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Research Report

Socioeconomic Status Modifies the Sex Difference in Spatial Skill

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ABSTRACT—*We examined whether the male spatial advantage varies across children from different socioeconomic (SES) groups. In a longitudinal study, children were administered two spatial tasks requiring mental transformations and a syntax comprehension task in the fall and spring of second and third grades. Boys from middle- and high-SES backgrounds outperformed their female counterparts on both spatial tasks, whereas boys and girls from a low-SES group did not differ in their performance level on these tasks. As expected, no sex differences were found on the verbal comprehension task. Prior studies have generally been based on the assumption that the male spatial advantage reflects ability differences in the population as a whole. Our finding that the advantage is sensitive to variations in SES provides a challenge to this assumption, and has implications for a successful explanation of the sex-related difference in spatial skill.*

A substantial body of research indicates that males outperform females on spatial tasks, particularly those involving mental rotation (e.g., Hyde, 1981; Linn & Peterson, 1985; Voyer, Voyer, & Bryden, 1995). This difference appears to be the most substantial sex difference in cognitive functioning (e.g., Kimura, 1999). Although it has been claimed that the male advantage does not emerge until age 10 or later (e.g., Johnson & Meade, 1987; Maccoby & Jacklin, 1974; Voyer et al., 1995), differences are reported as early as the preschool years (e.g., Levine, Huttenlocher, Taylor, & Langrock, 1999).

Increasing understanding of the factors affecting the emergence and magnitude of the male advantage on spatial tasks is not only an interesting scientific question, but is also relevant to improving children's academic performance and to meeting the workforce demands of today's technological society. Spatial ability is related to success in math and science courses (e.g., Delgado & Prieto, 2004; Govier & Feldman, 1999), to performance on standardized mathematics tests such as the SAT, and to the choice of math or science as a college major (e.g., Casey, 1996). Spatial ability also is related to employment in a wide range of technological and science-related occupations (e.g., McGee, 1979). Thus, it is not surprising that females, with their lower average level of spatial skill, are markedly underrepresented in these fields (e.g., Kahle, Parker, Rennie, & Riley, 1993; see Terlecki, 2004, for a review).

Only a handful of studies have examined whether the male spatial advantage is present across different population groups. There are reports that this sex difference is present in African, Asian, and Western cultures (e.g., Berry, 1966; Li, Nuttall, & Zhu, 1999; Mann, Sasanuma, Sakuma, & Masaki, 1990). However, Eastern Canadian Eskimos from the Baffin Islands do not show a sex difference on a variety of spatial tasks, possibly because both males and females in this culture hunt, which involves navigating across land and sea environments sparse in landmarks (Berry, 1966). Further, Icelandic high school girls outperform their male counterparts on the PISA (Program for International Student Assessment) mathematics test, even on the section that is highly spatial, possibly because of their interest in math and motivational factors (Lemke et al., 2004). Because both of these populations are relatively isolated, these patterns may reflect genetic rather than experiential factors.

Surprisingly, there has not been systematic examination of whether the male spatial advantage varies across different socioeconomic (SES) groups within the United States. Such research could provide data relevant to understanding the nature of the sex difference. For example, various theories posit that differential engagement in activities that promote spatial skill contributes to the male advantage (e.g., Caldera, Huston, & O'Brien, 1989; Casey, 1996). These activities, in turn, may serve to induce, maintain, or enhance a male advantage. But differential male engagement in activities that support the development of spatial skills is predicated on the availability of these kinds of activities in the environment—a factor that may vary

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across SES groups. In contrast, biological explanations of the male advantage, at least as currently formulated, would not predict systematic variation across SES groups.

In the present experiment, we examined whether the male spatial advantage varies across second- and third-grade children from different SES groups. Two spatial tasks, a newly developed aerial-maps task (Liben, 2001) and a mental rotation task (Thurstone, 1974), were administered. Both tasks require spatial transformations on which children might be expected to show sex differences. A syntax comprehension task (Huttenlocher, Vasilyeva, Cymerman, & Levine, 2002), on which we did not expect a sex difference, was also administered to ensure that any male advantage on the spatial tasks did not reflect generally higher cognitive skill among the males in our sample.

