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Born to be wild: Second-to-fourth digit length ratio and risk preferences

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Abstract

The second-to-fourth digit length ratio of an individual's hand (digit ratio) is a putative biomarker for prenatal exposure to testosterone. We are examining the hypothesized negative association between the digit ratio and the preference for risk taking within a large U.S. population survey. Our statistical framework provides a cardinal proxy for the true digit ratio based on ordinal digit ratio measurements and accounts for measurement error under the assumptions of Gaussianity and time-invariant true digit ratios. Our empirical findings support the hypothesis and suggest a meaningful biological basis for risk preferences.

J.E.L. Codes: A12, C8, D01

Keywords: risk preferences, prenatal testosterone exposure, digit ratio, 2D:4D

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I. INTRODUCTION

Risk preferences are fundamental building blocks of models of economic and health behavior (Schildberg-Hörisch 2018), and their biological roots have been examined with data on twins and with genetic data (Benjamin et al. 2012; Cesarini et al. 2009; Cronqvist et al. 2015; Linnér, Biroli, Kong et al. 2019). We contribute to the literature on the biological roots of risk preferences by investigating the hypothesized negative association between the second-to-fourth digit length ratio of an individual's hand (the digit ratio) and the individual's preference for risk taking. This association is hypothesized to follow from (prenatal) testosterone's positive association with the preference for risk taking (Coates, Gurnell, and Sarnyai 2010; Cronqvist et al. 2015; Nofsinger, Patterson and Shank 2018) and the digit ratio's status as a retrospective biomarker of prenatal testosterone exposure; higher exposure is thought to decrease the digit ratio (Manning, Scutt, and Lewis-Jones 1998, Manning et al. 2003; Manning 2011; Voracek 2014)[1]. Empirical evidence of the digit ratio's association with risk preferences has, however, thus far proved inconclusive (Neyse et al. 2020).

In economics, interest in the relationship between the digit ratio and risk preferences was triggered by Coates and Herbert (2008), who found that financial traders' levels of circulating testosterone were positively related to their profits on trading days, and subsequent studies that partly explained this by finding digit ratios to be negatively associated with risk taking (Coates, Gurnell, and Rustichini 2009; Brañas-Garza and Rustichini 2011). While some studies have confirmed the negative association between the digit ratio and the preference for risk taking

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[1] Online Appendix 1 provides background information on the relationship between prenatal testosterone exposure and the digit ratio.

(Garbarino, Slonim, and Sydnor 2011; Stenstrom et al. 2011; Brañas-Garza, Galizzi, and Nieboer 2018), most studies could not confirm it, despite often having used similar research designs (Apicella et al. 2008; Drichoutis and Nayga 2015; Neyse et al. 2020; Parslow et al. 2019).

The lack of replicability of the association between the digit ratio and risk preferences could be due to small sample sizes, as argued by Apicella, Carré, and Dreber (2015), or measurement error in the elicited digit ratio (Ribeiro et al. 2016). Apicella, Carré, and Dreber (2015) suggest that, to avoid false positives and false negatives, studies need to be conducted with larger samples; to date, sample sizes in the literature have ranged from around 50 to 700 observations (Neyse et al. 2020). Brañas-Garza, Galizzi, and Nieboer (2018) used the largest sample size to date (704) and show that a lab-experimental measure of the preference for financial risk taking, but not a self-reported measure of a general preference for risk taking, is significantly and negatively associated with the digit ratio. Thus, they could replicate some of the earlier findings, but could not replicate the findings of Stenstrom et al. (2011) and Bönte, Procher, and Urbig (2016) who find a significant negative association between the digit ratio and the response to a question about the general preference for risk taking, albeit for the right hand only and not for women separately. Gaining insights into the digit ratio's association with a general risk preference measure is of particular interest because recent studies have argued that compared to, e.g., lab-experimental measures of financial risk taking, a general risk preference measure has a higher validity for real-world risky choices (Charness et al. 2019; Kapteyn and Teppa 2011; Verschoor, D'Exelle, and Perez-Viana 2016).

The aim of our paper is to revisit previous findings on the negative association of the digit ratio with general risk preferences and to provide firm empirical evidence regarding the existence and strength of this association. Empirical evidence in favor of such an association would be in support of a biological basis for risk preferences. It would also suggest the use of digit ratio elicitation in population surveys to facilitate research on the biological roots of risk preferences and of, e.g., education and health (Klimek et al. 2014; Nye, Bryukhanov, and Polyachenko 2017).

Our contributions to the literature are, first, to answer the call of Apicella, Carré, and Dreber (2015) by using a large population survey of about 6,000 adults from the Understanding America Study (see Section II). This is a far larger sample than was available in any prior work, as noted above. Second, to facilitate replicability of results and to address the issue of how to measure the digit ratio in a large survey. We have elicited the digit ratio with a short survey question that asks, for each hand, whether the ring finger is shorter than, longer than, or equal in length to, the index finger. Risk preferences were elicited with a general question that measures the preference for risk taking on a Likert scale (Falk et al. 2018). Third, we elicited each hand's digit ratio twice, in a pair of surveys spaced about seven months apart. This longitudinal design makes it possible to account for measurement error in the reported digit ratios, using a modified version of the estimator proposed by Kimball, Sahm, and Shapiro (2008). This is a two-step estimator that first uses the ordinal digit ratio reports from our surveys to obtain a cardinal proxy for the expected true digit ratio. This proxy is then used in a second-step linear regression model for risk preferences (see Section III).

Our empirical results, discussed in Section IV, support the hypothesized negative association between the digit ratio and the preference for risk taking. This association is about the same for both genders and remains when accounting for characteristics at birth, such as race and mother's education, to control for possible hereditary or intergenerationally transmittable factors, and for education and health characteristics, which represent possible causal pathways. In terms of effect size, the estimated difference in the preference for risk taking between individuals with a high and those with a low digit ratio equals on average about 40% of the estimated gender difference in the preference for risk taking. Our findings, therefore, suggest a meaningful biological basis for risk preferences and, arguably, support the use of the digit ratio as a biomarker for prenatal exposure to testosterone in population surveys. Section V discusses the main findings and concludes.

II. The Data

Our empirical analysis is based on a sample of about 6,000 adults from the Understanding America Study (UAS; https://uasdata.usc.edu). UAS is a probability-based internet panel, which at the time of the survey comprised about 7,000 respondents (age 18+) who are representative of the U.S. population (Alattar, Messer and Rogofsky 2018). The UAS oversamples Native Americans and residents of Los Angeles County.

We have twice fielded a module to all UAS panel members, which elicited individuals' digit ratios and their risk preferences. Of the 6,554 panel members invited in November and December of 2018, 4,966 (76%) completed the module, and of the 7,259 panel members invited in June and July of 2019, 5,393 (74%) completed the module. We included in our analysis sample respondents who completed the module in one or both years. We excluded 185 observations with missing values for gender, race, or age, and, subsequently, excluded 66 observations with missing values for the digit ratio or risk preferences. A further 132 observations were dropped because the digit ratios could not be measured because of physical impairment of either the left or right hand, or because respondents were under the age of 20.[2] The final analysis sample therefore comprised

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[2] Gillam et al. (2008) show that women's digit lengths attain their maxima around the ages 12–15 while for men it is around 17–20 years of age.

9,976 observations for 5,898 unique respondents, of whom 4,078 were observed twice. Respondents' educational attainment, mother's education, cognitive skills, and health-related characteristics were elicited by other UAS questionnaires before the digit ratio questionnaires were fielded, making these time-invariant covariates in our analysis. Summary statistics of all variables for the analysis are in Table A-1 (Online Appendix 2).

A. The Digit Ratio

The lengths of the ring and index fingers can be measured by using a caliper or ruler, either directly or indirectly based on a photocopy, scan, or radiographic image of the hands (Jeevanandam and Muthu 2016). Alternatively, one can use software designed to measure digit lengths (Huang, Basanta, and Sandnes 2014). See Ribeiro et al. (2016), Kim and Cho (2013), and Mikac et al. (2016) for a discussion of these methods of measurement. The UAS is a large internet population survey, which makes these methods impractical. We have therefore asked respondents to compare their index and ring fingers and to report which one is longer.[3] The survey also includes illustrations showing hands with different digit ratios to clarify the possible responses (see Online Appendix 3). The exact wording of the digit ratio question (for the left hand) is:

Please turn your left hand with the palm towards you, fingers next to each other. Keeping your fingers straight, look to see which finger is longer on your left hand: the index finger or the ring finger?

On my left hand...

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[3] An alternative elicitation method is to ask respondents to measure the lengths of their index and ring fingers with a ruler, as done in the BBC Internet Study (Reimers 2007).

1 My index finger is longer than my ring finger (Picture included)

2 My ring finger is longer than my index finger (Picture included)

3 My ring and index finger are the same length (Picture included)

4 I am physically unable to do this

Following this, the same question was asked for the right hand. Buser (2012) reports test statistics suggesting a high correlation between a digit ratio measure based on scans and an elicitation like ours. Compared to using scans or radiographic images, the main advantage of our survey question for eliciting information on individuals' digit ratios is that it takes much less time and can easily be incorporated into any survey. A disadvantage is that it yields a less accurate measure of the digit ratio, which is already an assumed proxy for prenatal testosterone exposure, and therefore adds measurement error to the analysis.

In line with most previous studies (Swami et al. 2013), the reported digit ratios show the sexually dimorphic nature of the digit ratio for each hand (Table 1; Panel A): women reported, on average, a higher digit ratio than men. The null hypothesis of independence of the digit ratio and gender is, for each hand and for each year, rejected with a p-value that is close to zero (these test results are not reported in the table). For both genders, the reported digit ratio is on average somewhat higher for the left hand than for the right hand. Further, the percentage of respondents who answered that their index finger is shorter than their ring finger (and hence have a digit ratio smaller than 1), is somewhat lower than what can be expected based on the findings of, e.g., Hönekopp and Watson (2010) that (true) digit ratios are, on average, smaller than 1 for both genders.

Table 1 *Ordinal digit ratio reports*

Panel A: Digit ratios by hand, year, and gender

Cells: %	Year	2018	2018	2019	2019
	Gender	Female	Male	Female	Male
Left hand	index<ring (low digit ratio)	33.6	49.3	31.8	48.8
	index=ring	24.7	20.9	24.0	24.3
	index>ring (high digit ratio)	41.7	29.9	44.2	26.9
	Total	100.0	100.0	100.0	100.0
Right hand	index<ring (low digit ratio)	35.2	51.9	32.4	50.1
	index=ring	25.8	23.6	27.4	24.7
	index>ring (high digit ratio)	39.1	24.5	40.3	25.2
	Total	100.0	100.0	100.0	99.8

Panel B: Digit ratios for the right hand, given those for the left hand

Cells: %	Cronbach's alpha = 0.80	Right hand			
	Correlation = 0.66	index<ring	index=ring	index>ring	Total
Left hand	index<ring (low digit ratio)	80.2	11.7	8.1	100.0
	index=ring	21.0	65.8	13.2	100.0
	index>ring (high digit ratio)	12.8	14.6	72.7	100.0

Panel C: Digit ratios for the left and right hand in 2019, given those in 2018

Cells: %	Cronbach's alpha = 0.65	Left hand	2019		
	Correlation = 0.48	index<ring	index=ring	index>ring	Total
Left hand 2018	index<ring (low digit ratio)	66.5	16.6	17.0	100.0
	index=ring	25.6	45.0	29.5	100.0
	index>ring (low digit ratio)	20.1	17.1	62.8	100.0
	Cronbach's alpha = 0.67	Right hand	2019		
	Correlation = 0.50	index<ring	index=ring	index>ring	Total
Right hand 2018	index<ring (low digit ratio)	67.6	16.5	15.9	100.0
	index=ring	23.8	50.7	25.5	100.0
	index>ring (high digit ratio)	20.8	17.0	62.3	100.0

Notes ‘Index’ refers to index finger length (second digit length) and ‘ring’ refers to ring finger length (fourth digit length). Survey weights are used for constructing this table. Rank order correlation coefficients are reported and for each case the null hypothesis of the correlation being equal to zero is rejected with a p-value close to zero.

Although the Cronbach's alpha of 0.80 in Panel B suggests that the same construct was measured for both hands (Sijtsma 2009), the differences between the ordinal digit ratio reports for the left and right hands are substantial. For instance, among respondents who reported that the index finger was shorter than the ring finger of their left hand, 80.2% reported the same of their right hand, 11.7% reported that their right index and ring fingers were about equal, and 8.1% reported that their right index finger was longer than their right ring finger. Similar patterns are observed by gender (not reported).

