Nurture affects gender differences in spatial abilities

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Edited* by Marc Nerlove, University of Maryland, College Park, MD, and approved July 14, 2011 (received for review November 24, 2010)

Women remain significantly underrepresented in the science, engineering, and technology workforce. Some have argued that spatial ability differences, which represent the most persistent gender differences in the cognitive literature, are partly responsible for this gap. The underlying forces at work shaping the observed spatial ability differences revolve naturally around the relative roles of nature and nurture. Although these forces remain among the most hotly debated in all of the sciences, the evidence for nurture is tenuous, because it is difficult to compare gender differences among biologically similar groups with distinct nurture. In this study, we use a large-scale incentivized experiment with nearly 1,300 participants to show that the gender gap in spatial abilities, measured by time to solve a puzzle, disappears when we move from a patrilineal society to an adjoining matrilineal society. We also show that about one-third of the effect can be explained by differences in education. Given that none of our participants have experience with puzzle solving and that villagers from both societies have the same means of subsistence and shared genetic background, we argue that these results show the role of nurture in the gender gap in cognitive abilities.

cross-cultural research | nature–nurture debate | women in science | cognitive gender differences | sex differences

Among tenure track professors at elite universities, women make up 8.3% of math professors, 12.1% of chemistry professors, 6.6% of physics professors, and 6.7% of mechanical engineering professors (1). Furthermore, women make up only 19% of the science, engineering, and technology workforce (2). The debate regarding the origin of this difference is highly emotional. When the President of Harvard University suggested that this gap may be explained by innate differences in abilities (3), members of the audience left the room. On the scientific side, many researchers have argued for the important role of nature, and others have argued for the important role of nurture (1, 4).

In this paper we introduce important empirical evidence into this debate. Our study concentrates on gender differences in spatial abilities. Spatial abilities are used in major discoveries in physics and chemistry (1) and are correlated with success in engineering courses (5), the decision to major in the physical sciences (5), and performance on the Test of Mechanical Reasoning and the Bennett Mechanical Comprehension Test (6). The literature reports that men surpass women at spatial reasoning (7).

Could this gender gap in spatial reasoning be substantially driven by nurture? There are plausible mechanisms. For instance, spatial skills are influenced by training (8, 9), and males typically have relevant training (10). Alternatively, females are stereotyped to have inferior spatial skills, and the salience of negative stereotypes may lead to decreased performance (11). However, direct evidence that nurture matters is lacking. As our own society became more egalitarian, gender differences in spatial abilities have not shown consistent reductions (6). Additionally, societies promoting gender equality, such as Sweden (12), Norway (13), and traditional Kibbutzim in Israel, retain standard gender differences in spatial abilities (14) just like most societies studied (15). Moreover, whereas cross-cultural studies often find main effects of culture on spatial abilities, they rarely find interaction effects between culture and gender (15). The one exception is Canadian Eskimos, who, compared with African Temne, seem to have a smaller gender gap (16). However, the comparison between these societies is hard to interpret, because these societies are not only culturally but also ethnically dissimilar, and this paper fails to report a significant interaction between society and gender.

Results and Discussion

Our empirical identification strategy is based on a comparison of two distinct tribes in Northeast India (the Khasi and the Karbi) that share a genetic background. This comparison allows us to identify the role of nurture. In this region, geographic contiguity is a better predictor of genetic similarity than culture. Both tribes are located in the hills surrounding the city of Shillong, and the Karbi and Khasi appear to be close kin, based on genetic analysis of six polymorphic loci (17). The villagers in both societies are agriculturalist and subsist primarily off rice, with little variation in wealth or diet.

There are many cultural differences between the tribes; thus, we cannot isolate the particular aspect of nurture that matters. However, the most obvious difference between the tribes is that the Karbi are a patrilineal tribe (for example, women are not supposed to own land, and the oldest son inherits the property), whereas the Khasi are a matrilineal tribe (property is inherited by the youngest daughter, men are not allowed to own land, and any earnings of the male are supposed to be handed over to his wife or sister). The different societies are described in greater details elsewhere (18, 19).

The participants in the field experiment solved a four-piece puzzle (Fig. 1) (a total of 1,279 participants from four Khasi and four Karbi villages). None of them had previous experience with such a task. To incentivize participants, we offered 20 rupees—25% of a day's wage—to each participant who solved the puzzle in less than 30 s. Some of our subjects also answered survey questions.

The null hypothesis that we test is that, although culture may have a main effect on time to solve the puzzle, it will not affect the gender gap. The alternative hypothesis is that the gender gap is less pronounced among the matrilineal society.

First, we confirm that the two societies treat men and women differently; our survey data show that women get a better education and are more likely to own property in the matrilineal society. In the matrilineal society, males and females have the same years of education (tobit, two-sided $P = 0.159$, $n = 530$), whereas in the patrilineal society, males have 3.67 y more years of education (tobit, $P < 0.001$, $n = 426$). Men predominantly own the property in which our patrilineal participants dwelled, with only 35 of 347 exceptions. However, male ownership is strictly forbidden among the matrilineal villages. Details on these regressions and all others are in *SI Text*.

Our main result, the average time of each group to solve the puzzle, is presented in Fig. 2 and Table 1. As can be seen from

Author contributions: M.H. and U.G. designed research; M.H. performed research; M.H. and J.A.L. analyzed data; and M.H., U.G., and J.A.L. wrote the paper.

The authors declare no conflict of interest.

*This Direct Submission article had a prearranged editor.

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This article contains supporting information online at www.pnas.org/lookup/suppl/doi:10.1073/pnas.1015182108/-/DCSupplemental.

Fig. 1. The puzzle used in the experiment. Subjects solved a four-piece jigsaw puzzle. The time that it took to complete the puzzle acted as our measure of spatial ability.

Table 1. Summary statistics for time to solve the puzzle

	Patrilineal	Matrilineal	Total
Female			
Mean	57.2	35.4	42.6
Median	42	20	33
SD	55.8	20.1	37.4
n	218	443	661
Male			
Mean	42.3	32.1	36.2
Median	32.5	27	29
SD	37.3	19.2	28.4
n	250	368	618
Total			
Mean	49.2	33.9	39.5
Median	37	28	30
SD	47.4	19.7	33.5
N	468	811	1,279

Subjects solved a four-piece jigsaw puzzle. The time, in seconds, that it took to complete the puzzle acted as our measure of spatial ability.

Fig. 2 and Table 1 (consistent with other cross-cultural studies) (15), we find a main effect of culture on spatial abilities; however, unlike other cross-cultural studies, Fig. 2 and Table 1 also indicate an interaction effect between gender and culture. Men take 36.4% less time than women among the patrilineal society (ordinary least squares, $P < 0.001$, $n = 468$) but are no faster among the matrilineal society (OLS, $P = 0.252$, $n = 811$). The interaction between gender and society is statistically significant (OLS, $P < 0.001$, $n = 1{,}279$). *SI Text* shows the robustness of these results.

