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Abstract

We analyze the association between performance in a mathematics course among university students at the Faculty of Business and Economics and exposure to prenatal sex hormones using the second-to-fourth digit ratio. In a sample of 516 freshmen (304 women), we find an inverted U-shaped relationship between digit ratio and mathematics grades. Males and females show the same pattern in that subjects with both high and low digit ratios earn lower grades in mathematics, while subjects with the highest grades in mathematics have intermediate digit ratios. We also find that there is no statistically significant relationship between the digit ratio and the average grades earned by students in other courses except mathematics taken in the first semester at the Faculty of Business and Economics.

Keywords: Prenatal Sex Hormones, 2D:4D Digit Ratios, Performance

Highlights

The second-to-fourth digit ratio has a non-monotonic impact on mathematics grades.

There is an inverted U-shaped relation between digit ratio and mathematics grades.

The results are the same for men and women.

The digit ratio does not have an influence on grades earned in the rest of the courses.

Abbreviations: DR=Digit Ratio

1. Introduction

The ratio between the index (2D) and the ring (4D) fingers is widely used as a proxy of prenatal exposure to testosterone. A low DR (male typical ratio) is indicative of higher prenatal testosterone levels (Drichoutis and Nayga, 2012; Lutchmaya, Baron-Cohen, Raggatt, Knickmeyer and Manning, 2004; Manning, Scutt, Wilson and Lewis-Jones, 1998). The DR has been shown to be correlated to some cognitive skills, such as visual-spatial (Austin, Manning, McInroy K and Mathews, 2002; Bull and Bensona, 2006; Castho, Osvath, Karadi, Bisak, Manning and Kallai, 2003; Poulin, O'Connell and Freeman, 2004; Scarbrouh and Johnston, 2005; Van Anders and Hampson, 2005) or music abilities (Sluming and Manning, 2000). In particular, a lower DR has been associated with higher ability in some numeric competencies (Brookes, Neave, Hamilton and Fink, 2007; Brosnan, 2008; Fink, Brookes, Neave, Manning and Geary, 2006; Kempel, Gohlkea, Klempaua, Zinsbergera, Reutera, Hennig, 2005; Luxen and Buunk, 2005). Recent studies have found that the DR also influences social and economic behavior and decision making (Apicella, Dreber, Campbell, Gray, Hoffman and Little, 2008; Brañas-Garza and Rustichini, 2011; Brosnan, 2006; Coates, Gurnell, and Rustichini, 2009; Coates, Gurnell and Sarnyai, 2010; Drichoutis and Nayga, 2012;

Garbarino, Slonim and Sydnor, 2011; Guiso, and Rustichini, 2011; Haoran, Martinsson and Sutter, 2012; Millet and Dewitte, 2006; Sapienza, Zingales and Maestripieri, 2009; Stenstrom, Saad, Nepomuceno and Mendenhall, 2011; Voracek, Pietschnig, Nader and Stieger, 2011; White, Thornhill and Hampson, 2006).

Our study analyzes the contributions of DR on academic performance. As the digit ratio is determined early in life, the potential link between academic performance and exposure to testosterone (Coates et al., 2009) cannot be reversed, that is, the digit ratio predicts academic performance, not vice versa.

The relationship between the DR and academic performance has only been studied in very recent years. Brosnan, Gallop, Iftikhar and Keogh (2011) found a negative and significant correlation between DR and academic assessments in Java Programming. Hopp, Pucci de Moraes and Jorge (2012) have partially confirmed previous results, finding that theoretical and practical grades were significantly negatively correlated to DR in males controlled by age and hours of study, but not in females. Nye, Androuschak, Desierto, Jones and Yudkevich (2012) have provided evidence from two samples (students in Moscow and Manila). They found that DR had a nonlinear effect on different measures of academic achievement. Their results suggest that this relationship might be dependent on several factors such as culture, field of study or sex. The results for men and women show similar nonlinear effects, but are generally insignificant for men in the Moscow sample and significant for the Manila sample. Coco, Perciavalle, Maci, Nicoletti, Di Corrado and Perciavalle (2011) have concluded that prenatal androgens increase performance in situations that require prompt decision making and the ability to take risks, but do not influence performance when a more analytical and planned approach is called for. However, it should be noted that due to the small number of studies and sample sizes, the empirical results on the relationship between DR and academic performance are not conclusive.