For both hands, there are substantial differences between the ordinal digit ratio reports in 2018 and in 2019 (Panel C). For instance, respondents who reported that their index finger was shorter than their ring finger of their left hand in 2018, 65.5% reported the same for their left hand in 2019. The Cronbach's alphas are 0.65 for the left hand and 0.67 for the right hand, which are still acceptable, but the correlations over time of the digit ratios are about 0.5 for both hands and suggest low reliability. Overall, Table 1 suggests substantial measurement error in the ordinal digit ratio reports.

Table 2 *Risk preferences and the ordinal digit ratio reports.*

Gender	Males	Females	Total
Number of observations	4,294	5,682	9,976
Panel A: Preference for risk taking			
(0-10 scale with 10 Very willing to take risks)			
Mean	6.09	5.42	5.74
(Standard deviation)	(2.15)	(2.31)	(2.26)
Answer category	Percentage	Percentage	Percentage
0 (Not at all willing to take risks)	1.55	2.55	2.07
1	1.28	3.36	2.35
2	2.14	5.13	3.68
3	8.02	8.99	8.52
4	7.11	11.43	9.33
5	17.8	19.88	18.87
6	15.64	15.2	15.41
7	21.18	16.11	18.57
8	14.48	9.46	11.9
9	4.27	2.47	3.34
10 (Very willing to take risks)	6.52	5.41	5.95
Panel B: Average of preference for risk taking by digit ratio categories			
Left hand	mean	mean	mean
Index<ring (low digit ratio)	6.14	5.52	5.89
Index=ring	6.06	5.45	5.74
Index>ring (high digit ratio)	6.01	5.32	5.58
Correlation, digit ratio and risk-taking preference	-0.02	-0.04***	-0.06***
Right hand	mean	mean	Mean
Index<ring (low digit ratio)	6.16	5.43	5.86
Index=ring	5.98	5.46	5.70
Index>ring (high digit ratio)	6.04	5.38	5.62
Correlation, digit ratio and risk-taking preference	-0.04***	-0.02	-0.05***

Notes ‘Index’ refers to index finger length and ‘ring’ refers to ring finger length. Survey weights are used for this table’s statistics. Rank order correlation coefficients are reported. * $p<0.05$; ** $p<0.01$; *** $p<0.005$.

B. The Digit Ratio and Risk Preferences

Individuals' risk preferences in a large population survey are, for reasons of feasibility, often elicited with a question about general risk preferences, with answer categories on a Likert scale. Validation tests for such a question are presented in Falk et al. (2016).[4] We follow Falk et al. (2018) for the elicitation of risk preferences:

> *Are you generally a person who tries to avoid taking risks or one who is fully prepared to take risks? Please rate yourself from 0 to 10, where 0 means "not at all willing to take risks" and 10 means "very willing to take risks."*

In line with previous studies (e.g., Dohmen et al. 2011), on average men have a higher preference for risk taking than women (Table 2, Panel A). Panel B presents evidence in favor of a negative correlation between the digit ratio and the preference for risk taking. On average, men or women who reported that their index finger is shorter than their ring finger had a relatively higher preference for risk taking. These correlations are, however, low. For men and women combined, for both hands the findings are in support of a negative correlation. By gender, for either the left or right hand, but not for both hands, the findings are in support of a negative correlation.

Using the ordinal responses to the digit ratio survey question, the estimated associations between risk preferences and the digit ratio in panel A of Table 3 are by and large in line with those of previous studies: men or women with a high digit ratio (index>ring) have a lower preference for risk taking than men or women with a low digit ratio (index<ring, which is the

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[4] Charness et al. (2018, 2019), Kapteyn and Teppa (2011), and Verschoor, D'Exelle, and Perez-Viana (2016) provide further support for using a question about general risk preferences.

reference group).[5] Many of the associations in Panel A, however, are either borderline or not statistically significant (H_0: No DR). These results echo the conclusion of Brañas-Garza, Galizzi, and Nieboer (2018) that it is difficult to replicate previous findings concerning the associations between the digit ratios and risk preferences, and in particular to do so by gender and by hand.

The null hypothesis of the same digit ratio associations with risk preferences for the left and right hands (H_0: DR L=R) and the null hypothesis of the same digit ratio associations for both genders (H_0: DR M=W) are not rejected for any specification (Panel A). Under these two null hypotheses, the first column of Panel B shows a pattern in line with Panel A: a higher digit ratio is associated with a lower preference for risk taking. The results by gender show a similar pattern, albeit less precisely estimated.

It is likely there is measurement error in the ordinal digit ratio reports (Table 1) which attenuates the estimated associations between the digit ratio categories and the preference for risk taking (Table 3). The next sections, therefore, employ an empirical strategy that collapses the ordinal digit ratio data for each hand into a single digit ratio proxy whose association with risk preferences is easily interpretable and not subject to such attenuation bias.

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[5] Based on linear models. The main findings remain when based on ordered probit models (see Online Appendix 6).

Table 3 *Estimated associations of gender and the ordinal digit ratio reports with the preference for risk taking.*

L = Left hand R = Right hand DR=Digit ratio	Men & women	Men & women	Men & women	Men	Men	Women	Women
	Coef. (Std.Err.)	Coef. (Std.Err.)	Coef. (Std.Err.)	Coef. (Std.Err.)	Coef. (Std.Err.)	Coef. (Std.Err.)	Coef. (Std.Err.)
Panel A							
Male	0.523***	0.527***	0.531***				
	(0.055)	(0.054)	(0.054)				
Index=ring, L	-0.102	-0.134*		-0.12		-0.156	
	(0.070)	(0.060)		(0.086)		(0.084)	
Index>ring, L	-0.143	-0.178***		-0.104		-0.228***	
	(0.076)	(0.057)		(0.086)		(0.077)	
Index=ring, R	-0.057		-0.119*		-0.233**		-0.024
	(0.069)		(0.059)		(0.086)		(0.082)
Index>ring, R	-0.054		-0.147*		-0.177*		-0.108
	(0.076)		(0.057)		(0.087)		(0.077)
H_0: No DR a)	0.021*	0.005***	0.023*	0.277	0.013*	0.011*	0.335
H_0: DR L=R a)	0.811			0.316		0.113	
H_0: DR M=W a)	0.113	0.537	0.215				
R^2	0.018	0.018	0.017	0.001	0.003	0.003	0.002
N	9,976	9,976	9,976	4,294	4,294	5,682	5,682
Panel B: Estimates under the null hypothesis of the same associations by hand							
Male	0.523***						
	(0.055)						
Index=ring	-0.080*			-0.114*		-0.054	
	(0.034)			(0.049)		(0.049)	
Index>ring	-0.098***			-0.083		-0.102*	
	(0.031)			(0.047)		(0.042)	
H_0: No DR a)	0.004***			0.037*		0.055	
H_0: DR M=W a)	0.545						
R^2	0.018			0.002		0.003	
N	9,976			4,294		5,682	

Notes Dependent variable: preference for risk taking (0-10 scale). The references categories are female respondents or respondents with 'Index<ring'. 'Index' refers to index finger length and 'ring' refers to ring finger length. The results are based on least squares estimates of linear models with individual random effects. N= Number of observations. A year dummy for 2019 is included in all specifications. Weighted average marginal effects are computed and the standard errors are clustered at the individual level. * $p<0.05$; ** $p<0.01$; *** $p<0.005$.

a) "H_0: No DR", "H_0: DR L=R" and "H_0: DR M=W" are the null hypotheses of the digit ratio associations being equal to zero, the same for both hands, or the same across gender, respectively. Entries shown are *p*-values.

III. Empirical Strategy

Our empirical strategy is based on Kimball, Sahm, and Shapiro (2008) and relates risk preferences to the expected digit ratio, conditional on observables which include the ordinal digit ratio reports. In a nutshell, a cardinal proxy for each hand's digit ratio is constructed based on the ordinal responses. This reduces the multiple, ordinal measurements of a hand's digit ratio to a one-dimensional cardinal measure that can be analyzed much as the digit ratio would be if it were observed directly. Furthermore, it exploits the repeated measurements of each hand's digit ratio to account for measurement error, under the assumption that the true digit ratio is constant over time. Our one-dimensional cardinal measure, referred to as the expected digit ratio, serves as a proxy of the unobserved true digit ratio, but the error structure does not lead to attenuation of estimated coefficients, as would be the case with classical measurement error. This error structure was first discussed by Berkson (1950).

To simplify notation, the model discussed below assumes respondents are observed in both years of the survey. The extension to our case, where some individuals are observed in only one year, is straightforward.

A. Empirical Model

The true, unobserved digit ratio of individual i's hand h, $d_{h,i}^{**}$, is not expected to change during adulthood (Garn et al. 1975; Galis et al. 2010; Gillam et al. 2008), so we assume it to be constant over time. We further assume it to be linearly related to the preference for risk taking, y_{it}, at time t:

$$(1) \qquad y_{it} = \beta_0 + \sum_{h\in\{l,r\}} \beta_h d_{h,i}^{**} + \boldsymbol{X}_{it}\boldsymbol{\beta}_2 + \alpha_i + \varepsilon_{it},$$

where l denotes the left hand and r the right hand, $i \in \{1..n\}$, n is the number of respondents, and $t \in \{1,2\}$. $\boldsymbol{X}_{it}$ is a vector of covariates with corresponding parameter vector $\boldsymbol{\beta}_2$, α_i is an individual-specific random effect, and ε_{it} is an idiosyncratic error term. While the true digit ratio, $d^{**}_{h,i}$, is unobserved, we observe $d_{h,it}$, a variable indicating whether, at time t, individual i reported that the ring finger of hand h was shorter than, longer than, or equal in length to the index finger (see Section II). We define $\boldsymbol{d}_i = (d_{l,i1}, d_{l,i2}, d_{r,i1}, d_{r,i2})$ and $\boldsymbol{X}_i = (\boldsymbol{X}_{i1}, \boldsymbol{X}_{i2})$, and assume $\mathbb{E}(\alpha_i|\boldsymbol{d}_i, \boldsymbol{X}_i) = \mathbb{E}(\varepsilon_{it}|\boldsymbol{d}_i, \boldsymbol{X}_i) = 0$. With the compound error $u_{it} = \varepsilon_{it} + \sum_{h\in\{l,r\}} \beta_h d^{**}_{h,i} - \sum_{h\in\{l,r\}} \beta_h \mathbb{E}\left(d^{**}_{h,i}|\boldsymbol{d}_i, \boldsymbol{X}_i\right)$, (1) can be transformed into

$$(2) \qquad y_{it} = \beta_0 + \textstyle\sum_{h\in\{l,r\}} \beta_h \mathbb{E}\left(d^{**}_{h,i}|\boldsymbol{d}_i, \boldsymbol{X}_i\right) + \boldsymbol{X}_{it}\boldsymbol{\beta}_2 + \alpha_i + u_{it},$$

where the new error term u_{it} includes expectation errors in the digit ratios.

We use a two-step estimator that first estimates $\mathbb{E}\left(d^{**}_{h,i}|\boldsymbol{d}_i, \boldsymbol{X}_i\right)$ and then, in a second step, plugs this into (2) and estimates the resulting equation using least squares. The first-stage estimates of $\mathbb{E}\left(d^{**}_{h,i}|\boldsymbol{d}_i, \boldsymbol{X}_i\right)$ come from a panel data bivariate ordered probit model that relates the true, unobserved digit ratios to the reported digit ratios and covariates. The parameters of this "digit ratio model" fully characterize $\mathbb{E}\left(d^{**}_{h,i}|\boldsymbol{d}_i, \boldsymbol{X}_i\right)$, so we estimate these true, unobserved digit ratio expectations by the corresponding expectations from the maximum likelihood estimate of the digit ratio model (see Online Appendix 4).

We develop our digit ratio model from a triplet of equations describing the generation of the digit ratio reports, $\boldsymbol{d}_i$. First, the true digit ratios, $d^{**}_{h,i}$, are assumed to be time-invariant, and associated with $\boldsymbol{Z}^{\boldsymbol{1}}_{\boldsymbol{i}}$, a time-invariant subset of the covariates $\boldsymbol{X}_{it}$.

$$(3) \qquad d^{**}_{h,i} = \gamma^0_h + \boldsymbol{Z}^1_i \boldsymbol{\gamma}^1_h + \eta_{h,i} + \theta_i.$$

The error components, $\eta_{h,i}$ and θ_i, capture hand- and individual-specific influences on the true digit ratio, including any effect of prenatal testosterone exposure. The true digit ratio is allowed to correlate between hands due to the presence of θ_i.