Education could be one mechanisms involved in generating the interaction between society, gender, and spatial abilities. This question has policy relevance, because policymakers have sway over education. Recall that there is a gender gap in education in the patrilineal but not the matrilineal society. Better educated subjects solve the puzzle faster, with each 1 y corresponding to a reduction in time of 4.3% (OLS, $P < 0.001$, $n = 956$). This finding is consistent with findings elsewhere that spatial abilities correlate with education (16). We find that, when adding education as a control variable, the gender by society interaction term remains significant (OLS, $P < 0.001$, $n = 956$) and quite sizeable, amounting to the effect of 6 y education, but it is reduced in magnitude by nearly a one-third, indicating that our main result is partly but not fully explained by education.

Next, we test whether household variation within a village matters. This question has practical implications, because it may be easier for ordinary people to influence household variation than alter an entire society. In particular, we test whether the gender gap in time to solve the puzzle differs between homes owned by males, which is traditional, and homes owned by females or jointly owned by males and females. The gender gap is, in fact, one-third the size among those people who live in homes not owned solely by males (10% OLS, $P = 0.735$, $n = 35$ vs. 42% OLS, $P < 0.001$, $n = 312$). Of course, this finding might be the result of selection into such household. A similar comparison cannot be made among matrilineal households, because men are outright forbidden to own property, preventing variation.

Recall that the youngest daughter traditionally inherits property among the Khasi and the oldest son traditionally inherits property among the Karbi. One might worry that our results are

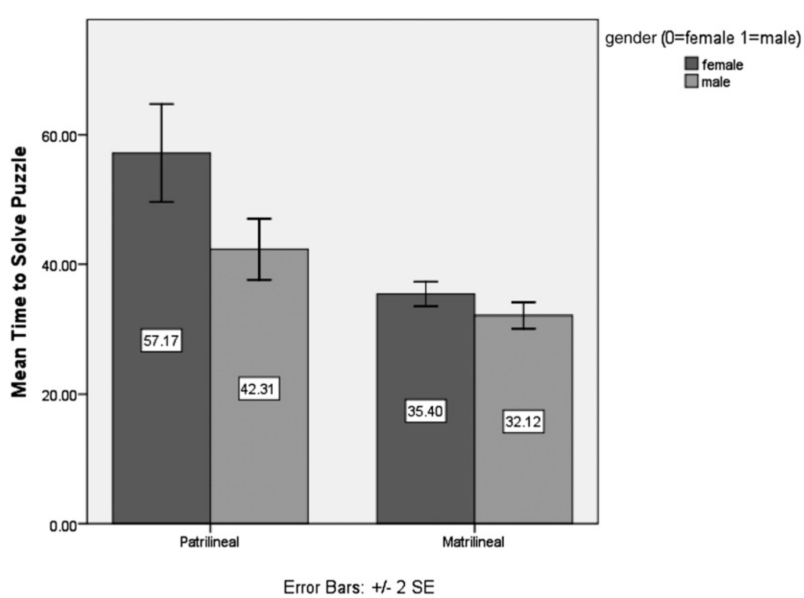

Fig. 2. Female villagers took longer to solve the puzzle in the patrilineal society but no longer in the matrilineal society. Mean time to solve the puzzle by society and gender. Subjects solved a four-piece jigsaw puzzle. The time that it took to complete the puzzle acted as our measure of spatial ability.

being driven solely by the privileged individuals. However, the youngest daughters were not significantly faster among Khasi females (OLS, $P = 0.80$, $n = 176$) and the oldest sons were not significantly faster among Karbi males (OLS, $P = 0.47$, $n = 203$). Moreover, if we restrict our analysis to subjects who are not these privileged inheritors, our main result remains unchanged.

It has earlier been shown (18–20) that, although men are generally more competitive than women, this is not the case in the matrilineal society. Thus, one may worry that time to solve the puzzle is merely picking up on competitiveness, and the current interaction between gender and society in time to solve the puzzle is caused by the interaction between gender and society in competitiveness. This conclusion is not the case. Using the same measure as in an earlier work (described in *SI Text*), we find no relationship between competitiveness and time to solve the puzzle (OLS, $P = 0.864$, $n = 976$), and including competitiveness as a control does not influence our main result (18).

Conclusion

Our paper shows that the gender gap in spatial abilities in the task that we study interacts with culture. In the matrilineal society, we observe no gender difference in this task. These results show that nurture plays an important role in the gender gap in spatial abilities. Our results also indicate that providing equal education and improving treatment of women at the family level may make a difference; however, this implication should be taken with a grain of salt, because causality cannot be ascertained. Nevertheless, the implications for both policymakers and ordinary people interested in reducing the gender gap cannot be overstated: reducing the gender gap in spatial abilities may reduce the gender gap in the science, engineering, and technology workforce. It is worth mentioning that our results do not provide evidence against the role of nature.

Methods

Participants. Villagers (1,279) participated from four patrilineal villages and four matrilineal villages. Several weeks before the study, village headmen were asked to enroll villagers interested in the study. Headmen were asked to inform villagers that they would be paid a 100-rupee show-up fee ($2 or approximately wages for 1.25 d) for 0.5 d participation in experiments. Furthermore, they may earn additional money depending on their performance in the experiments. All participants signed a consent form and eventually solved the puzzle. Participants were 18 y or older. Two participants opted out, and one participant did not have gender properly coded; therefore, these subjects are not included in any of our analysis or the 1,279 figure reported above.

Procedure. Participants were individually led into either a private room or a secluded area in the courtyard and given instructions in their native tongue. They were shown four puzzle pieces arranged properly to form the image of a horse. They were instructed to replicate these four pieces using a second set of puzzle pieces. They were told that, if they did so within 30 s, they would receive 20 rupees—approximately one-quarter of 1-d wage. Participants were told to begin, and a stop watch was started outside of the participants' view. If a participant claimed to be done but in fact, was not, a discrepancy between the participant's puzzle pieces and the correct image was pointed out, and we allowed the subject to continue. When participants were interviewed, none expressed experience in solving puzzles. Afterward, most participants were asked their age, birth order, years of schooling, and who owns the property in which they reside. Some subjects participated in the competitive measure. Details of this measure as well as additional details on the other measures can be found in *SI Text*.

ACKNOWLEDGMENTS. We thank Andrew Mattarela-Micke, Juliette Caminade, Erez Yoeli, Anna Dreber, Daniel Fessler, and Diane Halpern.

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Corrections

ECONOMIC SCIENCES

Correction for "Nurture affects gender differences in spatial abilities," by Moshe Hoffman, Uri Gneezy, and John A. List, which appeared in issue 36, September 6, 2011, of *Proc Natl Acad Sci USA* (108:14786–14788; first published August 29, 2011; 10.1073/pnas.1015182108).