METHOD

Participants

A sample of 547 students (276 boys, 271 girls) was recruited from 15 schools in the greater Chicago area. Participants were assessed in the fall and spring of the 1999–2000 and 2000–2001 school years. The number of children participating at each time point varied somewhat because of children being absent from school or moving, and because one low-SES school dropped out of the study after the first year. SES was assigned at the school level, on the basis of census-track data from the 2000 U.S. Census on the neighborhoods in which the schools were located. The income ranges of the different SES groups were nonoverlapping. The income level of the middle-SES group ($39,373–$50,733; median: $44,781) was close to the median household income for a family of four in Illinois ($46,064), whereas the income level of the high-SES group ($59,124–$124,855; median: $92,312) was well above this level and the income level of the low-SES group ($19,371–$26,242; median: $21,242) was well below this level. The income level of the low-SES group was somewhat above the poverty line for a family of four, which is set annually by the U.S. Department of Health and Human Services ($16,700 in 1999 and $17,050 in 2000). Boys and girls were approximately equally represented in each of the SES groups, but there were more participants in the middle-SES group than in the other groups (low: 113, middle: 278, high: 156).

Procedure

Participants were followed for 2 years and were assessed at four testing sessions—in the autumn and spring of second and third grades. At each testing point, the children received the aerial-maps, mental rotation, and syntax comprehension tasks. The aerial-maps task, based on Liben's (2001) work, assessed the children's ability to draw correspondences between geographical locations depicted in photographs and maps. The children were asked to select the map location (from among four choices) that matched the location of a star on each photograph. The mental rotation task was based on the Spatial Relations subtest from the Primary Mental Abilities (PMA) Readiness Level (Thurstone, 1974). The children were asked to select the figure (from among four choices) that could be put together with each target figure to make a square. Finally, on the syntax comprehension task, the children were asked to select the picture (from among three or four choices, depending on the item) corresponding to each sentence they were read. At each session, children were assessed as a group in their classroom during a 30-min session.

RESULTS

An analysis of variance (ANOVA) was conducted for each task, with the proportion of correct responses (arcsine transformed) as the dependent variable. Children who were not present for at least two sessions were excluded from this and subsequent analyses (approximately 6%, distributed evenly across the SES groups). For each task, there was a significant effect of testing session, $F(3, 1229) = 130.04$ for the aerial-maps task, $F(3, 1228) = 56.85$ for the mental rotation task, and $F(3, 1235) = 113.31$ for the syntax comprehension task, all $ps < .0001$. This effect reflected improvement in performance over successive time points ($p < .05$ between each pair of sessions, Tukey HSD tests). Testing session did not interact with any other variable.

There was also a significant effect of SES for each task, $F(2, 505) = 7.50$ for the aerial-maps task, $F(2, 508) = 14.72$ for the mental rotation task, and $F(2, 507) = 8.62$ for the syntax comprehension task, all $ps < .001$. This effect reflected the better performance of the high- and middle-SES groups (which were not significantly different from each other) relative to the low-SES group ($p < .05$ in each case, Tukey HSD tests). In addition, both spatial tasks showed a significant main effect of sex, $F(1, 505) = 16.85$, $p < .0001$, for the aerial-maps task and $F(1, 508) = 13.53$, $p < .001$, for the mental rotation task. This effect reflected the better performance of boys than girls. The finding of a male advantage on the mental rotation task is consistent with our previous findings on this type of task with younger children (Levine et al., 1999). The finding of a male advantage on the aerial-maps task extends the range of tasks for which there is evidence of an early sex difference. Note that there was no effect of sex on the syntax comprehension task, $F(1, 507) = 1.46$, $p = .23$, showing that the boys in our sample did not generally score higher than the girls.