Next, measurement error is assumed to enter respondents' perceptions of their digit ratios, owing to factors like variation in hand position during measurement or arthritis in the hands. The perceived digit ratio, $d^*_{h,it}$, equals the true values, plus a mean-zero "perception error" and systematic distortion associated with the subset of (potentially time-varying) covariates $\boldsymbol{X}_{it}$ not present in $\boldsymbol{Z}^1_i$. Denoting these covariates $\boldsymbol{Z}^2_{it}$, so that $\boldsymbol{X}_{it} = (\boldsymbol{Z}^{\mathbf{1}}_i, \boldsymbol{Z}^{\mathbf{2}}_{it})$, the perceived ratios are generated according to

$$d^*_{h,it} = d^{**}_{h,i} + \boldsymbol{Z}^2_{it}\boldsymbol{\gamma}^2_h + \zeta_{it} + \upsilon_{h,it}. \tag{4}$$

The perception error has two components: $\upsilon_{h,it}$ is fully idiosyncratic, while ζ_{it} is specific to time, but not to hand. The inclusion of ζ_{it} allows correlation between the two hands' perception errors in a particular time period.

Finally, individuals report the observed digit ratio, $d_{h,it}$, based on which of three bins the perceived ratio falls in.

$$d_{h,it} = \begin{cases} 1 & \text{if} \quad -\infty < d^*_{h,it} < \tau_1 \\ 2 & \text{if} \quad \tau_1 \le d^*_{h,it} < \tau_2 \\ 3 & \text{if} \quad \tau_2 \le d^*_{h,it} < \infty \end{cases}. \tag{5}$$

Note that the threshold parameters τ_1 and τ_2 are time- and hand-invariant.

For estimation, we substitute (3) into (4) to obtain the reduced-form equation

$$d^*_{h,it} = \gamma^0_h + \boldsymbol{X}_{it}\boldsymbol{\gamma}_h + \eta_{h,i} + \theta_i + \zeta_{it} + \upsilon_{h,it}, \tag{6}$$

where $\boldsymbol{\gamma}_h = (\boldsymbol{\gamma}_h^{\mathbf{1}}, \boldsymbol{\gamma}_h^{\mathbf{2}})$. We further assume that the error components θ_i, $\eta_{l,i}$, $\eta_{r,i}$, ζ_{i1}, ζ_{i2}, $\upsilon_{l,i1}$, $\upsilon_{r,i1}$, $\upsilon_{l,i2}$, and $\upsilon_{r,i2}$ are mean-zero, mutually independent, independent of the covariates, and jointly normal with respective variances σ_θ^2, $\sigma_{l,\eta}^2$, $\sigma_{r,\eta}^2$, σ_ζ^2, σ_ζ^2, σ_υ^2, σ_υ^2, σ_υ^2, and σ_υ^2. We normalize the perception error to have unit variance (i.e., $\sigma_\upsilon^2 + \sigma_\zeta^2 = 1$) and normalize $\gamma_l^0 = 0$ because only the between-hand difference of the intercepts $\gamma_r^0 - \gamma_l^0$ is identified. The combination of (5) and (6) with these assumptions gives us a panel data bivariate ordered probit model, which we estimate with maximum likelihood. Collecting the digit ratio model's parameters into the vector $\boldsymbol{\Gamma} = (\gamma_l^0, \gamma_r^0, \boldsymbol{\gamma}'_l, \boldsymbol{\gamma}'_r, \tau_1, \tau_2, \sigma_\theta^2, \sigma_{l,\eta}^2, \sigma_{r,\eta}^2, \sigma_\zeta^2, \sigma_\upsilon^2)'$, we denote the corresponding maximum likelihood estimator by $\hat{\boldsymbol{\Gamma}}$.

Next, we define $\mathbb{E}(d_{h,i}^{**} | \boldsymbol{d}_i, \boldsymbol{X}_i; \hat{\boldsymbol{\Gamma}})$ as the conditional expectation $d_{h,i}^{**}$ would have if the digit ratio reports were truly generated by the estimated digit ratio model (i.e. if $\boldsymbol{\Gamma} = \hat{\boldsymbol{\Gamma}}$). This is our estimator of $\mathbb{E}(d_{h,i}^{**} | \boldsymbol{d}_i, \boldsymbol{X}_i)$. We refer to Online Appendix 4 for details on computation. $\mathbb{E}(d_{h,i}^{**} | \boldsymbol{d}_i, \boldsymbol{X}_i)$ is identified only up to scale (determined by our model's normalization), so, using similar notation, we renormalize our estimate by $SD(d_{h,i}^{**} | \boldsymbol{X}_i; \hat{\boldsymbol{\Gamma}}) = \sqrt{\hat{\sigma}_\theta^2 + \hat{\sigma}_{h,\eta}^2}$ for each hand. Where the context is clear, we will refer to the estimated renormalized conditional digit ratio expectation, $\frac{\mathbb{E}(d_{h,i}^{**} | \boldsymbol{d}_i, \boldsymbol{X}_i; \hat{\boldsymbol{\Gamma}})}{SD(d_{h,i}^{**} | \boldsymbol{X}_i; \hat{\boldsymbol{\Gamma}})}$, simply as the expected digit ratio. Substituting this into (2), we obtain

$$(7) \qquad y_{it} = \beta_0 + \sum_{h \in \{l,r\}} \tilde{\beta}_h \frac{\mathbb{E}(d_{h,i}^{**} | \boldsymbol{d}_i, \boldsymbol{X}_i; \hat{\boldsymbol{\Gamma}})}{\sqrt{\hat{\sigma}_\theta^2 + \hat{\sigma}_{h,\eta}^2}} + \boldsymbol{X}_{it} \boldsymbol{\beta}_2 + \alpha_i + \tilde{u}_{it},$$

where the new error term $\tilde{u}_{it}$ includes the estimation error in the digit ratio expectation. Owing to our renormalization, $\tilde{\beta}_h$ is interpretable as the change in the dependent variable associated with a one-standard deviation change in the true digit ratio, conditional on $\boldsymbol{X}_i$. Furthermore, we refer in our empirical analysis to $\tilde{\beta}_h$ as the association of the digit ratio with risk preferences.

Our estimator's second step simply estimates (7) by least squares.[6] We cluster standard errors at the individual level to account for serial correlation and heteroskedasticity. While we do not adjust these standard errors for the first-stage estimation of the digit ratio, they remain valid for tests of null hypotheses where all digit ratio associations (i.e. $\tilde{\beta}_l$ and $\tilde{\beta}_r$) are zero (Hansen 2019, pp. 420-423).[7]

Finally, our estimator of the digit ratios' second-stage coefficients, $\tilde{\beta}_l$ and $\tilde{\beta}_r$, is robust to how the time-invariant covariates are split between $\boldsymbol{Z}_i^{\boldsymbol{1}}$, which is associated with the true digit ratio in (3), and $\boldsymbol{Z}_{it}^{\boldsymbol{2}}$, which is associated with the misperceptions in (4).[8] This robustness is ensured by controlling for the same covariates in the first and second stage (see Online Appendix 4). This robustness allows us to be agnostic about whether associations between time-invariant covariates and the reported digit ratios represent systematic differences in digit ratios or in reporting behavior.

B. Empirical Specifications

We estimate three different specifications of the model presented above, differentiated by the control variables used. The first specification controls only for gender, placing it in the true digit ratio equation (3). The second controls also for survey year and the level and square of respondent

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[6] Our main findings remain when using random effects ordered probit models (see Online Appendix 6).

[7] Test results also suggested there was no need for making such corrections (Wooldridge 2014; Vella 1990), and Kimball, Sahm, and Shapiro (2008), in an application of their method, report finding minimal differences between the unadjusted standard error estimates and those based on a bootstrap method.

[8] While the estimates of the covariates' second-stage coefficients, β_0 and $\boldsymbol{\beta}_2$, do not share this robustness, these are not of primary interest.

age, placing these in the perceived digit ratio equation (4) because the true digit ratio is not expected to change during adulthood (Garn et al. 1975; Galis et al. 2010; Gillam et al. 2008). The inclusion of gender is strongly supported in the literature, with the average digit ratio being lower for men than for women (see, e.g., Phelps 1952, and Swami et al. 2013, Table 9, for an overview). The inclusion of age can control for the inability to fully extend the digits at advanced ages, e.g., because of arthritis in the hands, which can affect the measurement of digit ratios (Haugen et al. 2011; Richards, Bellin and Davies 2017; Yaku et al. 2016; Zhang et al. 2008). Gender and age have also been shown to relate to risk preferences and are thus also useful controls in the second-stage model: e.g., men have a higher preference for risk taking than women and the preference for risk taking decreases with age (Dohmen et al. 2011; Donkers, Melenberg and van Soest 2001).

The third empirical specification uses an extended set of controls to assess if the digit ratio associations remain when accounting for possible hereditary or intergenerationally transmittable factors, or possible causal pathways. These additional controls are time-invariant (see Section II) and assumed to be associated with the true digit ratio. The controls for race, left-handedness, and mother's level of education account for the presence of possible hereditary or intergenerationally transmittable factors that are associated with both risk preferences and the digit ratio (Kalichman, Batsevich, and Kobyliansky 2019, Alan et al. 2017). Further controls are added for several possible pathways (i.e. life outcomes) through which the digit ratio could be associated with risk preferences. For instance, education was shown to be positively associated with both the digit ratio and risk preferences (Nye, Bryukhanov, and Polyachenko 2017; Donkers, Melenberg and van Soest 2001). Therefore, it is possible that the digit ratio is related to risk preferences only indirectly, through a direct relationship with education. If so, we expect the digit ratio's association with risk preferences to diminish once education is controlled for. We include life outcomes that were identified in the literature to be related to the digit ratio, or prenatal testosterone, and to risk preferences: educational attainment, cognitive skills, self-reported health, body mass index (BMI), height, and smoking behavior (see Online Appendix 2 for references). Again, our estimates of the digit ratio's association with risk preferences are robust to these controls also or instead entering the perceived digit ratio equation (see Section III.A or Online Appendix 4).

While the associations of the additional covariates of the third empirical specification with the digit ratios and risk preferences are of independent interest, we refrain from discussing these in the main text. The mechanisms governing these associations are complex and deserve more thorough investigations than we could provide here. Online Appendix 2 discusses the relevant literature in more detail. Finally, for the empirical estimations we demeaned the covariates by gender.

Table 4 *The associations of gender and age with the probability of answering that the index finger is longer than the ring finger (a high digit ratio) based on the estimation results of the digit ratio model (Eqs. (5)-(6)).*

M=men W=women	M & W Left hand	M & W Right hand	M Left hand	M Right hand	W Left hand	W Right hand
Index >ring (proportion)	0.359	0.325	0.284	0.248	0.430	0.397
Number of observations	9,976		4,294		5,682	
Number of individuals	5,898		2,496		3,402	
Panel A: Controlled for gender.	Coef. (Std.Err.)	Coef. (Std.Err.)	Coef. (Std.Err.)	Coef. (Std.Err.)	Coef. (Std.Err.)	Coef. (Std.Err.)
Male (vs female)	-0.222***	-0.219***				
	(0.012)	(0.012)				
SD random effect	1.212***	1.233***	1.267***	1.252***	1.371***	1.490***
	(0.035)	(0.035)	(0.055)	(0.055)	(0.105)	(0.112)
Correlation random effects	0.833***		0.819***		0.845***	
	(0.011)		(0.017)		(0.015)	
Correlation error terms	0.737***		0.779***		0.704***	
	(0.014)		(0.020)		(0.020)	
H$_0$: Pooling men & women [a]	0.087					
Panel B: Controlled for gender and age	Coef. (Std.Err.)	Coef. (Std.Err.)	Coef. (Std.Err.)	Coef. (Std.Err.)	Coef. (Std.Err.)	Coef. (Std.Err.)
Male (vs female)	-0.218***	-0.217***				
	(0.012)	(0.012)				
Age/10 [b]	0.022***	0.008*	0.002	-0.008	0.046***	0.027***
	(0.004)	(0.004)	(0.005)	(0.005)	(0.006)	(0.006)
SD random effect	1.211***	1.236***	1.269***	1.252***	1.161***	1.218***
	(0.035)	(0.035)	(0.055)	(0.055)	(0.045)	(0.046)
Correlation random effects	0.834***		0.820***		0.843***	
	(0.011)		(0.016)		(0.015)	
Correlation error terms	0.735***		0.778***		0.707***	
	(0.014)		(0.020)		(0.020)	
H$_0$: No age associations [a]	0.000***		0.076		0.000***	
H$_0$: Pooling men & women [a]	0.000***					

Notes. Weighted average marginal effects are computed. Index= index finger length, ring=ring finger length, SD=Standard deviation. 'Random effect' and 'error term' refer to, respectively, the individual-hand random effect $\theta_i + \eta_{h,i}$ and the perception error $\zeta_{it} + \upsilon_{h,it}$ of Eq.(6). The models of Panel B include a year-dummy for 2019 and a quadratic age profile. Table A-2 shows the associations for the extended empirical specification discussed in Section III.B. The standard errors are clustered at the individual level. * p<0.05; ** p<0.01; *** p<0.005

[a] Entries shown are p-values. A LR-test is used for testing the null-hypothesis 'Pooling men & women'. The pooled model allows for a gender specific intercept (i.e. the model in the first two columns *vs*. the models in last four columns).