The authors note that on page 14786, left column, first full paragraph, line 1, "Among tenure track professors at elite universities" should instead appear as "Among tenured and tenure track professors at elite universities." Additionally, the following reference should be added to the article:

21. Nelson D, Rogers D (2005) *A National Analysis of Diversity in Science and Engineering Faculties at Research Universities.* Available at http://www.nber.org/~sewp/events/2005.01.14/Bios+Links/Krieger-rec4-Nelson+Rogers_Report.pdf. Accessed September 11, 2011.

www.pnas.org/cgi/doi/10.1073/pnas.1115576108

CELL BIOLOGY

Correction for "Ammonia-induced autophagy is independent of ULK1/ULK2 kinases," by Heesun Cheong, Tullia Lindsten, Junmin Wu, Chao Lu, and Craig B. Thompson, which appeared in issue 27, July 5, 2011, of *Proc Natl Acad Sci USA* (108:11121–11126; first published June 20, 2011; 10.1073/pnas.1107969108).

The authors note that the following text for Figs. 1*A*, 3*A*, 3*D*, 4*B*, and 5*C* should be added to their respective legends: "Data are presented as the mean and standard deviation (mean ± SD) from three independent experiments." These errors do not affect the conclusions of the article.

www.pnas.org/cgi/doi/10.1073/pnas.1115120108

DEVELOPMENTAL BIOLOGY

Correction for "Functional melanocytes derived from human pluripotent stem cells engraft into pluristratified epidermis," by Xavier Nissan, Lionel Larribere, Manoubia Saidani, Ilse Hurbain, Cédric Delevoye, Jessica Feteira, Gilles Lemaitre, Marc Peschanski, and Christine Baldeschi, which appeared in issue 36, September 6, 2011, of *Proc Natl Acad Sci USA* (108:14861–14866; first published August 19, 2011; 10.1073/pnas.1019070108).

The authors note that on page 14862, left column, first full paragraph, all unit concentrations in "μM" should instead appear as "nM."

The authors also note that on page 14865, right column, second paragraph, line 15 "20 nM human recombinant BMP4" should instead appear as "0.02 nM human recombinant BMP4."

www.pnas.org/cgi/doi/10.1073/pnas.1115035108

MICROBIOLOGY

Correction for "Minimization of the *Legionella pneumophila* genome reveals chromosomal regions involved in host range expansion," by Tamara J. O'Connor, Yewande Adepoju, Dana Boyd, and Ralph R. Isberg, which appeared in issue 36, September 6, 2011, of *Proc Natl Acad Sci USA* (108:14733–14740; first published August 22, 2011; 10.1073/pnas.1111678108).

The authors note that the GenBank accession number for Hextuple 2q is CP003023, and the GenBank accession number for Hextuple 3a is CP003024.

www.pnas.org/cgi/doi/10.1073/pnas.1115233108

Supporting Information

Hoffman et al. 10.1073/pnas.1015182108

SI Text

Regression Details. All regressions are ordinary least squares and control for age, age squared, and village fixed effects, except where noted otherwise.

Gender gap in education across societies. Fig. S1 presents the average number of years of schooling in each society by gender. It is clear that there is large gender gap in the patrilineal but not the matrilineal sample.

Table S1 reports the corresponding regressions. Because our dependent variable, self-reported years of schooling, is censured above at 16 and below at 0, we use tobit instead of OLS. We regress years of schooling on a male dummy and a male × matrilineal interaction term, which is one if the subject is a male from a matrilineal village. We restrict these regressions to subjects for whom years of schooling are known. Table S1, column 1 reports the results for the entire sample, whereas columns 2 and 3 restrict the sample to matrilineal and patrilineal subjects, respectively. As can be seen from these regressions, the gender gap in education is sizeable in the patrilineal society (males have 3.67 y more education; tobit, $P < 0.001$, $n = 426$) and nonexistent in the matrilineal society (tobit, two-sided $P = 0.159$, $n = 530$), and the difference is significant.

Gender gap in time to solve the puzzle across societies. As indicated in Fig. S2 *Upper* and *Lower*, time to solve the puzzle (in seconds) is log-normally distributed; hence, we use log time to solve the puzzle as our dependent variable in Table S2. Aside from the new dependent variable and the inclusion of our entire sample, Table S2 is constructed just as Table S1. As can be seen from Table S2, column 3, men take 36.4% less time than women among the patrilineal society (OLS, $P < 0.001$, $n = 468$), but Table S2, column 2 indicates that males are no faster among the matrilineal society (OLS, $P = 0.252$, $n = 811$). Table S2, column 1 verifies that the interaction between gender and society is statistically significant (OLS, $P < 0.001$, $n = 1{,}279$).

Table S3 verifies that the results do not depend on this log transformation. Table S3 is constructed just as Table S2 but uses time to solve the puzzle instead of log-transformed time to solve the puzzle. The results look much the same.

Because subjects are paid a bonus if they complete the puzzle within 30 s, one might suspect that the only important behavioral measure is whether the puzzle is completed within 30 s or not. Thus, for one final robustness check, we transform the dependent variable into a dummy variable that is one if the subject completed the puzzle within 30 s. The first three columns of Table S4 present the corresponding OLS regressions with this new dependent variable.

However, our dependent variable is now binary, making probit a preferable regression model. Table S4, columns 3–6 report the corresponding probit regressions. However, recall that all our regressions include village fixed effects, and using probit with fixed effects is questionable; therefore, Table S4, columns 4–6 report probit with village random effects instead of village fixed effects. Regardless of the specification that we choose, we obtain the same results as before.

Role of education. Table S5 displays the role of education analogous to Table S2. Unlike Table S2, however, we restrict the sample to subjects for whom education is known, and we report the regressions in pairs, where the second of the pair does not include an education control and the first of the pair does include an education control.

The coefficient on education in Table S5, column 1 indicates that each 1 y schooling corresponds to a reduction in time to solve the puzzle of 4.3% (OLS, $P < 0.001$, $n = 956$). A comparison of the coefficient matrilineal × male and the coefficient education in the same column shows that the gender by society interaction term amounts to the effect of 6 y education. A comparison between the matrilineal × male interaction term in Table S5, columns 1 and 2, indicates that the gender by society interaction term remains significant (OLS, $P < 0.001$, $n = 956$) but is reduced in magnitude by nearly one-third when education is added as a control. Male × matrilineal and education are jointly significant (f test, $P < 0.001$, $n = 956$) as are male and education (f test, $P < 0.001$, $n = 956$) in the regression reported in Table S5, column 1.

Tables S6 and S7 show that the robustness of these results are analogous to Tables S3 and S4.