The observed relationship between DR and academic performance is not surprising since subjects with a low DR exhibit high skills (Brosnan et al., 2011; Hopp et al., 2012; Romano, Leoni and Saino, 2006), thus we would expect high academic performance. That is, DR has been related to numerical competency, which might impact on academic performance in mathematics. Therefore, we conjecture that the DR could be related to academic achievement in mathematics. This relationship would be consistent with the claim that sex hormones influence academic achievement.

This paper provides more evidence on the effect of the DR on academic performance in mathematics. The main objective of this article is to check whether the DR has a significant effect on math performance among university students. Performance in mathematics is measured through a standardized measurement with an identical value and scoring for all students. We sampled 516 students (304 females and 212 males) enrolled in their first academic year at the Faculty of Business and Economics of the University of Granada (Spain).

In line with the existing literature, we first test if there is a negative relationship between DR and academic performance in mathematics. Some studies conclude that this relationship is observed only in the case of men (Hopp et al., 2012). However as reported by other studies (Sanders, Sjodin and de Chastelaine, 2002; Nye et al., 2012), we study whether the relationship between DR and academic performance in mathematics might not be linear but curvilinear[1].

[1] Nonlinear effects of DR have also been suggested in social decision making settings (e.g., Millet and Dewitte, 2006).

2. Material and Methods

2.1. Sample

In October 2011, first-year students at the Faculty of Business and Economics of the University of Granada (Spain) were asked to participate in a survey-experiment at the EGEO Experimental Economics Laboratory. During the survey-experiment we gathered information about the subjects' academic performance and measured their finger lengths. A total of 927 freshmen were asked to participate in the experiment. Participation was voluntary. Of the 659 students initially chosen as subjects, three non-Caucasian subjects were excluded from our data set to ensure ethnic homogeneity. Thus, 656 ethnically homogeneous subjects (378 females and 278 males) enrolled in the first year of the BA in Economics, Finance, Management and Marketing at the University of Granada participated in the experiment.

Given that our goal was to analyze whether biological factors (DR) influence mathematics performance, subjects that had not been evaluated, and hence had not been assigned a math grade, were eliminated from the initial sample of 656 students. The final data set therefore consisted of 516 subjects (304 women and 212 men). The average age of the subjects was 18.73 ± 1.50 (range: 17 to 27 years of age). Our sample represents 55.67% of the population. Moreover, using a probit model, we found that DR does not affect the likelihood that the students will take the mathematics exams (dy/dx=-0.233, p=0.530, N=655).

2.2. Procedure

The survey-experiment was run in 27 sessions with about 24 students per session. An identical protocol was followed in all the sessions. Upon arriving at the laboratory, each participant was assigned to a computer and given an identification number prior to scanning their DR. They then received a plastic card with an ID number and were asked to keep it for purposes of identification in future experiments. The card also served to record the experimental data and the digit ratios of each of the participants. The students were not allowed to communicate with the other participants. All the participants received the same instructions and signed an informed consent form. The participants were asked to complete a computerized survey about their time preferences, socioeconomic status, grade point average in high school, etc., which were used as controls in the study. The subjects also made five experimental decisions.

During the experiment, the subjects were asked to go one by one to the main desk to have both of their hands scanned (see section 2.4).