[b] Based on a quadratic age profile. These profiles show no strong curvature and have no turning points within the sample's age range (20-89).

IV. Empirical Results

A. The Digit Ratio Model

Both panels A and B in Table 4 confirm the sexually dimorphic nature of the digit ratio: for both the left and right hand, men are about 22 pp (percentage points) less likely than women to report that their index finger is longer than their ring finger. This latter finding of about equal gender differences for both hands does not support the conclusion of Hönekopp and Watson (2010) that the digit ratio shows greater sex difference in the right hand. Further, the estimated standard deviations of the random effects are in the range of 1.2 to 1.5 and, given the normalized standard deviation of the error term is equal to 1, suggest that a large proportion of the variation in the reported digit ratio is due to measurement error.

The digit ratio is not expected to change during adulthood. For men, the age effect is minor, but for women the probability of reporting that the index finger is longer than the ring finger goes up with age (Panel B). As argued in the literature, these findings could be related to the inability to fully extend the digits at advanced ages (Richards, Bellin and Davies 2017).

Furthermore, there is no empirical support for pooling across genders for both specifications (last rows of Panels A and B). Not reported in tables is that a specification with interactions between gender and the covariates included in the model of Panel B, also provides no empirical support for pooling across genders.[9]

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[9] There are gender differences in the variance-covariance matrix. Computing the estimated expected digit ratio based on the pooled estimates (Table 4, first two columns) has, however, no discernible impact on the estimated associations of the digit ratios with the preference for risk taking in Tables 5 and 6. See also Online Appendix 5.

Table 5 *Estimated associations of the digit ratio (DR) with preference for risk taking (Eq.(7)).*

L=Left hand R=Right hand	Men & Women	Men & Women	Men & Women	Men & Women	Men	Women
Panel A: *Controlled for gender.*	Coef. (Std.Err.)	Coef. (Std.Err.)	Coef. (Std.Err.)	Coef. (Std.Err.)	Coef. (Std.Err.)	Coef. (Std.Err.)
Male (vs female)	0.558***	0.558***	0.557***	0.557***		
	(0.054)	(0.054)	(0.054)	(0.054)		
DR L, $\tilde{\beta}_l$	-0.073	-0.106***				
	(0.084)	(0.034)				
DR R, $\tilde{\beta}_r$	-0.036		-0.102***			
	(0.083)		(0.034)			
DR L or R, $\tilde{\beta}_l = \tilde{\beta}_r$				-0.055***	-0.051*	-0.058*
				(0.017)	(0.025)	(0.024)
H_0: No DR [a]	0.007**	0.002***	0.003***	0.002***	0.046*	0.015*
H_0: DR L=R [a]	0.819					
H_0: DR M=W [a]	0.068	0.451	0.744	0.842		
R^2	0.017	0.017	0.017	0.017	0.001	0.002
N	9,976	9,976	9,976	9,976	4,294	5,682
Panel B: *Controlled for gender and age.*	Coef. (Std.Err.)	Coef. (Std.Err.)	Coef. (Std.Err.)	Coef. (Std.Err.)	Coef. (Std.Err.)	Coef. (Std.Err.)
Male (vs female)	0.550***	0.550***	0.550***	0.550***		
	(0.055)	(0.055)	(0.055)	(0.055)		
Age/10 [b]	-0.056***	-0.056***	-0.056***	-0.056***	-0.037	-0.074***
	(0.019)	(0.019)	(0.019)	(0.019)	(0.029)	(0.025)
DR L, $\tilde{\beta}_l$	-0.052	-0.099***				
	(0.084)	(0.034)				
DR R, $\tilde{\beta}_r$	-0.051		-0.098***			
	(0.084)		(0.034)			
DR L or R, $\tilde{\beta}_l = \tilde{\beta}_r$				-0.052***	-0.054*	-0.050*
				(0.017)	(0.025)	(0.024)
H_0: No DR [a]	0.012*	0.004***	0.004***	0.003***	0.035*	0.035*
H_0: DR L=R [a]	0.996					
H_0: DR M=W [a]	0.073	0.640	0.541	0.926		
R^2	0.020	0.020	0.020	0.020	0.003	0.005
N	9,976	9,976	9,976	9,976	4,294	5,682

Notes. Weighted average marginal effects are computed. Dependent variable: preference for risk taking (0-10 scale). The estimated expected digit ratios that enter Eq. (7) are based on Table 4 results with the same covariates as in Eq. (7). The model of Panel B includes a year-dummy for 2019 and a quadratic age profile. N = number of observations. The models include individual random effects and are estimated with least squares. The standard errors are clustered at the individual level. * $p<0.05$; ** $p<0.01$; *** $p<0.005$.

[a] “H_0: No DR”, “H_0: DR L=R” and “H_0: DR M=W” are the null hypotheses of the digit ratio association(s) being equal to zero, the same for both hands, or the same across gender, respectively. Entries shown are *p*-values.

[b] Based on a quadratic age profile. These profiles show no significant curvature at the 5% level.

B. Risk Preferences and the Digit Ratio

The estimated expected digit ratios that enter the risk preferences model, Eq. (7), are computed based on the results of the digit ratio model estimated by gender (Table 4, last four columns).[10] This latter implementation prevents an assessment of the extent to which the gender difference in the digit ratio accounts for the gender difference in the preference for risk taking.[11]

Table 5 presents estimation results for various versions of equation (7). In line with, e.g., Croson and Gneezy (2009) and Dohmen et al. (2011) we find that, on average, men have a higher preference for risk taking than women, and that older men or women have a lower preference for risk taking than the younger ones (Table 5, Panels A and B).[12] Also, the strength of the association of gender with risk preferences is about the same as the one in Dohmen et al. (2011). Although the digit ratio associations are individually insignificant (column 1), they are jointly significant at the 1% level for the specification of Panel A and at the 5%-level for the specification of Panel B (H_0: No DR). Further, the test statistics at the bottom of both panels do not reject the null of equal associations with the digit ratio of the left and right hand (H_0: DR L=R), and of identical associations with the digit ratio for men and women (H_0: DR M=W).

For men and women combined, and allowing for a gender difference in risk preferences, the estimated associations of the digit ratio with the preference for risk taking are about -0.1 in the second and third columns and are about the same as two times the estimated association in the

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[10] To preserve robustness of our model of Section III.A to whether controls affect the true digit ratio or its measurement error, interactions between the covariates and gender are included in the risk preferences model.

[11] See Online Appendix 5 for such an assessment based on the results in the first two columns of Panel A (Table 4).

[12] For all specifications, the coefficient corresponding to age-squared was not significantly different from zero at the 5% level.

fourth column (and rows “DR L or R, $\tilde{\beta}_l = \tilde{\beta}_r$”). For such a comparison of associations, the estimated association in the fourth column needs to be doubled because it is for each hand. Furthermore, the associations by gender in the last two columns are about the same as those based on the combined sample of men and women, albeit less precisely estimated (see Table A-4 for the results by gender). Finally, allowing for measurement error in the reported digit ratio to be related to age hardly affects the estimated associations of the digit ratio with risk preferences (Panel A *vs*. Panel B).

For an interpretation of the size of the digit ratio association of about -0.1 we consider for both men and women a 2.4 standard deviation change in their true digit ratio. This change equals about the average difference in the estimated expected digit ratio between those who reported for both hands and in both years that their index finger is longer than their ring finger, referred to as a individuals with a high digit ratio, and those who reported that their index finger is shorter than their ring finger, referred to as individuals with a low digit ratio (see details in Panel A of Online Appendix Table A-3). The preference for risk taking is, therefore, on average 0.24 points (on a 0-10 scale), lower among individuals with a high digit ratio than among individuals with a low digit ratio. This difference equals about 40% of the gender difference in the preference for risk taking (0.56 points; Table 5). Or when compared with an average preference for risk taking of 5.74 points (Table 2), this difference of 0.24 points is about 4% of the average preference for risk taking, while the estimated gender difference in the preference for risk taking is about 10%.

C. Extended Empirical Specification of the Risk Preference model

Hereditary or intergenerationally transmittable factors that are associated with both risk preferences and the digit ratio can explain part of the estimated association of the digit ratio with the preference for risk taking. To examine this, we controlled for characteristics typically known at birth or in early life, namely race, left-handedness, and mother's level of education. Furthermore, the digit ratio's association with risk preferences can be mediated through later life outcomes related to human capital formation (level of education, numeracy, vocabulary, and verbal skills), or related to health (BMI, having arthritis, height, self-assessed health, and smoking behavior). We refer to Section III.B and Online Appendix 2 for further discussion.

When controlling for these characteristics, the associations of the digit ratio with risk preferences are marginally strengthened (Table 6). Furthermore, as is also the case for the empirical specifications of Table 5, the test results in Table 6 suggest equal digit ratio associations with risk preferences for the left and right hand (H_0: DR L=R) and identical associations for men and women (H_0: DR M=W).

Table 6 *Estimated associations of the digit ratio (DR) with the preference for risk taking (Eq.(7)): The importance of controlling for possible hereditary or intergenerationally transmittable factors and pathways through education and health outcomes.*

L=Left hand R=Right hand	Men & Women	Men & Women	Men & Women	Men & Women	Men	Women
	Coef. (Std.Err.)	Coef. (Std.Err.)	Coef. (Std.Err.)	Coef. (Std.Err.)	Coef. (Std.Err.)	Coef. (Std.Err.)
Male (vs female)	0.556***	0.556***	0.558***	0.557***		
	(0.066)	(0.066)	(0.066)	(0.066)		
DR L, $\tilde{\beta}_l$	-0.109	-0.112***				
	(0.086)	(0.035)				
DR R, $\tilde{\beta}_r$	-0.004		-0.102***			
	(0.084)		(0.035)			
DR L or R, $\tilde{\beta}_l = \tilde{\beta}_r$				-0.056***	-0.057*	-0.055*
				(0.018)	(0.026)	(0.025)
H_0: No DR a)	0.006**	0.001***	0.003***	0.002***	0.026*	0.024*
H_0: DR L=R a)	0.528					
H_0: DR M=W a)	0.100	0.647	0.597	0.962		
R^2	0.056	0.056	0.056	0.056	0.027	0.051
N	9,247	9,247	9,247	9,247	4,031	5,216

Notes. Weighted average marginal effects are computed. Dependent variable is the preference for risk taking (0-10 scale). The estimated expected digit ratios (DRs) are based on the estimates of the digit ratio model (Eqs. (5)-(6)) with the extended empirical specification (see Tables A-2). The covariates are gender, year, age, race, left-handedness, mother's education, level of education, numeracy, vocabulary, verbal skills, BMI, having been diagnosed with arthritis, height, self-assessed health, and smoking behavior. Interactions between the covariates and gender are included in the risk preferences model to preserve robustness of our model of Section III.A to whether controls affect the true digit ratio or its measurement error (see Table A-5 for the marginal effects). N= Number of observations. The models include individual random effects and are estimated with least squares. The standard errors are clustered at the individual level. * $p<0.05$; ** $p<0.01$; *** $p<0.005$.

a) “H_0: No DR”, “H_0: DR L=R” and “H_0: DR M=W” are the null hypotheses of the digit ratio association(s) being equal to zero, the same for both hands, or the same across gender, respectively. Entries shown are *p*-values.