Role of home ownership. Table S8 investigates the role of living in a home owned by a female in the patrilineal society. Table S8, column 1 regresses log-transformed time to solve the puzzle on gender among patrilineal subjects residing in a home owned by a male; Table S8, column 2 regresses log-transformed time to solve the puzzle on gender among patrilineal subjects residing in a home owned by a female or jointly owned by a male and a female. A comparison of the gender coefficients in these two regressions leads us to conclude that the gender gap is, in fact, one-third of the size among those people who live in homes not owned solely by males (10% OLS, $P = 0.735$, $n = 35$ vs. 42% OLS, $P < 0.001$, $n = 312$).

Role of birth order. Table S9 investigates the role of birth order. Table S9, column 1 looks only at male subjects within the patrilineal villages and regresses log-transformed time to solve the puzzle on a dummy variable that is one whenever the subject is the oldest son, indicating that oldest sons were not significantly faster among Karbi males (OLS, $P = 0.47$, $n = 203$). The coefficient on this dummy variable is insignificant. Likewise, Table S9, column 2 looks only at female subjects within the matrilineal villages and regresses log-transformed time to solve the puzzle on a dummy variable that is one whenever the subject is the youngest daughter. The coefficient is again insignificant, indicating that the youngest daughters were not significantly faster among Khasi females (OLS, $P = 0.80$, $n = 176$).

Table S10 shows that our main result holds up even when we restrict our analysis to those people who we are sure are not the privileged few standing to inherit. Table S10 is constructed like Table S2 but restricted to subjects who we are sure are either not the youngest daughter in the matrilineal society or not the oldest son in the patrilineal society.

Gender differences in variance in time to solve the puzzle. Finally, one might wonder if men are faster in the patrilineal society partly because they have larger variance than women and are more likely to be represented in both tails in the patrilineal society. In fact, as Table 1 illustrates, in the patrilineal society, females have larger SD in time to solve the puzzle than males (55.8 s for females vs. 37.3 s for males). In the matrilineal society, there is no such difference (20.1 s vs. 19.20 s). Moreover, in both societies, females are more likely to take more than 1 min (28% vs. 19% in patrilineal and 12% vs. 9% in matrilineal societies) and 2 min (7% vs. 3% in patrilineal and 0% for each in matrilineal societies).

Competitiveness. Table S11 is constructed like Table S2, except that the sample is restricted to those people for whom competitiveness is known, and competitiveness is added as a dependent variable. As the competitiveness coefficient in Table S11, column 1 indicates, we find no relationship between competitiveness and time to solve the puzzle (OLS, $P = 0.864$, $n = 976$).

Role of village. Table S12 shows the substantial intervillage variation in time to solve the puzzle, which is consistent with previous literature showing a main effect of society on spatial reasoning, a common finding discussed in the text. Table S12, column 1 repeats our preferred regression (like Table S2, column 1) but reveals the coefficients and SDs of each of the village fixed effects. Table S12, column 2 replaces the village fixed effects with a dummy that indicates whether the subject comes from a matrilineal village. Table S12, column 3 presents the regression in Table S12, column 1 without our male × matrilineal interaction term. The village fixed effects are jointly significant (f test, $P < 0.001$) and explain more of the variation than our male × matrilineal interaction term.

Education by gender interaction. One may worry that the effect of education is largely driven by males, thereby invalidating our claim that improving education for women would reduce the gender gap. Table S13 investigates this concern. Table S13, column 1 reports our preferred regression (Table S5, column 1), with a male × education interaction term included. The effect of education is slightly larger for males than females; however, when we restrict the analysis to female subjects (Table S13, column 2), we see that there is still a sizeable and significant effect of education for women.

Method Details. The experiment was carried out in eight villages in the Meghalaya region of India. In each session, we recruited the participants in advance and asked each potential subject to arrive at a central place in the village (either a school or town hall) at a given time. This method attenuated selection problems, because everyone was interested in participating in the experiment after they were made aware of the pecuniary incentives involved.

Spatial reasoning measure. Subjects formed a line outside a private room or an external location fenced off with tarp and waited until they were called on by the experimenter. One by one, the research assistant privately called participants to the private room or tarped area. The experimenter explained the task. Instructions from the research assistant are reproduced below. The experimenter was always the same female assistant.

The task was to solve a four-piece puzzle. Participants were informed that, if they solved the puzzle within 30 s, they would be paid an additional 20 rupees. When subjects were interviewed, none expressed familiarity with puzzles, and we are aware of no other popular task in this area that is similar to puzzle solving.

Instructions given to the experimenter for the puzzle.

i) Scramble puzzle pieces. Lead the subject into the experimental room.

ii) Then, say (in Khasi), “In this experiment, you will be asked to copy this horse.” Show the subject the image of the horse as well as the four scrambled puzzle pieces. Then, solve it one time for them and rescramble.

iii) Then, say, “You will be timed while you try to make the horse. If you manage to make the horse within 30 s, you will get paid an additional 20 rupees in addition to whatever else you have earned so far today. Otherwise, you will not be paid anything for this part of the study, but everything else you have earned beforehand is still yours to keep. Do you have any questions?”

iv) If the subject claims to have finished when, in fact, the puzzle is not complete, tell the subject that there is an error, and point to at least one discrepancy between the image of the horse and the four pieces that the subject claims are solved. Do not stop the timer until the subject has actually completed the puzzle.

Ownership measure. Participants were asked, “Who owns the property in which you live?” (“Mano ba dei trai jong ka ing ka sem ba phi sah?”).

Responses were coded as male if the response was father, brother, son, or self in the case that subject was male.

Sibling measure. Female participants were asked the following questions in their native tongue. Male participants were asked analogous questions. “In your immediate family, are you the youngest daughter?” (“Ha ki shipara trai jongphi, phi dei I khun khyntheri ba khatduh ne em?”), and “In your immediate family, are you the oldest daughter?” (“Ha ki shipara trai jongphi, phi dei I khun nyngkong ne em?”).

Competition measure. On arrival at each experimental site, participants were directed to stand in two separate lines, one for each gender, outside of the experimental room. The first six subjects from each line were taken aside; an experimenter explained the task to the group of 12 subjects. When there were less than 12 subjects or more subjects of one gender remaining, the group was smaller or had a slightly uneven distribution of males and females.

Instructions are reproduced below. The instructions were translated from English to the local language (Khasi) and were checked by having a different person translate them back into English. The instructions were read aloud to the individual participant by the experimenter. In each session we balanced the gender of the experimenter to have an equal ratio of male and female experimenters per session.

The experimental task was to toss a tennis ball into a bucket that was placed 3 m away. Participants were informed that they will have 10 chances to toss the ball. A successful shot meant that the tennis ball entered the bucket and stayed there. The task was chosen, because it was simple to explain and implement. Furthermore, we are aware of no other popular task in this society that is similar to the ball game that we implemented. Indeed, the villagers play cricket and soccer for sport, but because our task can only be completed with an underhand toss, the traditional skills do not advantage individuals with experience in any of these games.

