficulty of choosing the correct non-linear specification point to the need for substantially more work in this area. There is especially a need to separate out the effects of prenatal hormone exposure on personality or psychological variables (e.g. risk aversion, conscientiousness, openness, etc.) vs those that might be more directly correlated with cognitive ability or nutritional health.

Our work also keeps open the question of whether the effects of prenatal testosterone exposure on various forms of achievement are either a) different across different ethnic or racial groups or b) are mediated by different cultural conditions which may suppress, enhance, or change the direction of these effects. This paper is only the first work in the literature to present such a large cross-national, cross-ethnic, and cross-cultural comparison.

Methods

Moscow

Data on digit ratios, gender, and (proxies for) academic performance are drawn from students at Higher School of Economics in Moscow and represent four different departments (Economics, Law, Management, and Political Science). Both right and left 2D:4D digit ratio measurements were taken for all students using a laser caliper. We omit students who stated in a questionnaire that they had broken one of these fingers. In addition, our data set includes various admission criteria used for the students. Admission to the university and offers of scholarship are heavily dependent on criteria which are a weighted average of high school test scores (the national Russian university entrance exam) and performance on various precollege competitions known as Olympiads which are offered in a number of subjects mostly in math and the sciences. We have information on student entrance exam scores, Olympiad results, and receipt of high school honors.

Since all scholarships are merit based, they are an indicator of precollege academic achievement and can serve as proxies for college academic performance, and are also outcome measures in their own right. We also use the actual test scores on the entrance exam and a dummy for admission via a high Olympiad score, information on high school honors, and current cumulative grade point average while in college.

Manila

Our second set of results comes from a smaller sample of a little over a hundred students drawn from the University of the Philippines School of Economics. All students were members of the same department and all were upper class men or women recruited voluntarily during registration for the school year 2011-2012. Their hands were photocopied and all completed a survey about their backgrounds and their grades in required courses.

OLS Regressions

For each of the Moscow and Manila samples, we run OLS regressions of each of our measures of academic performance on the digit ratios and squared digit ratios, to capture the possible nonlinearity of the effect of testosterone on students' grades. To verify whether the effect of testosterone on academic performance may be sexually dimorphic, we run separate regressions for male and females. Also, note that we only use digit ratios to proxy for testosterone, since we do not have actual data for the latter. Thus, to control for factors that may affect the way testosterone affects the growth of digits, we run regressions using the left and right hands.

We find that both the coefficients of the digit ratio and squared digit ratios are significant (and that omitting the squared term generates insignificant estimates of the coefficient of the digit ratio). Furthermore, we find some difference across male and female subsamples, which highlights the sexual dimorphism of testosterone. Lastly, estimated coefficients are also different when using left and right hand digit ratios, although the results still seem consistent for the 'average' student in the sample.

Acknowledgements

We would like to thank Ekaterina Orel, DilyaraValeeva, Ekaterina Kochergina, Karen Lazaro, and Filipinas Bundoc for excellent research assistance.

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