2.3. Performance in mathematics

We used the final grade earned by students in the mathematics course (1st term). The students' grades were obtained from the university database. The mathematics course content and evaluation system is the same for all the groups taking this course at the Faculty of Business and Economics, hence the same academic level is required of all the students enrolled in the course[2]. The graded examinations were scored on a scale of 0-10 (fail-excellent).

2.4. Digit ratio 2D:4D

During the experiment, we scanned the left and right hands of the participants. The subjects were asked to straighten their fingers and gently press their hand on the scanner. The quality of the scanner was checked (Canon Slide 90). Later, two marks were made at the crease at the base of the finger proximal to the palm and tip of the

[2] The final grade is obtained as the weighted sum of two mid-term exams given during the course. The exams are given on the same day and at the same time to all the students. Finally, a single grade is recorded on the students' academic transcripts.

finger, and the length of the two fingers was measured with a ruler. The research assistant in charge of collecting the finger length measurements did not know the responses given by the subjects on the questionnaire and is not involved in the present study.

To ensure the most accurate measurements, we measured the ratio obtained from the scanned pictures twice. The lengths of the index (2D) and ring (4D) fingers were measured by the same rater with a time span of one month. As expected, both measurements were highly correlated (correlation coefficient right hand: r=0.94, p=0.0001; left hand: r=0.92, p=0.0000). The value of the DR used here is the arithmetic mean between the average of the two measurements of the left hand and the average of the two measurements of the right hand (Brosnan et al., 2011; Sapienza et al., 2009).

2.5. High school

The variable 'high school' denotes the grade point average obtained by the subjects in 11^{th} and 12^{th} grade, that is, the two pre-university academic years (equivalent to A Levels in the UK, and Bachillerato in Spain). This information was provided by the students in the questionnaire. The grade point average was calculated on a scale of 0-10 (fail-excellent). Numerous works consider academic performance before college (i.e., high school) a predictor of academic achievement (see Wilson and Hardgrave, 1995; Gaviria Soto, 2005; Tejedor and García-Valcárcel, 2007). In this sense, the high school grade point average is a synthetic variable which incorporates several factors such as the student's ability, tenacity, and effort, as well as the characteristics of the program of studies. We use this variable as an index of subjects' previous abilities.

2.6. Grade point average of other courses

The grade point average of other courses (*GPA-other*) is the average grade obtained by first-year students in all courses except mathematics. In the first semester of the first year the students take the following courses: Economics, Foundations of Business Organization, Introduction to Financial Management, Introduction to Marketing, and Mathematics. The graded examinations were scored on a scale of 0-10 (fail-excellent). This information was obtained from the university database.

2.7. Ethics statement

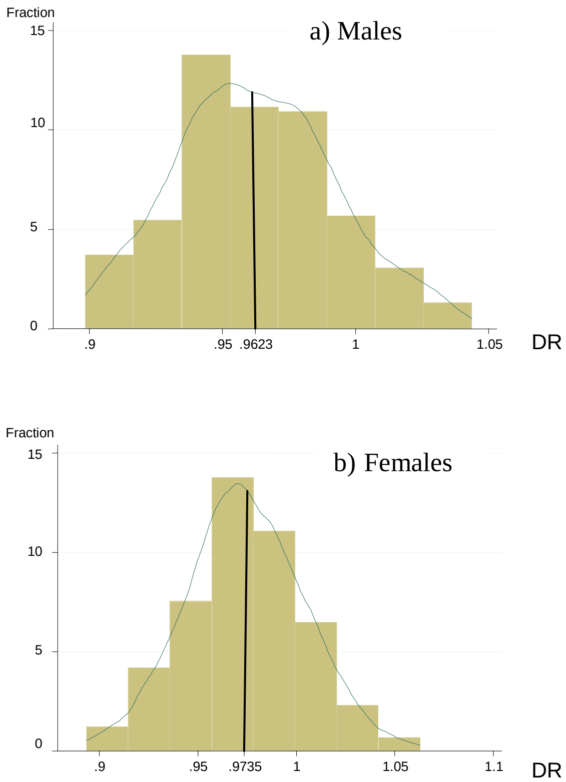
This research was conducted in accordance with the Code of Ethics of the University of Granada. All the experimental subjects reported in the manuscript signed an informed consent prior to participating. In accordance with the Spanish Law on Personal Data Protection, the anonymity of the subjects was ensured throughout the experiment by randomly assigning them a username to identify them in the system. No association was ever made between their real names and the results. As is standard in socioeconomic experiments, no ethic concerns are involved other than preserving the anonymity of participants. This procedure was checked and approved by the Vice Provost for Research at the University of Granada, the institution hosting the experiment.