V. Summary and Discussion

Our analysis provides empirical support for the hypothesized negative association between the digit ratio and the general preference for risk taking. The estimated difference in the preference for risk taking between individuals with a high and a low digit ratio suggests a meaningful biological basis for risk preferences: this difference equals about 40% of the estimated gender difference in the preference for risk taking. Furthermore, the estimated negative association between the digit ratio and the preference for risk taking remains after having controlled for characteristics related to possible intergenerationally transmittable factors and mediating pathways. An interpretation of this negative association, based on insights from human biology and economics, is that the digit ratio is a retrospective biomarker of prenatal exposure to testosterone, i.e. a higher exposure decreases the digit ratio, therefore leading it to be negatively associated with the preference for risk taking (e.g., Coates, Gurnell, and Sarnyai 2010; Manning 2011).

Lack of replicability of the estimated association between the digit ratio and risk preferences is a major concern in this strand of literature and hinders the use of the digit ratio as a biomarker for prenatal exposure to testosterone and to gain insights into the possible biological roots of life outcomes. To improve on previous studies, which mostly relied on lab-experimental evidence with small samples (Neyse et al. 2020), we chose a rather different research setup. First, we have used a large population survey of about 6,000 adults from the Understanding America Study. Individuals' risk preferences were elicited with a question about general risk preferences, with answer categories on a Likert scale, and the digit ratios were elicited by asking respondents to compare the lengths of their ring and index fingers for each hand. These survey questions can easily be included in large population surveys, which can facilitate replication studies. Second, each hand's digit ratio was elicited twice, which, together with a statistical model based on Kimball, Sahm, and Shapiro (2008), made it possible to account for measurement error that was shown to be abundantly present. Our digit ratio question was apparently difficult to answer for many respondents as shown by the changes in answers over time. Further research on survey methodology to improve accuracy is warranted. Technological innovations that use the camera on respondents' devices to measure the lengths of their digits may further facilitate the elicitation of the digit ratio in large surveys (Huang, Basanta, and Sandnes 2014). Third, and specific to our research setup, an important advantage of our statistical model is that it reduces the multiple ordinal measurements of the digit ratio to a one-dimensional measure, which facilitates the interpretation of empirical results. In particular, our statistical model provides estimates of the associations with the true digit ratio, which makes our estimates comparable with those from studies that use a continuous measure of the digit ratio.[13]

Our empirical findings settle the mixed findings on the digit ratio's association with general risk preferences of Bönte, Procher, and Urbig (2016), Brañas-Garza, Galizzi, and Nieboer (2018) and Stenstrom et al. (2011). We provide firm empirical support for a negative association of the digit ratio with the general preference for risk taking. In addition, our findings suggest similar associations of the digit ratio with risk preferences for both hands and for both genders. Finally, for men and women combined, the precision of the estimated associations of the digit ratio with risk preferences suggests that these associations are plausibly replicable (Benjamin et al. 2018). The associations by gender are estimated to be about the same as those for both genders combined, but with lower precision because of smaller sample sizes.

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[13] Unfortunately, based on the information provided in previous studies we could only compare the directions of the associations.

Our findings suggest the presence of a biological basis for risk preferences and, arguably, support the use of the digit ratio as a biomarker for prenatal exposure to testosterone in population surveys. Little is known, however, about why individuals differ in their levels of prenatal testosterone. Findings of Rizwan, Manning, and Brabin (2007) suggest an effect of maternal smoking on the fetus' digit ratio for boys (not for girls), which points toward the importance of in utero conditions for later life outcomes (Barker 1995). The findings of Loehlin et al. (2006) suggest that differences in the digit ratio are due to genetic differences rather than environmental factors. Heritability of the digit ratio has been shown (Paul et al. 2006), as well as its genetic roots (Kalichman, Batsevich and Kobyliansky 2019; Voracek and Dressler 2009; Warrington et al. 2018). Next to further research on the link between genetic endowments and the digit ratio (Warrington et al. 2018), further research on the endocrinology of the digit ratio and on the possible factors affecting the digit ratio in utero, can shed light on the causal mechanisms underlying the association of the digit ratio with risk preferences and, possibly through it, health and economic outcomes.

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ONLINE APPENDIX 1

BACKGROUND ON THE DIGIT RATIO (2D:4D) AND PRENATAL EXPOSURE TO TESTOSTREONE

The digit ratio or 2D:4D is the ratio of the lengths of a hand's index finger (second digit, 2D) and ring finger (fourth digit, 4D). The formation in utero of the digits of a fetus occurs by 13 weeks, with the tenth through thirteenth weeks being critical for the digit ratios and sexual dimorphism in the digit ratio (Garn et al. 1975; Galis et al. 2010). The bone-to-bone ratio is consistent from this point onward into an individual's adulthood (Garn et al., 1975) although findings of Galis et al. (2010), and references therein, suggest that during childhood the second digit grows somewhat faster than the fourth digit (positive allometric growth of the second digit). Gillam et al. (2008) show that women's digit lengths attain their maxima around the ages 12–15 while for men it is around 17–20 years of age.

Human gender development is likely to be influenced by testosterone in weeks 8 to 24 of gestation and in the first few months after birth (Hines, Constantinescu, and Spencer 2015). Studies have also reported that the digit ratio is negatively associated with the ratio of prenatal testosterone relative to prenatal estradiol and that this association is independent of sex (Manning, Scutt, and Lewis-Jones 1998; Lutchmaya et al. 2004). Gender differences in estradiol are, however, relatively small compared to the gender differences in testosterone.[14] If the digit ratio is a biomarker for prenatal exposure to testosterone (relative to estradiol) it may provide a valid test of the organizational hypothesis of Phoenix et al. (1959) that prenatal exposure to androgens such as

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[14] Testosterone levels are about 72.0-235.0 ng/dL for men aged 30-39, and 0.8-10.0 ng/dL for women aged 20-50 (not on oral estrogen), while estradiol levels are about 10-40 pg/mL for men and 15-350 pg/mL for premenopausal women and less than 10 pg/mL for postmenopausal women (Endocrine Society 2019).

testosterone permanently masculinizes the brain and behavior and this hypothesis is the starting point of most empirical research on the relationships between the digit ratio and later life outcomes. The organizational hypothesis is also at the basis of twin studies exploiting possible testosterone transfer to females from their male co-twins (Bütikofer et al. 2019; Cronqvist et al. 2015; Gielen, Holmes, and Meyers 2016; Vuoksimaa et al. 2010). In addition, van Anders, Vernon, and Wilbur (2006) show that females with male co-twins have, on average, a significantly lower digit ratio for the left hand (and not for the right hand) than females with female co-twins.

A negative effect of testosterone, and a positive effect of estrogen, on the digit ratio was confirmed by Zheng and Cohn (2011) in an experiment with mice which were given, prenatally, additional androgen or estrogen. See also Manning (2011) for an excellent summary of the literature on the validity of the digit ratio as a marker for prenatal testosterone (relative to estrogen). For humans, Hollier et al. (2015) find no empirical support for an association between the digit ratio and fetal androgens or estrogens, which are however measured at delivery, while Ventura et al. (2013) provide empirical support for such an association with testosterone measurement in, on average, the 17th week of gestation. Further, Klimek et al. (2014) report a negative association between the digit ratio and testosterone levels during adulthood.

Phelps (1952) already argued the possibility of the digit ratio as a diagnostic aid under the assumption that the digit ratio is genetically linked to the onset of severe diseases. Manning et al. (2003) has shown a relationship between the digit ratio and the androgen receptor (AR) gene; a result that could not be replicated in Hampson and Sankar (2012). Breedlove (2010) and Voracek (2014), based on literature reviews, conclude that use of the digit ratio as a prenatal testosterone marker is questionable and that for instance genome-wide association studies (GWAS) might provide more insights into this relationship. Warrington et al. (2018) identified eleven loci in a

GWAS that explained 3.8% of the variation in the digit ratio, confirming a genetic association, but none of the loci were related to pathways involving adult testosterone. They also find weak evidence for an association between the digit ratio and sensitivity to testosterone (AR gene) but for females only. While, as they discuss, this does not exclude the possibility that the digit ratio is a biomarker of prenatal exposure to androgen and estrogen, empirical evidence concerning this issue remains inconclusive. These inconclusive findings might be related to the finding based on a meta study by Hönekopp et al. (2007) that suggests that the digit ratio is not correlated with adult sex hormones levels. Likewise, Muller et al. (2011) did not find associations between adult circulating concentration of sex hormone or SHGB and the digit ratio. García-Cruz et al (2011), on the other hand, find that the digit ratio is significantly related to adult testosterone levels but for a small and biased sample of male patients with testosterone deficiency.

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ONLINE APPENDIX 2

SUMMARY STATISTICS, ESTIMATED EXPECTED DIGIT RATIOS, AND EMPIRICAL RESULTS WITH THE EXTENDED EMPIRICAL SPECIFICATION.

Summary statistics of all variables used are presented in Table A-1, Table A-3 presents details of the computed expected digit ratios, Tables A-4 shows the estimation results of the models for the first three columns of Table 5 by gender. Tables A-2 and A-5 contain estimation results with the extended empirical specification of, respectively, the digit ratio and the risk preferences models. The estimated associations in Tables A-2 and A-4 are mostly in line with those reported in previous studies, insofar as previous studies reported these. The remainder of this Appendix discusses the additionally included characteristics of the extended specification (see Section III.B).

The extended specification controls for race, left-handedness, and mother's level of education. Concerning the inclusion of race in our model, Minami (1952), Manning, Churchill, and Peters (2007) and Brañas-Garza, Galizzi, and Nieboer (2018) report significant variation in the digit ratio by race and the findings of Loehlin et al. (2006) suggest that this variation can be attributed to genetic factors and not to environmental factors. Gillam et al. (2008) show that the digit ratios tend to be higher, albeit insignificantly, for sinistral individuals compared to dextral individuals. In line with the latter finding, the results of Vuoksimaa et al. (2010) suggest that higher prenatal testosterone exposure is related to a higher prevalence of righthandedness. Although the literature does not provide strong support for an association between the digit ratio and handedness (Swami et al. 2013), we controlled for it to shed some light on this issue. Further, Pfannkuche et al. (2009) conclude that the lateralization of the brain or behaviors, including handedness, is not affected by testosterone. Race and mother's education can also be related to risk preferences, next to their influence through the digit ratio, and are therefore also controlled for in the risk preferences equation. Previous studies provided empirical support for this: e.g., for South Africa, Dickason-Koekemoer and Suné Ferreira (2018) show that African investors have a higher preference for risk taking than non-African investors and, using German data, Dohmen et al. (2011) show that mother's level of education is positively associated with the willingness to take risks in general. Further, left-handedness has, arguably through a differential brain structure and usage, been associated with lower labor market earnings (Goodman 2014); an association that could be mediated through risk preferences.

The extended specification also controls for educational attainment, cognitive skills, self-reported health, body mass index (BMI), height, and smoking behavior. A higher level of education is associated with a higher preference for risk taking (Donkers, Melenberg and van Soest 2001), individuals with lower cognitive ability are more risk averse (Dohmen et al. 2010), taller individuals are less risk averse (Dohmen et al. 2011), adverse health shocks are associated with higher risk aversion, and risk preferences with risky health behavior (Booth, Johnson and Granger 1999, Decker and Schmit 2016; Galizzi and Miraldo 2017; Hammitt, Haninger, and Treich 2009). At the same time, the digit ratio literature has shown relationships between the digit ratio and education and health outcomes. For instance, the digit ratio is negatively associated with BMI (Klimek et al. 2014), and positively associated with the level of education (Nye, Bryukhanov, and Polyachenko 2017) and with numeracy and verbal skills **(**Luxen and Buunk 2005)[15]. Also, Kalichman, Batsevich and Kobyliansky (2017) show that the osseographic score, a skeletal biomarker of biological aging, was, after having controlled for age, sex and BMI, higher for

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[15] Arguably, prenatal testosterone stimulates the development of the right hemisphere of the brain, which results in better spatial abilities and worse verbal abilities (Gurvich et al. 2018).

individuals with a lower digit ratio. Further, Kratochvil and Flegr (2009) argue that the digit ratio is related to finger lengths, which is positively correlated with height and can explain some of the gender differences in the digit ratio. In addition, adult testosterone levels are associated with risky health behavior (Booth, Johnson and Granger 1999) and the literature on prenatal testosterone exposure of women due to a male co-twin shows that it can decrease educational attainment and mathematical skills (Bütikofer et al. 2019; Gielen and Zwiers 2018).[16] Further, Rohr (2002) discusses the impact of testosterone imbalance on women's health, and in particular its associations with osteoporosis, depression, substance abuse, obesity, type II diabetes, breast cancer and cardiovascular risk. Finally, as argued above, a possible association of age with the perceived digit ratio can be because of arthritis in the hands, and Haugen et al. (2011) argues that osteoarthritis in the hand affects the digit ratio.