Participants were told that they were matched with a participant from another group. No other information was given about the individual to whom they were matched. The only decision that participants were asked to make concerned the manner in which they would be paid for their performance. They made this choice before performing the task but only after they fully understood the instructions and the payment schemes. The two options that participants were asked to choose between were (*i*) 20 rupees per successful shot, regardless of the performance of the participant from the other group with whom they were randomly matched and (*ii*) 60 rupees per successful shot if they outperformed the other participant. They were told that, in case they chose the second option and scored the same as the other participant, they would receive 20 rupees per successful shot. After choosing the incentive scheme, participants completed the task and were told how the other participant performed. Only a subsample of our subjects participated in this measure because of time constraints. As promised, participants were never given the opportunity to learn with whom they were paired.

Competition instructions. Welcome to this study of decision-making. The experiment will take about 20 min. The instructions are simple, and if you follow them carefully, you can earn a considerable amount of money. All of the money you earn is yours to keep and will be paid to you, in cash, in private at the end of today. Your confidentiality is assured.

Pay attention to these instructions. Please do not talk with each other from this point on. If you have a question, you can raise your hand and ask. Otherwise, please be quiet and listen carefully. After the instructions are finished, we will take you inside, and you will play the game.

The task that we ask you to perform is throwing this ball into a bucket from a line. (Show them the ball, bucket, and line.) You will have 10 chances, and you will be paid for your performance. Before you do the task, you will have a choice between two ways of earning money.

Option 1 (individual payment). If you choose this option, you receive 20 rupees for each ball you throw in successfully.

Option 2 (tournament). If you choose this option, your performance will be compared with a random person from another group. You will receive a reward only if you succeed more times than this person. If you succeed more times than your opponent and win the competition, you will be paid 60 rupees for every ball you throw in successfully. So, if you succeed once, then you will get 60 rupees. If you succeed two times, then you will get 120 rupees. If you succeed three times, you will get 180 rupees and so on. However, you will only receive a reward if you are better than your opponent. Otherwise, you will get zero. If you both succeed the same number of times, you get 20 rupees for each success.

Do you have any questions?

In a few minutes, we will take you inside to play the game. Inside, we will ask you individually/privately which option you would like to choose.

(Ngi pdiang snewbha iaphi sha kane ka jingpule jongka jingshim ia ka rai. Kan shim por tang kumba 20 minit. K_i jingbatai ki long kiba suk ban sngewthuh,bad lada phi bud bniah ia ki, phin kham kamai kham bun. Baroh ka pisa ba phi ioh ka dei ka jong phi ba phin buh, yn siew ia phi, da ka pisa, tang para marwei, ynda la sep ka sngi. Ka jingsngew skhem bad jingshaniah jong phi ia lade ka long ka ba donkam bha.

Mynta ngin batai ia phi shaphang ka rukom lehkai. Sngap bha ia kine ki jingbatai namar ba katba phi nang kham sngewthuh kham bha katta phin nang kham ioh ban kamai kham bun ka pisa. Lada phi don kano kano ka jingkylli, phi lah ban rah ka kti bad kylli. Hyrei te, sngewbha long ki ba sngapjar bad shah shkor bha. Ynda ladep kine ki jingbatai, ngin sa ialam iaphi shapoh ba phin sdang ia ka jingialehkai.

Shwa ba phin sdang, phin jied na kine 2 tylli ki lad bad kamai pisa.

K_a jingjied kaba 1 (Kaba ialeh marwei): La da phi jied ia kane, phin ioh 20 tyngka manla kawei pa kawei ka bol kaba phi lah ban thep ne pynrung.

K_a jingjied daka ba 2 (kompetition/ ka jingiakob): Lada phi jied da kane pat, ia ka jinglah ban lehbha jongphi yn pyniatynjuh bor bad ka ____(green/yellow) krup. Phin ioh ia ka bainong jongphi tang lada phi lah ban leh khambha ban ia u nongialeh pyrshah jongphi. Lada phi lah ban leh khambha ban ia u nongialeh pyrshah jongphi, bad jop ia ka competition, yn siew 60 tyngka manla kawei pa kawei ka bol kaba phi lah ban pynrung. Kumta lada phi lah bah pynrung tang shisien, phin ioh 60 tyngka. Lada phi lah ban pynrung 2 sien, phin ioh 120 tyngka. Lada phi lah ban pynrung 3 sien phin ioh 180 tyngka bad kumta ter ter. Hynrei phin ioh ia kane tang lada phi lah ban leh kham bha ban ia u nongialeh pyrshah jong phi. Lym kumta phin ioh not (zero). Lada baroh ar ngut phi ia long mar kum juh, baroh ar ngut na phi phin ia ioh tang mar 20 tyngka manla kawei pa kawei ka bol kaba phi lah ban pynrung.

Dong kano kano ka jingkylli?

Tang hapoh khyndiat minit, ngin sa ialam ia phi shapoh ba phin ioh ban leh kai. Ynda phi la don hapoh, ngin sa kylli iaphi para marwei kano napdeng kane ka jait jingialehkai phi kwah ban ialehkai. Ngi ruh ngin sa iathuh iaphi, shwa ba phin jied, ia u nongialeh pyrshah jongphi lada dei u ne ka.

Before you go inside, let us give the following examples.

(Shwa ban gin leit shapoh, ngin ia peit katto katne ki nuksa.)

Ask control questions to the whole group.

(Pyrshang kylli jingkylli ia ka krup baroh kawei).

If I choose the individual payment (that is, if I do not choose competition), and I throw in five balls successfully, how much money do I get?

[Lada nga jied da kaba ialehkai marwei (katta kamut, lada ngam treh ban ialeh da ka kopetition), bad lada nga rung 5 tylli ki bol katno ka pisa nga dei ban ioh?]

If I choose to compete and I throw in three balls successfully and my opponent makes two balls, how much money do I get?

(Lada nga jied ban ialehkai daka kompetition bad nga lah ban pynrung 3 tylli ki bol bad u nongialeh pyrshah jong nga u pynrung 2 tylli, katno ka pisa nga dei ioh?)

If I choose to compete and I throw in four balls successfully and my opponent throws in five balls, how much money do I get?

(Lada nga jied ban ialehkai daka kompetition bad nga pynrung 4 tylli ki bol bad u nongialeh pyrshah jongnga u pynrung 5 tylli ki bol, katno ka pisa nga dei ban ioh?)

If I choose to compete and I throw in two balls successfully and my opponent throws in two balls also, how much money do I get?

(Lada nga jied ban ialehkai daka competition bad nga pynrung 2 tylli ki bol bad u nongialeh pyrshah jongnga ruh u pynrung 2 tylli ki bol, katno ka pisa nga dei ban ioh?)

Do you have any questions?

(Don kano kano ka jingkylli?)

Take them into the room.

(Ialam ia ki sha ka kamra.)

Competition instructions are read inside.

Remember that with option 1 (individual pay), you get 20 rupees per successful throw. With option 2 (tournament), you get 60 rupees per successful throw if you are better than your opponent, zero if you are worse, and 20 rupees per successful throw if your performance is the same.