3. Results

In line with previous literature (e.g., Fink et al., 2004; Manning, 2000; Williams, Greenhalgh and Manning, 2003), the 2D:4D digit ratio was found to be significantly lower for men (mean=0.9623, standard deviation=0.0296) than for women (females=0.9735, standard deviation=0.0298) (Figures 1a, 1b) in our study as shown by ANOVA (F=17.74, p=0.0000).

With regard to sex differences in the grades earned in the mathematics course, no significant differences were found between the males and females in our study (males 4.87 ± 2.76, females 5.15 ± 2.59, F=1.33, p=0.2502). Moreover, no significant differences were observed between men and women as regards the average grades obtained in the other courses (*GPA-other*) (males 5.68 ± 1.79, females 5.72 ± 1.61, F=0.06, p=0.8074).

Figure 1: Density Digit Ratio



There was no significant pairwise correlation between *digit ratio* and *mathematics grade* in males (r=0.07, p=0.3046, N=212) or females (r=0.06, p=0.9224, N=304). OLS regression analysis shows that the relationship between *digit ratio* and *mathematics grade* is not significant (Table 1, model 1) for all subjects (the variable gender was included as a dummy, male=1 and female=0). The results of model 2 show that the lack of a linear relationship holds true irrespective of gender (i.e., the interaction between DR and gender is not significant).

Table 1. Academic performance and Digit Ratio

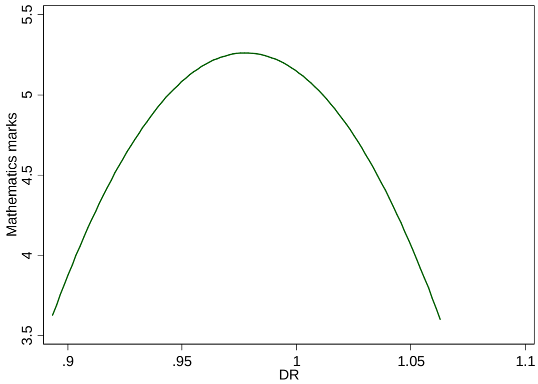
Dependent variable:	Mathematics grade				GPA-other			
	(1)	(2)	(3)	(4)	(5)	(6)	(7)	(8)
DR	2.977	0.487	446.487	454.062	2.698	1.023	-12.841	-7.791
	(0.451)	(0.924)	(0.015)	(0.007)	(0.282)	(0.753)	(0.913)	(0.942)
DR^2			-228.667	-233.121			8.012	5.042
			(0.016)	(0.008)			(0.895)	(0.927)
Gender (male)	-0.241	-6.150	-0.234	-0.102	-0.007	-3.980	-0.007	0.081
	(0.321)	(0.429)	(0.333)	(0.648)	(0.966)	(0.420)	(0.965)	(0.062)
DR X Gender		6.112				4.110		
		(0.447)				(0.420)		
High school				0.958				0.639
				(0.000)				(0.000)
Constant	2.248	4.672	-212.598	-222.919	3.091	4.721	10.619	3.738
	(0.559)	(0.350)	(0.017)	(0.007)	(0.206)	(0.137)	(0.852)	(0.942)
N	516	516	516	516	516	516	516	516
p-value (model)	0.3888	0.4814	0.0529	0.0000	0.5435	0.6001	0.7444	0.0000