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[16] See also Nye et al. (2017) for a negative association between the digit ratio and wages.

Table A-1 *Summary of the data by year and gender.*

Year	2018		2018		2019		2019	
Gender	Male		Female		Male		Female	
Number of observations	2,074		2,712		2,220		2,970	
	mean	SD	mean	SD	mean	SD	mean	SD
Preference for risk taking (0-10 Likert scale with 10 Very willing to take risks)	6.0	2.2	5.5	2.3	6.1	2.1	5.4	2.3
Age (in full years)	48.2	15.8	48.4	15.8	50.5	16.1	46.3	16.0
Numeracy skills (0-10 scale)	5.2	0.9	5.0	0.9	5.3	0.9	4.9	0.9
Vocabulary skills (0-10 scale)	5.2	0.9	5.0	0.9	5.2	0.9	4.9	0.9
Verbal skills (0-10scale)	5.3	0.9	5.2	0.9	5.2	0.9	5.1	0.9
Body Mass Index (BMI)	28.9	6.1	28.8	7.3	28.9	6.2	29.1	7.8
Height (in meters)	1.8	0.1	1.6	0.1	1.8	0.1	1.6	0.1
	%		%		%		%	
Left-handed	12.0		9.5		12.7		11.0	
Arthritis	20.8		26.4		22.7		25.5	
Race	%		%		%		%	
White, Hispanic	14.1		13.6		11.4		14.7	
White, non-Hispanic	66.2		62.3		67.5		60.9	
Black Only	10.2		14.4		11.0		14.4	
Native American	0.6		0.7		0.7		1.2	
Asian Only	4.6		4.5		5.1		4.5	
Mixed	4.3		4.5		4.2		4.3	
Level of education	%		%		%		%	
At most a high school diploma	40.3		37.6		36.6		40.7	
Some college	27.2		29.1		27.1		29.4	
At least a college degree	32.6		33.3		36.3		29.8	
Mother's level of education	%		%		%		%	
At most a high school diploma	64.8		63.3		65.0		63.4	
Some college	14.5		17.4		15.9		17.1	
At least a college degree	20.7		19.3		19.1		19.5	
Self-assessed health	%		%		%		%	
Excellent health	11.2		14.9		12.3		14.0	
Very good health	40.4		37.8		38.9		34.9	
Good health	34.0		30.4		33.7		33.4	
Fair or poor health	14.4		16.9		15.1		17.7	

Notes Survey weights are used for constructing this table. SD=Standard Deviation. Numeracy, vocabulary, and verbal skills are constructed IRT 0-100 scales, which we divided by 10, based on a battery of survey questions (Moldoff and Becker 2020). Native Americans include American Indians, Alaska Natives, and Pacific Islander Americans. There are somewhat fewer observations for mother's education, cognitive skills, and health-related variables due to missing values (see Table 6 for the number of observations).

Table A-2 *The estimation results of the digit ratio model (Eqs.(5)-(6)) with the third (extended) empirical specification (see Section III.B).*

Average marginal effects on P(index>ring)	Men & Women, Left hand	Men & Women, Right hand	Men, Left hand	Men, Right hand	Women, Left hand	Women, Right hand
	Coef. (Std.Err.)	Coef. (Std.Err.)	Coef. (Std.Err.)	Coef. (Std.Err.)	Coef. (Std.Err.)	Coef. (Std.Err.)
Male	-0.217***	-0.218***				
	(0.013)	(0.012)				
Year-dummy 2019	0.033***	0.029***	0.017	0.020*	0.049***	0.039***
	(0.008)	(0.008)	(0.010)	(0.009)	(0.013)	(0.013)
Age/10	0.022***	0.007	0.007	-0.004	0.041***	0.022**
	(0.005)	(0.005)	(0.007)	(0.007)	(0.008)	(0.008)
Left-handed	0.016	0.013	0.019	0.028	0.014	-0.001
	(0.021)	(0.021)	(0.026)	(0.023)	(0.034)	(0.034)
White, Hispanic	-0.042	-0.050*	0.024	-0.018	-0.091*	-0.077*
	(0.026)	(0.025)	(0.035)	(0.032)	(0.038)	(0.039)
Black Only	-0.077***	-0.081***	-0.05	-0.065*	-0.093*	-0.092*
	(0.026)	(0.025)	(0.036)	(0.033)	(0.038)	(0.039)
Native American	-0.136***	-0.102*	-0.104	-0.073	-0.141*	-0.112
	(0.044)	(0.042)	(0.059)	(0.054)	(0.063)	(0.064)
Asian Only	-0.046	-0.017	-0.071	-0.017	-0.023	-0.017
	(0.038)	(0.037)	(0.048)	(0.043)	(0.058)	(0.059)
Mixed race	-0.077**	-0.026	-0.089*	-0.042	-0.058	0.002
	(0.030)	(0.029)	(0.036)	(0.033)	(0.047)	(0.048)
HS diploma, mother [a)]	-0.012	-0.017	0.009	-0.02	-0.036	-0.014
	(0.019)	(0.018)	(0.024)	(0.022)	(0.029)	(0.029)
College degree, mother [a)]	0.032	0.039	0.017	0.007	0.042	0.070*
	(0.022)	(0.022)	(0.028)	(0.025)	(0.034)	(0.035)
HS diploma [a)]	0.028	0.022	-0.01	0.019	0.055*	0.021
	(0.018)	(0.018)	(0.023)	(0.022)	(0.027)	(0.028)
College degree [a)]	0.042*	0.048***	0.03	0.038*	0.054*	0.062*
	(0.017)	(0.016)	(0.020)	(0.019)	(0.026)	(0.026)
Numeracy (0-10)	-0.017	-0.017	-0.036***	-0.025*	0.004	-0.005
	(0.010)	(0.010)	(0.012)	(0.011)	(0.016)	(0.016)
Vocabulary (0-10)	0.009	0.007	-0.012	-0.006	0.033*	0.024
	(0.010)	(0.010)	(0.013)	(0.012)	(0.016)	(0.016)
Verbal skills (0-10)	-0.022*	-0.017	-0.019	-0.021	-0.03	-0.017
	(0.010)	(0.010)	(0.012)	(0.011)	(0.016)	(0.016)
Excellent health	0.026	0.014	-0.031	-0.023	0.078*	0.053
	(0.023)	(0.022)	(0.029)	(0.026)	(0.035)	(0.036)
Very good health	0.012	0.012	-0.01	-0.011	0.039	0.044
	(0.016)	(0.016)	(0.020)	(0.018)	(0.025)	(0.026)
Fair or poor health	0.007	0.014	-0.014	0.016	0.028	0.015
	(0.020)	(0.020)	(0.026)	(0.024)	(0.030)	(0.031)
BMI	-0.036***	-0.029***	-0.016	-0.018	-0.048***	-0.037*
	(0.010)	(0.010)	(0.015)	(0.014)	(0.014)	(0.015)
Height	0.007	0.005	-0.094	-0.116	0.133	0.164
	(0.087)	(0.084)	(0.111)	(0.101)	(0.132)	(0.135)
Ever smoked	-0.012	-0.019	-0.021	-0.019	-0.009	-0.027
	(0.014)	(0.014)	(0.018)	(0.016)	(0.022)	(0.022)
Arthritis	-0.019	-0.019	-0.014	-0.034	-0.024	-0.000
	(0.017)	(0.016)	(0.021)	(0.020)	(0.026)	(0.026)
N	9,247	9,247	4,031	4,031	5,216	5,216

Notes. Weighted average marginal effects are computed. P(index>ring): the probability that the index finger is longer than the ring finger. See Table A-1 for the reference groups. N= Number of observations. The standard errors are clustered at the individual level. There is no empirical support for pooling across gender; the p-values for testing this are smaller than 0.005. * p<0.05; ** p<0.01; *** p<0.005. [a)] HS= at most a high school diploma. College= at least a college degree.

Table A-3 *Average estimated expected digit ratio. The estimated expected digit ratio is* $\frac{\mathbb{E}(d_{h,i}^{**}|\boldsymbol{d}_i,\boldsymbol{X}_i;\hat{\boldsymbol{\Gamma}})}{SD(d_{h,i}^{**}|\boldsymbol{X}_i;\hat{\boldsymbol{\Gamma}})}$ *(see Section III.A). These estimates cannot be compared across gender because they are based on the results of the digit ratio model estimated by gender (Table 4, Panel B).*

Cells: Average estimated expected digit ratio	Men	Women	
Full sample	0.029	0.030	
Panel A:			
Subsample of respondents who provided the same answer to the digit ratio question for both hands and years			
Low digit ratio: index<ring (530 men; 306 women),	-0.966	-1.290	
Medium digit ratio: index=ring (107 men; 139 women)	0.316	-0.085	
High digit ratio: index>ring (162 men; 452 women),	1.459	1.162	
Difference (high − low)	2.425	2.452	
Panel B: Full sample, by hand			
Answer for the left hand			
Index<ring (low digit ratio)	-0.616	-0.796	
Index=ring	0.286	-0.077	
Index>ring (high digit ratio)	0.940	0.718	
Difference (high − low)	1.555	1.514	
Answer for the Right hand			
Index<ring (low digit ratio)	-0.474	-0.659	
Index=ring	0.277	-0.038	
Index>ring (high digit ratio)	0.820	0.662	
Difference (high − low)	1.294	1.321	
Panel C: Left-right hand combinations (years pooled)	*Men's answers for the right hand*		
Men's answers for the left hand	Index<ring	Index=ring	Index>ring
Index<ring (low digit ratio)	-0.695	-0.242	-0.137
Index=ring	0.222	0.287	0.402
Index>ring (high digit ratio)	0.684	0.861	1.020
Difference (high for both hands − low for both hands)	1.715		
	Women's answers for the right hand		
Women's answers for the left hand	Index<ring	Index=ring	Index>ring
Index<ring (low digit ratio)	-0.905	-0.523	-0.389
Index=ring	-0.205	-0.075	0.081
Index>ring (high digit ratio)	0.223	0.408	0.845
Difference (high for both hands − low for both hands)	1.750		

Notes. ‘Index’ refers to index finger length and ‘ring’ refers to ring finger length. Survey weights are used for constructing this table. The reported averages remain virtually the same when based on empirical specifications of the digit ratio model without controls for year and age (Panel A of Table 4), or with the extended empirical specification of Table A-2.

Table A-4 *Estimated associations of the digit ratio (DR) with the preference for risk taking by gender (Eq. (7)). That is, the models for Table 5's first three columns by gender. The findings are in line with those of previous studies: there is suggestive empirical evidence for a digit ratio association for either the left hand or right hand.*

L=Left hand R=Right hand	Men, L & R	Men, L	Men, R	Women, L & R	Women, L	Women, R
Panel A: No controls.	Coef. (Std.Err.)	Coef. (Std.Err.)	Coef. (Std.Err.)	Coef. (Std.Err.)	Coef. (Std.Err.)	Coef. (Std.Err.)
DR L, $\tilde{\beta}_l$	0.118	-0.077		-0.267*	-0.129**	
	(0.115)	(0.050)		(0.122)	(0.047)	
DR R, $\tilde{\beta}_r$	-0.22		-0.115*	0.15		-0.093*
	(0.114)		(0.049)	(0.120)		(0.046)
H_0: No DR a)	0.040*	0.124	0.020*	0.012*	0.006**	0.046*
H_0: DR L=R a)	0.131			0.079		
R^2	0.002	0.001	0.002	0.002	0.002	0.001
N	4,294	4,294	4,294	5,682	5,682	5,682
Panel B: Controlled for year and age.	Coef. (Std.Err.)	Coef. (Std.Err.)	Coef. (Std.Err.)	Coef. (Std.Err.)	Coef. (Std.Err.)	Coef. (Std.Err.)
Age/10	-0.038	-0.037	-0.037	-0.073***	-0.074***	-0.074***
	(0.029)	(0.029)	(0.029)	(0.025)	(0.025)	(0.025)
DR L, $\tilde{\beta}_l$	0.133	-0.081		-0.239*	-0.113*	
	(0.117)	(0.050)		(0.122)	(0.047)	
DR R, $\tilde{\beta}_r$	-0.241*		-0.122*	0.137		-0.081
	(0.115)		(0.049)	(0.121)		(0.046)
H_0: No DR a)	0.025*	0.106	0.013*	0.032*	0.017*	0.083
H_0: DR L=R a)	0.099			0.114		
R^2	0.004	0.002	0.003	0.006	0.006	0.005
N	4,294	4,294	4,294	5,682	5,682	5,682

Notes. Dependent variable: preference for risk taking (0-10 scale). Weighted average marginal effects are computed using the least squares estimates of Eq. (7) with the estimated expected digit ratios (DRs) based on the estimates of the digit ratio model with the same covariates. N= Number of observations. The standard errors are clustered at the individual level. * p<0.05; ** p<0.01; *** p<0.005.

a) "H_0: No DR" and "H_0: DR L=R" are the null hypotheses of the digit ratio association(s) being equal to zero and the same for both hands, respectively. Entries shown are *p*-values.