[Kynmaw ba lada phi jied da kaba nyngkong (kaba kamai marwei shimet), phin ioh 20 tyngka manla kawei pa kawei ka bol ba phi lah ban pynrung. Lada phi jied da kaba 2 pat (da kaba ialeh da ka competition pat) phin ioh 60 tyngka manla kawei pa kawei ka bol lada phi leh khambha ban ia u nongialeh pyrshah jong phi, phin ym ioh eiei lada phi rem, bad 20 tyngka lada jia ba phi ialong mar katjuh.]

We have matched you with someone from another group who did the same task. If you choose competition, we will compare your performance this person. Now, please tell us which option you would like to choose—individual pay (option 1) or competition (option 2).

[Ngi la pyniabuh mangi ia u nognialehpyrshah jongphi naka _____(YELLOW/GREEN) krup. ______U/ka briew (**iathuh lada dei kynthei/shynrang katkum ka jingthoh ha ka gender column, ia u/ka nongialeh pyrshah**). Lada phi jied da ka competition, phi hap ban iakhun pyrshah ban _____u/ka. Mynta, Sngewbha iathuh ia ngi kano napdeng kine ki lad phin jied ban iakeh kai – Kaba kamai marwei shimet (lada phi jied da kaba nyngkong) lane da ka kompetition (lada phi jied da kaba ar).]

Now you can start throwing the balls.

(Mynta phi lah ban sdang ban kawang ia ka bol.)

Subject throws 10 balls, and helper puts a check on the sheet for each ball made and adds.

(ki nongiashimbynta kin kawang ia ki shiphew tylli ki bol, ki nongiarap kin buh jingthoh ia ki bol kawei pa kawei ka bol kaba rung bad sa khein lang.)

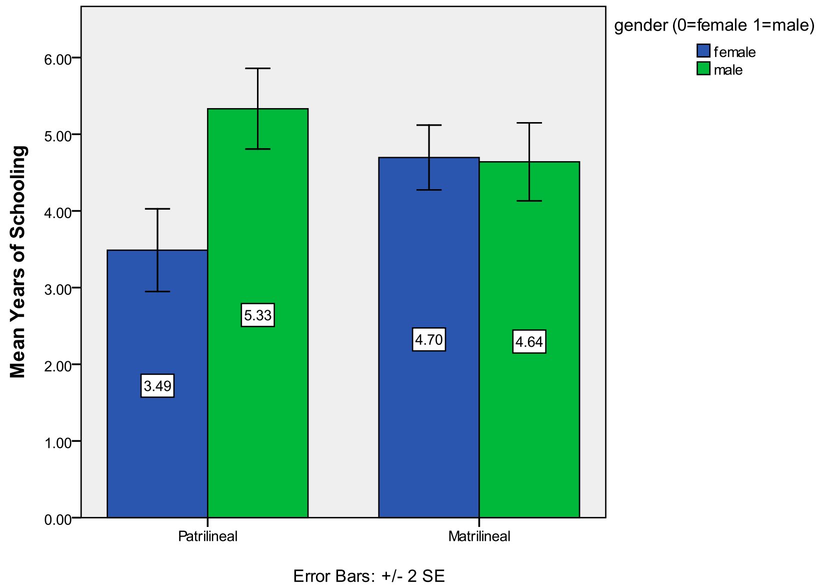

Fig. S1. Women are less well educated in the patrilineal society, but no such gender gap exists in the matrilineal society, offering a potential explanation for our main result. Mean years of schooling by society and gender. Years of education were self-reported.

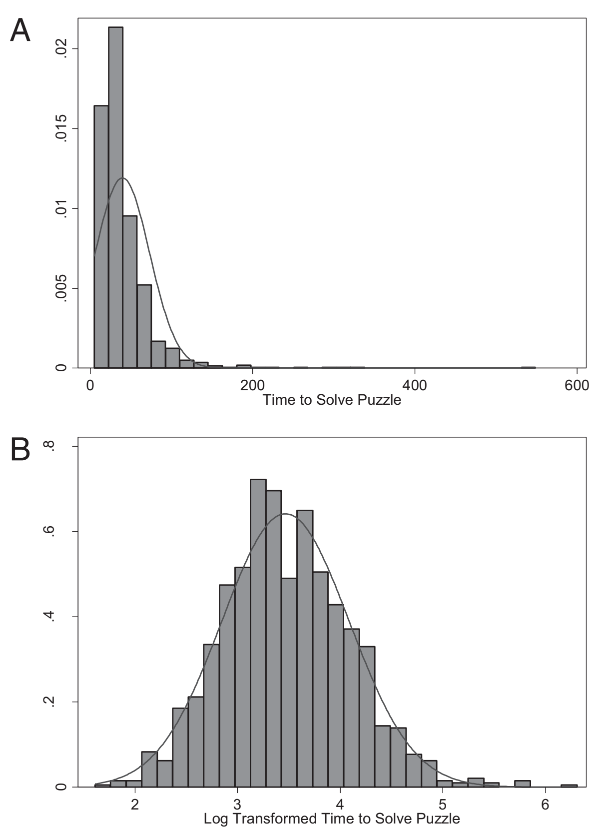

Fig. S2. Time to solve puzzle appears log normally distributed. Hence log time to solve puzzle will act as our preferred dependent variable in subsequent regressions. (*A*) Distribution of time to solve the puzzle. Time to solve the puzzle is in seconds and binned. The smooth curve is a fitted normal distribution (*n* = 1,279). (*B*) Distribution of log-transformed time to solve the puzzle. Time to solve the puzzle is in seconds, log-transformed, and then, binned. The smooth curve is a fitted normal distribution (*n* = 1,279).

Table S1. Regressing education on gender

	1	2	3
Matrilineal × male	−4.05* (0.66)		
Male	3.26* (0.50)	−0.55 (0.39)	3.67* (0.58)
N	956	530	426

The result illustrated in Fig. S1 proves significant; whereas women are less well educated in the patrilineal society (column 3), they are no less educated in the matrilineal society (column 2), and the society by gender interaction is significant (column 1). Dependent variable is years of education. Matrilineal × male is an indicator variable that equals one if the subject is a male from a matrilineal village. Column 1 includes all subjects for whom education is known, whereas columns 2 and 3 are restricted to the matrilineal and patrilineal subjects, respectively, for whom education is known. All regressions are tobit and include age controls and village fixed effects.
*Significance at the 1% level.