p-values in parentheses

This led us to propose a quadratic relationship between digit ratio and mathematics grades. We propose model 3 in which *mathematics grade* depends quadratically on the digit ratio (*DR* and DR^2) to capture increasing or decreasing marginal effects. For all subjects, the regression analysis showed that the relationship between *DR* and *mathematics grade* is significant (p=0.01 in both *DR* and DR^2). The control variable *gender* is not significant, thus the results can be extended to the entire sample. Given that the coefficient of *DR* is positive and the coefficient of DR^2 is negative, the quadratic function has a parabolic shape. That is, we find an inverted U-shaped relationship between *DR* and *mathematics grade*.

The critical value of the digit ratio value can be calculated for the highest *mathematics grade* as the absolute value of the ratio between the estimated coefficient of the digit ratio and twice the estimated coefficient of DR^2 such that the digit ratio=0.9763. For 59.50% of all subjects (subjects with a digit ratio less than 0.9763), the digit ratio has a positive effect on *mathematics grade*. For the remaining 41.50% (subjects with a digit ratio greater than 0.9763), the digit ratio has a negative effect on *mathematics grade*. In any case, the lowest and highest digit ratio values (parabola ends) are associated with a lower *mathematics grade* (Figure 2). Hence, subjects with an intermediate DR earn better grades in mathematics.

Figure 2. Quadratic regression between Digit Ratio and Mathematics grades in all subjects



(in 11th and 12th grade) as a control, the results improve ($p<0.01$ in both cases): higher grades in high school indicate higher grades in mathematics (Table 1, model 4). Hence, the introduction of this proxy of previous academic performance does not alter the main results shown in Table 1.

Finally, models 5, 6, 7 and 8 analyze the type of relationship that might exist between digit ratio and the grade point average of freshmen in their first semester at college, except in mathematics (*GPA-other*). The results of these four models show that the digit ratio does not have a statistically significant effect on the grades in the other courses taken in the first semester. That is, the digit ratio is important in math grades but not for the other courses[3]. Under the assumption that two students (one with an intermediate DR and another with a high DR) make the same effort in mathematics and in the other courses, the overall results may differ due to biological and genetic factors. A student with an intermediate digit ratio is likely to earn better grades.

[3] Furthermore, no statistically significant linear and quadratic relationship was found between digit ratio and one of the courses taken in the first semester (except mathematics).

4. Discussion

We report that part of the variation in mathematics grades among first-year students at the Faculty of Business and Economics is already determined by prenatal events. That is, biological and genetic factors play an important role in mathematics performance. For all subjects, we found an inverted U-shaped relationship between the DR (reflecting prenatal testosterone exposure) and mathematics grades. Lower mathematics grades were found to be related to both relatively higher and lower DRs, while higher mathematics grades were related to relatively intermediate DR values. Although there are significant differences between the digit ratios of men and women, the effect of DR on math grades is the same for both men and women. Furthermore, we find that DR does not have a significant effect on the grade point average of the subjects in the rest of the courses taken in the first semester.

Moreover, if we break the sample down into two subsamples (one consisting of subjects with a *GPA-other* higher than or equal to the GPA in all first-semester courses except mathematics, and another subsample comprising subjects with a lower *GPA-other* in the same courses), the results are similar to those obtained for all the subjects. This indicates that there is a quadratic relationship between DR and *mathematics grade* regardless of whether the student is in the group of subjects with higher academic performance or not.

Our results are in line with those of Sanders et al. (2002) regarding the relationship between DR and spatial/numerical ability, and those of Nye et al. (2012) on DR and academic performance for non-monotonic relationships. Our work provides new and robust results with a large sample of subjects, although we are aware that there remain interesting questions that deserve further research. For example, it would be interesting to track the academic performance of the subjects throughout the entire degree program.

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