Table A-5 *The estimated associations for the third empirical specification (Section III.B) with the preference for risk taking (Eq. (7)). The results are for the model that assumes equal digit ratio associations for both hands (Table 6, column 4).*

Preference for risk taking	Men & Women	Men	Women
	Coef. (Std.Err.)	Coef. (Std.Err.)	Coef. (Std.Err.)
Male	0.557***		
	(0.066)		
Year-dummy 2019	-0.132***	-0.06	-0.188***
	(0.030)	(0.044)	(0.042)
Age/10	-0.038	-0.025	-0.050
	(0.025)	(0.038)	(0.032)
Left-handed	-0.226*	-0.383***	-0.076
	(0.091)	(0.131)	(0.126)
White, Hispanic	0.373***	0.056	0.680***
	(0.112)	(0.172)	(0.146)
Black Only	0.181	0.035	0.319*
	(0.126)	(0.198)	(0.157)
Native American	-0.116	-0.462	0.217
	(0.198)	(0.309)	(0.250)
Asian Only	0.167	0.240	0.098
	(0.160)	(0.235)	(0.218)
Mixed race	0.258*	0.224	0.290
	(0.129)	(0.187)	(0.177)
At most a high school diploma, mother	-0.080	-0.229	0.063
	(0.079)	(0.122)	(0.102)
At least a college degree, mother	-0.013	-0.217	0.183
	(0.090)	(0.139)	(0.117)
At most a high school diploma	-0.436***	-0.341**	-0.528***
	(0.082)	(0.124)	(0.108)
At least a college degree	0.185**	0.128	0.239**
	(0.066)	(0.097)	(0.090)
Numeracy (0-10)	-0.074	-0.095	-0.055
	(0.041)	(0.060)	(0.058)
Vocabulary (0-10)	-0.010	0.001	-0.021
	(0.043)	(0.063)	(0.059)
Verbal skills (0-10)	-0.176***	-0.146*	-0.204***
	(0.043)	(0.062)	(0.059)
Excellent health	0.491***	0.381*	0.596***
	(0.102)	(0.156)	(0.133)
Very good health	0.313***	0.345***	0.281***
	(0.066)	(0.094)	(0.092)
Fair or poor health	-0.105	0.032	-0.236*
	(0.090)	(0.138)	(0.117)
BMI	0.068	0.089	0.048
	(0.047)	(0.077)	(0.054)
Height	0.742*	0.279	1.182*
	(0.378)	(0.561)	(0.507)
Ever smoked	0.281***	0.188*	0.371***
	(0.058)	(0.086)	(0.080)
Arthritis	0.041	-0.052	0.130
	(0.071)	(0.106)	(0.096)
DR L or R, $\tilde{\beta}_l = \tilde{\beta}_r$	-0.056***	-0.057*	-0.055*
	(0.018)	(0.026)	(0.025)
R-squared	0.056	0.027	0.051
Number of observations	9,247	4,031	5,216

Notes. Dependent variable: preference for risk taking (0-10 scale). Weighted average marginal effects are computed using the least squares estimates of Eq. (7) with the estimated expected digit ratios (DRs) based on the digit ratio model, Eqs. (5)-(6), with the same covariates as the one in this table (see Table A-2). See Table A-1 for the reference groups. The standard errors are clustered at the individual level. * p<0.05; ** p<0.01; *** p<0.005

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ONLINE APPENDIX 3

THE DIGIT RATIO SURVEY QUESTIONS

The digit ratio question was asked in UAS modules 164 and 193 in English or in Spanish (https://uasdata.usc.edu). For the comparison of the left fingers the question stipulates:

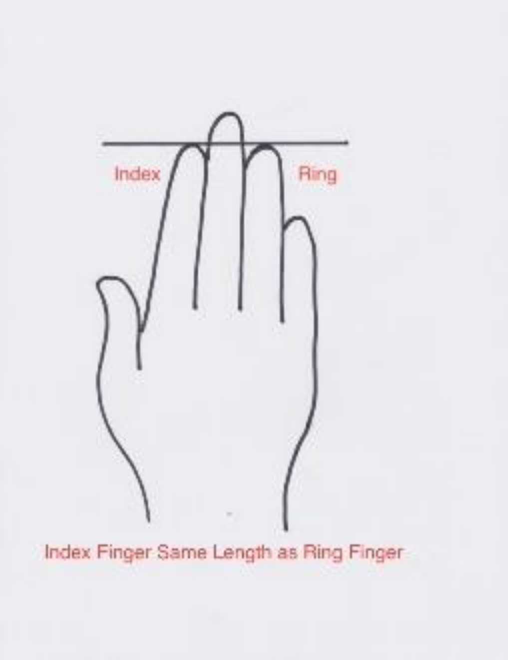
Please turn your left hand with the palm towards you, fingers next to each other. Keeping your fingers straight, look to see which finger is longer on your left hand: the index finger or the ring finger?

On my left hand...

1 My index finger is longer than my ring finger

2. My ring finger is longer than my index finger

3. My ring and index finger are the same length



4. I am physically unable to do this

The same question was asked for the comparison of the index and ring fingers of the right hand (including pictures of the right hand).

ONLINE APPENDIX 4

A. *The expected digit ratio*

The notation and model assumptions are as outlined in Section III. Conditional on $\boldsymbol{X_i}$, the true and perceived latent digit ratio variables in (3)-(4) are jointly normal:

$$(d^{**}_{l,i} \quad d^{*}_{l,i1} \quad d^{*}_{l,i2} \quad d^{**}_{r,i} \quad d^{*}_{r,i1} \quad d^{*}_{r,i2})^T \sim N((\mu^{**}_{l,i} \quad \mu^{*}_{l,i1} \quad \mu^{*}_{l,i2} \quad \mu^{**}_{r,i} \quad \mu^{*}_{r,i1} \quad \mu^{*}_{r,i2})^T, \Sigma),$$

with $\mu^{**}_{l,i} = \mathbb{E}\big(d^{**}_{h,i}|\boldsymbol{X_i}\big) = \gamma^0_h + \boldsymbol{Z}^1_i\boldsymbol{\gamma}^1_h$, $\mu^{*}_{l,i1} = \mathbb{E}\big(d^{*}_{h,it}|\boldsymbol{X_i}\big) = \gamma^0_h + \boldsymbol{X}_{it}\boldsymbol{\gamma}_h$, and

$$\Sigma = \begin{pmatrix} \sigma^2_\theta + \sigma^2_{l,\eta} & \sigma^2_\theta + \sigma^2_{l,\eta} & \sigma^2_\theta + \sigma^2_{l,\eta} & \sigma^2_\theta & \sigma^2_\theta & \sigma^2_\theta \\ \sigma^2_\theta + \sigma^2_{l,\eta} & \sigma^2_\theta + \sigma^2_{l,\eta} + 1 & \sigma^2_\theta + \sigma^2_{l,\eta} & \sigma^2_\theta & \sigma^2_\theta + \sigma^2_\zeta & \sigma^2_\theta \\ \sigma^2_\theta + \sigma^2_{l,\eta} & \sigma^2_\theta + \sigma^2_{l,\eta} & \sigma^2_\theta + \sigma^2_{l,\eta} + 1 & \sigma^2_\theta & \sigma^2_\theta & \sigma^2_\theta + \sigma^2_\zeta \\ \sigma^2_\theta & \sigma^2_\theta & \sigma^2_\theta & \sigma^2_\theta + \sigma^2_{r,\eta} & \sigma^2_\theta + \sigma^2_{r,\eta} & \sigma^2_\theta + \sigma^2_{r,\eta} \\ \sigma^2_\theta & \sigma^2_\theta + \sigma^2_\zeta & \sigma^2_\theta & \sigma^2_\theta + \sigma^2_{r,\eta} & \sigma^2_\theta + \sigma^2_{r,\eta} + 1 & \sigma^2_\theta + \sigma^2_{r,\eta} \\ \sigma^2_\theta & \sigma^2_\theta & \sigma^2_\theta + \sigma^2_\zeta & \sigma^2_\theta + \sigma^2_{r,\eta} & \sigma^2_\theta + \sigma^2_{r,\eta} & \sigma^2_\theta + \sigma^2_{r,\eta} + 1 \end{pmatrix}$$

for all $h \in \{l, r\}$, $t \in \{1,2\}$, and $i \in \{1..n\}$ (recall that we use the normalization $\sigma^2_v + \sigma^2_\zeta = 1$).

An expression for the expected digit ratio $\mathbb{E}\big(d^{**}_{h,i}|\boldsymbol{d_i}, \boldsymbol{X_i}\big)$ is derived based on the parameters of the digit ratio model (3)-(5). Using the law of iterated expectations:

(A-1) $\quad \mathbb{E}\big(d^{**}_{h,i}|\boldsymbol{d}_i, \boldsymbol{X}_i\big) = \mathbb{E}\big(\mathbb{E}\big(d^{**}_{h,i}|\boldsymbol{d}^*_i, \boldsymbol{d}_i, \boldsymbol{X}_i\big)|\boldsymbol{d}_i, \boldsymbol{X}_i\big),$

with $\boldsymbol{d}^*_i = (d^*_{l,i1} \quad d^*_{l,i2} \quad d^*_{r,i1} \quad d^*_{r,i2})^T$. Further, denote $\boldsymbol{\mu}^*_i = \mathbb{E}(\boldsymbol{d}^*_i|\boldsymbol{X}_i)$, $\boldsymbol{\Sigma}^h_{12} = \mathbb{E}\Big(\big(d^{**}_{h,i} - \mu^{**}_{h,i}\big)(\boldsymbol{d}^*_i - \boldsymbol{\mu}^*_i)^T|\boldsymbol{X}_i\Big)$, and $\boldsymbol{\Sigma}_{22} = \mathbb{E}\big((\boldsymbol{d}^*_i - \boldsymbol{\mu}^*_i)(\boldsymbol{d}^*_i - \boldsymbol{\mu}^*_i)^T|\boldsymbol{X}_i\big)$. $\mathbb{E}\big(d^{**}_{h,i}|\boldsymbol{d}^*_i, \boldsymbol{d}_i, \boldsymbol{X}_i\big) = \mathbb{E}\big(d^{**}_{h,i}|\boldsymbol{d}^*_i, \boldsymbol{X}_i\big)$, so we obtain from our normality assumptions the following expression for the inner expectation on the right-hand side of (A-1):

(A-2) $\quad \mathbb{E}\big(d^{**}_{h,i}|\boldsymbol{d}^*_i, \boldsymbol{d}_i, \boldsymbol{X}_i\big) = \mu^{**}_{h,i} + \boldsymbol{\Sigma}^h_{12}\,\boldsymbol{\Sigma}^{-1}_{22}(\boldsymbol{d}^*_i - \boldsymbol{\mu}^*_i),$

and (A-1) becomes

(A-3) $$\mathbb{E}\left(d^{**}_{h,i}|\boldsymbol{d}_i,\boldsymbol{X}_i\right)=\mu^{**}_{h,i}-\boldsymbol{\Sigma}^{h}_{12}\,\boldsymbol{\Sigma}^{-1}_{22}\boldsymbol{\mu}^{*}_{i}+\boldsymbol{\Sigma}^{h}_{12}\,\boldsymbol{\Sigma}^{-1}_{22}\mathbb{E}(\boldsymbol{d}^{*}_{i}|\boldsymbol{d}_i,\boldsymbol{X}_i),$$

The expected value on the right-hand side of (A-3) is the mean of a truncated multivariate normal distribution, through the conditioning on $\boldsymbol{d}_i$. This prevents further simplifications (see, e.g., Cartinhour 2007; Genz 1992; Manjunath and Wilhelm 2009).