Table S2. Regressing log-transformed time to solve the puzzle on gender

	1	2	3
Matrilineal × male	0.32* (0.06)		
Male	−0.36* (0.05)	−0.05 (0.03)	−0.36* (0.06)
N	1,279	811	468
R^2	0.27	0.23	0.26

The result illustrated in Fig. 1 proves significant using our preferred specification; whereas women take longer to solve the puzzle in the patrilineal society (column 3), they take no longer in the matrilineal society (column 2), and the interaction is significant (column 1). Dependent variable is log-transformed time to solve the puzzle. Matrilineal × male is an indicator variable that equals one if the subject is a male from a matrilineal village. Column 1 includes all subjects, whereas columns 2 and 3 are restricted to the matrilineal and patrilineal subjects, respectively. All regressions are OLS and include age controls and village fixed effects.
*Significance at the 1% level.

Table S3. Regressing time to solve the puzzle on gender

	1	2	3
Matrilineal × male	18.15* (3.47)		
Male	−18.80* (2.75)	−1.44 (1.26)	−19.39* (3.98)
N	1,279	811	468
R^2	0.23	0.21	0.20

The results in Table S2 do not rely on the log transformation of the dependent variable. Dependent variable is time to solve the puzzle in seconds. Matrilineal × male is an indicator variable that equals one if the subject is a male from a matrilineal village. Column 1 includes all subjects, whereas columns 2 and 3 are restricted to the matrilineal and patrilineal subjects, respectively. All regressions are OLS and include age controls and village fixed effects.
*Significance at the 1% level.

Table S4. Regressing solved the puzzle within the allotted time on gender

	1	2	3	4	5	6	7	8	9
Matri×male	−0.15* (0.05)			−0.45* (0.16)			−0.37† (0.16)		
Male	0.18* (0.04)	0.04 (0.03)	0.18* (0.04)	0.54* (0.13)	0.10 (0.10)	0.57* (0.13)	0.48* (0.13)	0.10 (0.10)	0.56* (0.13)
N	1,279	811	468	1,279	811	468	1,279	811	468
R^2	0.19	0.16	0.18	0.15	0.13	0.15	—	—	—

The result in Table S2 still holds, even if we only consider whether subjects solved the puzzle within the allotted 30 s and ignore their actual completion time (columns 1–3). Because the dependent variable is now binary, we also run probit regressions with village fixed effects (columns 4–6) and village random effects (columns 7–9), which yield the same results. Subjects were paid 20 rupees if they solved the puzzle within 30 s. Our dependent variable is a dummy variable that equals one if the subject solved the puzzle within the allotted time. Matrilineal × male (Matri×male) is an indicator variable that equals one if the subject is a male from a matrilineal village. Columns 1–3 are OLS. Columns 4–6 are probit with village fixed effects. Columns 7–9 are probit with village random effects. Columns 1, 4, and 7 include all subjects, columns 2, 5, and 8 are restricted to matrilineal subjects, and columns 3, 6, and 9 are restricted to patrilineal subjects.
*Significance at the 1% level.
†Significance at the 5% level.

Table S5. Regressing log-transformed time to solve the puzzle on gender and education

	1	2	3	4	5	6
Matri×male	0.26* (0.07)	0.37* (0.07)				
Male	−0.29* (0.05)	−0.38* (0.05)	−0.04 (0.04)	−0.03 (0.04)	−0.29* (0.06)	−0.38* (0.06)
Education	−0.04* (0.00)		−0.04* (0.01)		−0.05* (0.01)	
N	956	956	530	530	426	426
R^2	0.37	0.31	0.33	0.28	0.35	0.29

A substantial fraction of the main effect is explained by education; when education is added as a control variable, the coefficient on gender remains significant but decreases in magnitude in the patrilineal society (columns 6 and 5), remains insignificant in the matrilineal society (columns 4 and 3), and the interaction between gender and society remains significant but decreases in size (columns 2 and 1). Dependent variable is log-transformed time to solve the puzzle. Matrilineal × male (Matri×male) is an indicator variable that equals one if the subject is a male from a matrilineal village. Education is the number of years of schooling. Columns 1 and 2 include all subjects for whom education is known, columns 3 and 4 are restricted to the matrilineal subjects for whom education is known, and columns 5 and 6 are restricted to the patrilineal subjects for whom education is known. Odd regressions include education as a regressor, whereas even regressions do not. All regressions are OLS and include age controls and village fixed effects.
*Significance at the 1% level.

Table S6. Regressing time to solve the puzzle on gender and education

	1	2	3	4	5	6
Matri×male	16.04* (4.15)					
Male	−16.90* (3.07)	−20.10* (3.09)	−1.82 (1.38)	−1.38 (1.42)	−16.60* (4.32)	−20.67* (4.25)
Education	−1.66* (0.27)		−1.05* (0.19)		−2.08* (0.56)	
N	956	956	530	530	426	426
R^2	0.28	0.25	0.30	0.26	0.25	0.22

Once again, the result in Table S5 does not rely on the log transformation. Dependent variable is time to solve the puzzle. Matrilineal × male (Matri×male) is an indicator variable that equals one if the subject is a male from a matrilineal village. Education is the number of years of schooling. Columns 1 and 2 include all subjects for whom education is known, columns 3 and 4 are restricted to the matrilineal subjects for whom education is known, and columns 5 and 6 are restricted to the patrilineal subjects for whom education is known. Odd regressions include education as a regressor, whereas even regressions do not. All regressions are OLS and include age controls and village fixed effects.
*Significance at the 1% level.

Table S7. Regressing solved the puzzle within allotted the time on gender and education

	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18
Matrix×male	−0.10*	−0.17†					−0.33*	−0.53†					−0.33*	−0.53†				
	(0.06)	(0.06)					(0.19)	(0.18)					(0.19)	(0.18)				
Male	0.13†	0.19†	0.04	0.03	0.13†	0.19†	0.45†	0.58†	0.12	0.07	0.46†	0.60†	0.45†	0.58†	0.12	0.07	0.46†	0.60†
	(0.04)	(0.04)	(0.04)	(0.04)	(0.04)	(0.04)	(0.14)	(0.13)	(0.13)	(0.12)	(0.14)	(0.14)	(0.14)	(0.13)	(0.13)	(0.12)	(0.14)	(0.14)
Education	0.03†		0.03†		0.03†		0.09†		0.09†		0.09†		0.09†		0.09†		0.09†	
	(0.00)		(0.01)		(0.01)		(0.01)		(0.02)		(0.02)		(0.01)		(0.02)		(0.02)	
N	956	956	530	530	426	426	956	956	530	530	426	426	956	956	530	530	426	426
R^2	0.28	0.24	0.25	0.21	0.26	0.21	—	—	—	—	—	—	—	—	—	—	—	—

Once again, the result in Table S5 holds up when we simply code subjects as having solved the puzzle within the allotted 30 s. Subjects were paid 20 rupees if they solved the puzzle within 30 s. Our dependent variable is a dummy variable that equals one if the subject solved the puzzle within the allotted time. Matrilineal × male (Matrix×male) is an indicator variable that equals one if the subject is a male from a matrilineal village. Education is the number of years of schooling. Columns 1–6 are OLS, columns 7–12 are probit with village fixed effects, and columns 13–18 are probit with village random effects. Columns 1, 2, 7, 8, 13, and 14 include all subjects for whom education is known, columns 3, 4, 9, 10, 15, and 16 are restricted to the matrilineal subjects for whom education is known, and columns 5, 6, 11, 12, 17, and 18 are restricted to the patrilineal subjects for whom education is known. Columns 1, 3, 5, 7, 9, 11, 13, 15, and 17 include education as a regressor, whereas columns 2, 4, 6, 8, 10, 12, 14, 16, and 18 do not. All regressions include age controls and village fixed effects.

