Nurture affects gender differences in spatial abilities

Moshe Hoffman[a,1], Uri Gneezy[a], and John A. List[b]

[a]Rady School of Management, University of California at San Diego, La Jolla, CA 92093; and [b]Department of Economics, University of Chicago, Chicago, IL 60637

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.

[1]To whom correspondence should be addressed. E-mail: mohoffman@ucsd.edu.

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.

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.

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.

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

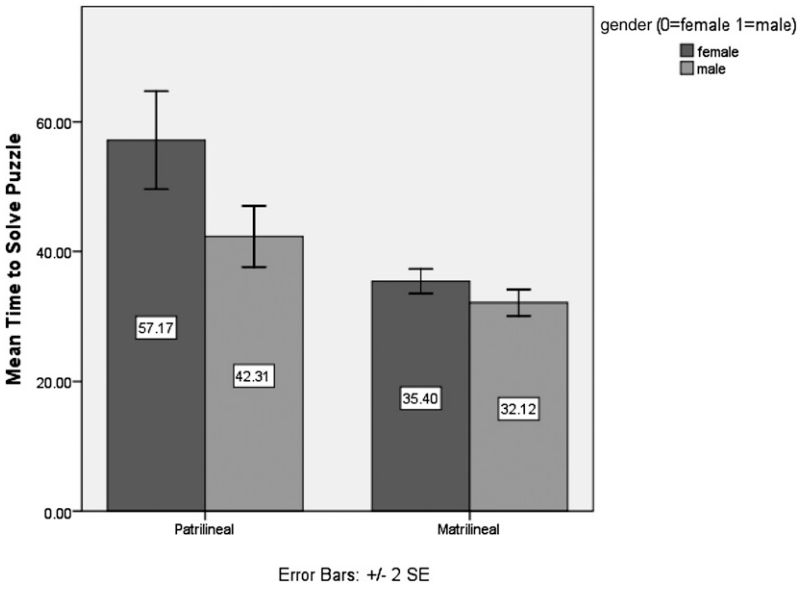

Fig. 2. Female villagers took longer to solve the puzzle in the patrilineal society but no longer in the matrilineal society. Mean time to solve the puzzle by society and gender. Subjects solved a four-piece jigsaw puzzle. The time that it took to complete the puzzle acted as our measure of spatial ability.

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.

1. Spelke E, Pinker S (2005) *The Science of Gender and Science. Pinker vs. Spelke: A Debate.* Available at http://www.edge.org/3rd_culture/debate05/debate05_index.html. Accessed August 3, 2011.
2. Congressional Commission on the Advancement of Women and Minorities in Science, Engineering, and Technology Development (2001) *Land of Plenty: Diversity as America's Competitive Edge in Science, Engineering and Technology. Report of the Congressional Commission on the Advancement of Women and Minorities in Science, Engineering, and Technology Development.* Available at http://www.nsf.gov/pubs/2000/cawmset0409/cawmset_0409.pdf.
3. Summer L (2005) *Remarks at NBER Conference on Diversifying the Science and Engineering Workforce.* Available at http://web.archive.org/web/20080130023006/http://www.president.harvard.edu/speeches/2005/nber.html. Accessed August 3, 2011.
4. Barres BA (2006) Does gender matter? *Nature* 442:133–136.
5. Poole C, Stanley G (1972) A factorial and predictive study of spatial abilities. *Aust J Psychol* 24(3):317–320.
6. Humphreys LG, Lubinski D, Yao G (1993) Utility of predicting group membership and the role of spatial visualization in becoming an engineer, physical scientist, or artist. *J Appl Psychol* 78:250–261.
7. Hegarty M, Sims VK (1994) Individual differences in mental animation during mechanical reasoning. *Mem Cognit* 22:411–430.
8. Voyer D, Voyer S, Bryden MP (1995) Magnitude of sex differences in spatial abilities: A meta-analysis and consideration of critical variables. *Psychol Bull* 117:250–270.
9. Sorby SA (2009) Educational research in developing 3-D spatial skills for engineering students. *Int J Sci Educ* 31(3):459–480.
10. Baenninger M, Newcombe N (1989) The role of experience in spatial test performance: A meta-analysis. *Sex Roles* 20(5):327–344.
11. Steele CM (1997) A threat in the air. How stereotypes shape intellectual identity and performance. *Am Psychol* 52:613–629.
12. Stage C (1988) Gender differences in test results. *Scand J Educ Res* 32(3):101–111.
13. Nordvik H, Amponsah B (1998) Gender differences in spatial abilities and spatial activity among university students in an egalitarian educational system. *Sex Roles* 38 (11):1009–1023.
14. Ortar G (1967) Fifteen years of the seker. *Megamot* 15:1220–1230.
15. Halpern DF (2000) *Sex Differences in Cognitive Abilities* (Lawrence Erlbaum Associates, Mahwah, NJ).
16. Berry WJ (1966) Temne and Eskimo perceptual skills. *Int J Psychol* 1(3):207–229.
17. Roychoudhury AK (1992) Genetic relationships of the populations in eastern India. *Ann Hum Biol* 19(5):489–501.
18. Gneezy U, Leonard KL, List JA (2009) Gender differences in competition: Evidence from a matrilineal and a patriarchal society. *Econometrica* 77(5):1637–1664.
19. Andersen S, Bulte E, Gneezy U, List JA (2008) Do women supply more public goods than men? Preliminary experimental evidence from matrilineal and patriarchal societies. *Am Econ Rev* 98(2):376–381.
20. Croson R, Gneezy U (2009) Gender differences in preferences. *J Econ Lit* 47:1–27.