In computing the estimated expected digit ratio $\mathbb{E}\left(d^{**}_{h,i}|\boldsymbol{d}_i,\boldsymbol{X}_i;\hat{\boldsymbol{\Gamma}}\right)$, i.e., the analogue of (A-3) with the estimated parameters $\hat{\boldsymbol{\Gamma}}$ of the digit ratio model (3)-(5) plugged in, we compute $\mathbb{E}\left(\boldsymbol{d}^{*}_{i}|\boldsymbol{d}_i,\boldsymbol{X}_i;\hat{\boldsymbol{\Gamma}}\right)$ for each individual by simulating draws from the estimated distribution of $\boldsymbol{d}^{*}_{i}$, conditional on $\boldsymbol{d}_i$ and $\boldsymbol{X}_i$, and taking their mean. We use 48 draws for individuals who were only one year in the sample and the square of this for individuals who were in the sample both years (Grayling and Mander 2018). Our empirical results are insensitive to changing the number of draws from 48 to 12 or to144.

B. Robustness to how the time-invariant covariates enter the digit ratio model (3)-(5)

One can allow all time-invariant covariates to enter both equation (3) and equation (4), and be agnostic about whether associations between these covariates and the reported digit ratios represent systematic differences in digit ratios (included in $\boldsymbol{Z}^{1}_{i}$), or in reporting behavior (included in $\boldsymbol{Z}^{2}_{it}$).

To show this, first note that the first-stage estimator, $\hat{\boldsymbol{\Gamma}}$, uses only the model's reduced form, Eqs. (5) and (6), and is unaffected by the composition of $\boldsymbol{Z}^{1}_{i}$ and $\boldsymbol{Z}^{2}_{it}$. Next, in estimating the expected digit ratios, with all time-invariant covariates in $\boldsymbol{Z}^{1}_{i}$, we have

(A-4) $$\mathbb{E}\left(d^{**}_{h,i}|\boldsymbol{d}_i,\boldsymbol{X}_i;\hat{\boldsymbol{\Gamma}}\right)=\hat{\gamma}^{0}_{h}+\boldsymbol{Z}^{1}_{i}\hat{\boldsymbol{\gamma}}^{1}_{h}+\mathbb{E}\left(\eta_{h,i}+\theta_i|\boldsymbol{d}_i,\boldsymbol{X}_i;\hat{\boldsymbol{\Gamma}}\right),$$

where $\mathbb{E}(\eta_{h,i} + \theta_i | \boldsymbol{d}_i, \boldsymbol{X}_i; \hat{\boldsymbol{\Gamma}})$ is a function of $\boldsymbol{X}_i$ only through its dependence on $\boldsymbol{d}_i$ and $\hat{\boldsymbol{\Gamma}}$. $\boldsymbol{d}_i$ depends on X_i only through its dependence on the perceived digit ratios, $d^*_{l,i1}$, $d^*_{l,i2}$, $d^*_{r,i1}$ and $d^*_{r,i2}$, which, by (6), are also unaffected by the composition of $\boldsymbol{Z}^1_i$ and $\boldsymbol{Z}^2_{it}$. It follows that $\boldsymbol{d}_i$, and therefore $\mathbb{E}(\eta_{h,i} + \theta_i | \boldsymbol{d}_i, \boldsymbol{X}_i; \hat{\boldsymbol{\Gamma}})$, are unaffected by the composition of $\boldsymbol{Z}^1_i$ and $\boldsymbol{Z}^2_{it}$, as well.

Finally, in the second stage, the estimated expected digit ratio for hand h is $\frac{\mathbb{E}(d^{**}_{h,i} | \boldsymbol{d}_i, \boldsymbol{X}_i; \hat{\boldsymbol{\Gamma}})}{SD(d^{**}_{h,i} | \boldsymbol{X}_i; \hat{\boldsymbol{\Gamma}})} = \frac{\hat{\gamma}^0_h + \boldsymbol{Z}^1_i \hat{\boldsymbol{\gamma}}^1_h + \mathbb{E}(\eta_{h,i} + \theta_i | \boldsymbol{d}_i, \boldsymbol{X}_i; \hat{\boldsymbol{\Gamma}})}{\sqrt{\hat{\sigma}^2_\theta + \hat{\sigma}^2_{h,\eta}}}$. Because $\frac{\hat{\gamma}^0_h + \boldsymbol{Z}^1_i \hat{\boldsymbol{\gamma}}^1_h}{\sqrt{\hat{\sigma}^2_\theta + \hat{\sigma}^2_{h,\eta}}}$ is colinear with the other regressors (and intercept) in the second stage (Eq.(7)), it follows from the Frisch-Waugh-Lovell theorem that this portion of the estimated expected digit ratio is partialled out and does not affect the estimator of $\tilde{\beta}_h$. Ultimately, then, only the portion of the estimated expected digit ratio that is unaffected by the composition of $\boldsymbol{Z}^1_i$ and $\boldsymbol{Z}^2_{it}$, i.e. $\mathbb{E}(\eta_{h,i} + \theta_i | \boldsymbol{d}_i, \boldsymbol{X}_i; \hat{\boldsymbol{\Gamma}})$, impacts our estimator of $\tilde{\beta}_h$, making this estimator robust to the composition of $\boldsymbol{Z}^1_i$ and $\boldsymbol{Z}^2_{it}$.

Additional references

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ONLINE APPENDIX 5

The estimation results of the digit ratio model for men and women combined are in the first two columns of Panel A in Table 4. For this specification, pooling of men and women is not rejected (last row, 'H_0: Pooling men & women'). For this reason, these results are used to assess the extent to which the digit ratio accounts, on average, for the gender difference in the preference for risk taking. Table A-6 shows that controlling for the estimated expected digit ratio reduces the gender difference in the preference for risk taking by about 10%. Not reported is that this reduction is about the same for the empirical specifications of Panel B in Table 4 and Table A-2 (first two columns). Furthermore, the estimated digit ratio associations are virtually the same as those in Table 5 that are based on the estimates of a digit ratio model for men and women separately.

Table A-6 *Estimated associations of the digit ratio (DR) with the preference for risk taking (Eq.(7)). The estimated expected digit ratios are based on the estimates of the digit ratio model for men and women combined (Table 4, Panel A).*

L=Left hand R=Right hand	Coef. (Std.Err.)	Coef. (Std.Err.)	Coef. (Std.Err.)	Coef. (Std.Err.)	Coef. (Std.Err.)
Male (vs female)	0.558***	0.491***	0.493***	0.495***	0.491***
	(0.054)	(0.057)	(0.057)	(0.057)	(0.057)
DR L, $\tilde{\beta}_l$		-0.086	-0.110***		
		(0.084)	(0.034)		
DR R, $\tilde{\beta}_r$		-0.026		-0.104***	
		(0.084)		(0.034)	
DR L or R, $\tilde{\beta}_l = \tilde{\beta}_r$					-0.056***
					(0.017)
H_0: No DR a)		0.006**	0.001***	0.002***	0.001***
H_0: DR L=R a)		0.715			
H_0: DR M=W a)		0.068	0.481	0.710	0.860
R^2	0.016	0.017	0.017	0.017	0.017
N	9,976	9,976	9,976	9,976	9,976

Notes. Dependent variable: preference for risk taking (0-10 scale). N = number of observations. Weighted average marginal effects are computed and the standard errors are clustered at the individual level. * $p<0.05$; ** $p<0.01$; *** $p<0.005$

a) "H_0: No DR", "H_0: DR L=R" and "H_0: DR M=W" are the null hypotheses of the digit ratio association(s) being equal to zero, the same for both hands, or the same across gender, respectively. Entries shown are *p*-values.

ONLINE APPENDIX 6

ORDERED PROBIT RESULTS

Table A-7 shows the results of Panel A in Table 3 when using ordered probit models to accommodate the ordinal responses to the risk preferences question. Table A-8 shows the results of Panel A in Table 5 when using ordered probit models. These latter results come with the cautionary remark that the expectation error $\left(\sum_{h\in\{l,r\}}\beta_{h,1}d_{h,i}^{**}-\sum_{h\in\{l,r\}}\beta_{h,1}\mathbb{E}\left(d_{h,i}^{**}|\boldsymbol{d}_i,\boldsymbol{X}_i\right)\right)$, Section III, is part of the error term ξ_{it} in Eq. (7) and this source of heteroskedasticity affects the consistency of a maximum likelihood estimator. For this reason, linear models for risk preferences are estimated for the main text. Our main findings are, however, robust to modelling risk preferences with random effects ordered probit models in the second stage, e.g. when y_{it} is treated as a latent variable in Eq.(7).

The estimates in Tables A-7 and A-8 are of the associations with the probability of providing the response ‘7’ to the risk preferences question. This probability is referred to as the probability of a high preference for risk taking. The sample proportion of a high preference for risk taking is 0.28 for men and women combined, 0.35 for men and 0.25 for women.

Table A-7 *Estimated associations of the digit ratio (DR) with the probability of a high preference for risk taking, based on an ordered probit model for risk preferences.*

L = Left hand R = Right hand	Men & women	Men & women	Men & women	Men	Men	Women	Women
	Coef. (Std.Err.)	Coef. (Std.Err.)	Coef. (Std.Err.)	Coef. (Std.Err.)	Coef. (Std.Err.)	Coef. (Std.Err.)	Coef. (Std.Err.)
Male (vs female)	0.024***	0.024***	0.024***				
	(0.003)	(0.003)	(0.003)				
Index=ring, L	-0.005	-0.006*		-0.005		-0.008	
	(0.003)	(0.003)		(0.003)		(0.004)	
Index>ring, L	-0.006	-0.008***		-0.004		-0.011***	
	(0.003)	(0.003)		(0.003)		(0.004)	
Index=ring, R	-0.003		-0.005*		-0.009**		-0.001
	(0.003)		(0.003)		(0.003)		(0.004)
Index>ring, R	-0.003		-0.007**		-0.007*		-0.005
	(0.003)		(0.003)		(0.003)		(0.004)
H_0: No DR a)	0.021*	0.005***	0.021*	0.267	0.011*	0.013*	0.346
H_0: DR L=R a)	0.84			0.349		0.121	
H_0: DR M=W a)	0.113	0.585	0.201				
N	9,976	9,976	9,976	4,294	4,294	5,682	5,682

Notes. Dependent variable: preference for risk taking (0-10 scale). A high preference for risk taking is defined as the response ‘7’ to the risk preferences question. N= Number of observations. “Index” refers to index finger length (second digit length) and “ring” refers to ring finger length (fourth digit length). Reference group is ‘index <ring’ (a low digit ratio). Weighted average marginal effects are computed and the standard errors are clustered at the individual level. * p<0.05; ** p<0.01; *** p<0.005.

a) “H0: No DR”, “H0: DR L=R” and “H0: DR M=W” are the null hypotheses of the digit ratio association(s) being equal to zero, the same for both hands, or the same across gender, respectively. Entries shown are *p*-values.

Table A-8 *Estimated associations of the digit ratio (DR) with the probability of a high preference for risk taking, based on an ordered probit model for risk preferences.*

L=Left hand R=Right hand	Men & Women	Men & Women	Men & Women	Men & Women	Men	Women
	Coef. (Std.Err.)	Coef. (Std.Err.)	Coef. (Std.Err.)	Coef. (Std.Err.)	Coef. (Std.Err.)	Coef. (Std.Err.)
Male (vs female)	0.025*** (0.003)	0.025*** (0.003)	0.025*** (0.003)	0.025*** (0.003)		
DR L, $\tilde{\beta}_l$	-0.003 (0.004)	-0.005*** (0.002)				
DR R, $\tilde{\beta}_r$	-0.002 (0.004)		-0.005*** (0.002)			
DR L or R, $\tilde{\beta}_l = \tilde{\beta}_r$				-0.002*** (0.001)	-0.002* (0.001)	-0.003* (0.001)
H_0: No DR [a)]	0.008**	0.002***	0.003***	0.002***	0.048*	0.018*
H_0: DR L=R [a)]	0.822					
H_0: DR M=W [a)]	0.065	0.486	0.696	0.891		
N	9,976	9,976	9,976	9,976	4,294	5,682

Notes. Dependent variable: preference for risk taking (0-10 scale). A high preference for risk taking is defined as the response '7' to the risk preferences question. The estimated expected digit ratios are based on Table 4 (Panel A). N = number of observations. Weighted average marginal effects are computed and the standard errors are clustered at the individual level. * p<0.05; ** p<0.01; *** p<0.005

[a)] "H_0: No DR", "H_0: DR L=R" and "H_0: DR M=W" are the null hypotheses of the digit ratio association(s) being equal to zero, the same for both hands, or the same across gender, respectively. Entries shown are *p*-values.