*Significance at the 1% level.

†Significance at the 5% level.

Table S8. Regressing log-transformed time to solve the puzzle on gender among patrilineal subjects who do and do not live in traditional households

	1	2
Male	−0.42* (0.07)	−0.10 (0.28)
N	312	35
R^2	0.28	0.18

Patrilineal households that are less traditional (column 2) do not exhibit the gender gap found in more traditional homes (column 1), providing some evidence that even household level treatment matters. Traditionally, although property in the patrilineal villages is usually owned solely by males, there are some exceptions, which we interpret as less traditional households. Dependent variable is log-transformed time to solve the puzzle. Column 1 includes patrilineal subjects who live in homes owned by a male. Column 2 includes patrilineal subjects who live in homes owned by a female or jointly owned by a male and a female. Both regressions are OLS and include age controls and village fixed effects.

*Significance at the 1% level.

Table S9. Regressing log-transformed time to solve the puzzle on a dummy indicating whether the subject is one of the privileged few who stand to inherit the family property

	1	2
Privileged	−0.06 (0.09)	0.02 (0.10)
N	203	176
R^2	0.21	0.31

Being the privileged individual who inherits the property does not influence time to solve the puzzle, providing evidence that our main result is not driven by these privileged subjects; the oldest son in the patrilineal society is no quicker at solving the puzzle (column 1) nor is the youngest daughter in the matrilineal society (column 2). In the matrilineal society, the youngest daughter inherits the property. In the patrilineal society, the oldest son inherits the property. The dependent variable is log-transformed time to solve the puzzle. Privileged is a dummy variable that equals one if the subject is either the oldest son who comes from a patrilineal village or the youngest daughter who comes from a matrilineal village. Column 1 includes patrilineal male subjects for whom birth order is known. Column 2 includes matrilineal males subjects for whom birth order is known. Both regressions are OLS and include age controls and village fixed effects.

Table S10. Regressing log-transformed time to solve the puzzle on gender among subjects who are not the privileged few who stand to inherit the family property

	1	2	3
Matrilineal × male	−1.04 (0.66)		
Male	0.08 (0.24)	−0.46 (0.61)	0.03 (0.28)
N	331	218	113
R^2	0.24	0.29	0.18

After we remove the privileged few who inherit the property, our main results hold up, providing further evidence that our main result from Table S2 is not driven by these privileged subjects. In the matrilineal society, the youngest daughter inherits the property. In the patrilineal society, the oldest son inherits the property. Dependent variable is log-transformed time to solve the puzzle. Matrilineal × male is an indicator variable that equals one if the subject is a male from a matrilineal village. Column 1 includes all subjects whom we know for sure are not either the youngest daughter from a matrilineal village or the oldest son from a patrilineal village, column 2 is restricted to the matrilineal subjects whom we know for sure are not the youngest daughter, and column 3 is restricted to the patrilineal subjects whom we know for sure are not the oldest son. All regressions are OLS and include age controls and village fixed effects.

Table S11. Regressing log-transformed time to solve the puzzle on competitiveness

	1	2	3
Matrilineal × male	0.37* (0.07)		
Male	−0.37* (0.05)	−0.01 (0.04)	−0.38* (0.06)
Competitive	−0.01 (0.04)	−0.05 (0.05)	0.05 (0.07)
N	976	574	402
R^2	0.29	0.29	0.27

Our main result from Table S2 holds up even when we control for competitiveness, indicating that this result is not merely driven by competitiveness. Some subjects tossed balls into a bucket and decided whether they wanted to get paid piece rate or competitively for successful tosses. Dependent variable is log-transformed time to solve the puzzle. Competitive is a dummy variable that equals one if the subject chose the competitive payment scheme. Matrilineal × male is an indicator variable that equals one if the subject is male from a matrilineal village. Column 1 includes all subjects who performed this task, column 2 is restricted to the matrilineal subjects who performed this task, and column 3 is restricted to the patrilineal subjects who performed this task. All regressions are OLS and include age controls and village fixed effects.
*Significance at the 1% level.

Table S12. Regressing log-transformed time to solve the puzzle on gender with village fixed effects displayed

	1	2	3
Matri×male	0.32* (0.06)	0.28* (0.07)	
Male	−0.36* (0.05)	−0.33* (0.05)	−0.16* (0.03)
Village2	−0.26* (0.09)		−0.24* (0.09)
Village3	−0.57* (0.09)		−0.39* (0.08)
Village4	−0.88* (0.10)		−0.70* (0.10)
Village5	−0.74* (0.09)		−0.55* (0.08)
Village6	−1.05* (0.09)		−0.86* (0.08)
Village7	−0.38* (0.09)		−0.34* (0.10)
Village8	−0.43* (0.09)		−0.40* (0.09)
Matrilineal		−0.45* (0.05)	
N	1,279	1,279	1,279
R^2	0.27	0.19	0.25

These regressions allow us to see that village fixed effects are substantial; nevertheless, our main result holds up with and without controlling for village fixed effects. Dependent variable is log-transformed time to solve the puzzle. Matrilineal × male (Matri×male) is an indicator variable that equals one if the subject is a male from a matrilineal village. Villages 3, 4, 5, and 6 are matrilineal. Column 1 includes village fixed effects and the MatriXmale interaction term. Column 2 replaces village fixed effects with a dummy variable, Matrilineal, which is one if the subject comes from a matrilineal village. Column 3 includes village fixed effects but not the Matri × male interaction term. All regressions are OLS, include all subjects, and include age controls.
*Significance at the 1% level.

Table S13. Regressing log-transformed time to solve the puzzle on education and gender

	1	2	3
Male × education	−0.02† (0.01)		
Education	−0.03* (0.01)	−0.03* (0.01)	−0.05* (0.01)
N	956	484	472
R^2	0.37	0.37	0.37

Education has a positive effect on both genders, providing evidence that the role of education reported in Table S5 is not driven solely by males, suggesting that improving education for women could reduce the gender gap in spatial abilities. Dependent variable is log-transformed time to solve the puzzle. Education is the number of years of schooling. Column 1 includes all subjects for whom education is known, column 2 is restricted to female subjects for whom education is known, and column 3 is restricted to male subjects for whom education is known. All regressions are OLS and include age controls and village fixed effects.

*Significance at the 1% level.

†Significance at the 5% level.