Critically for the interpretation of the main effects of sex, there was a significant Sex × SES interaction for the two spatial tasks, $F(2, 505) = 3.74$, $f = .10$, for the aerial-maps task and $F(2, 508) = 3.40$, $f = .10$, for the mental rotation task, both $ps < .05$, but not for the syntax comprehension task, $F(2, 507) = 0.80$, $p = .45$. The top panel in Figure 1 shows that high- and middle-SES boys outperformed their female counterparts on the aerial-maps task, Tukey-Kramer $q(6, 505) = 5.75$, $p < .01$, for the high-SES group and Tukey-Kramer $q(6, 505) = 4.07$, $p < .05$, for the

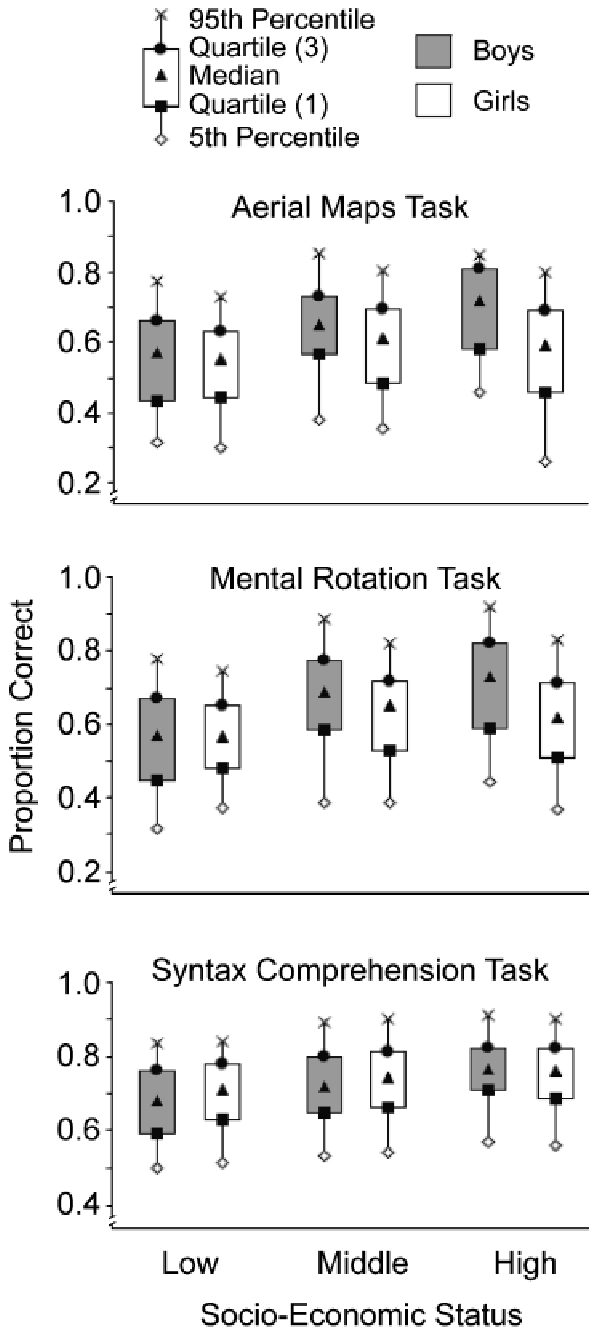

Fig. 1. Box plots of score distributions (across time points) on the aerial-maps task (top panel), mental rotation task (middle panel), and syntax comprehension task (bottom panel) as a function of sex and socioeconomic status.

middle-SES group, but there was no sex difference in the low-SES group, Tukey-Kramer $q(6, 505) = 0.40$, $p > .1$. The effect sizes (d) for the high- and middle-SES groups were .42 and .19, respectively. Similarly, the middle panel of Figure 1 shows that high- and middle-SES boys performed better than their female counterparts on the mental rotation task, Tukey-Kramer $q(6, 508) = 4.72$, $p < .05$, for the high-SES group and Tukey-Kramer $q(6, 508) = 4.95$, $p < .01$, for the middle-SES group, but, again, there was no sex difference in the low-SES group, Tukey-Kramer $q(6, 508) = -0.14$, $p > .1$. The effect sizes (d) for the high- and middle-SES groups were .35 and .23, respectively. Although the effects sizes are in the small-to-medium range, they overlap with those reported for mental rotation tasks in school-aged children (Voyer et al., 1995). To make sure that our findings were not related to attrition, we ran an additional ANOVA on each spatial task in the first two testing sessions, when there was very little attrition, and found the same pattern of results—namely, significant Sex × SES interactions, $F(2, 503) = 6.07$, $p < .01$, for the aerial-maps task and $F(2, 506) = 3.31$, $p < .05$, for the mental rotation task.

DISCUSSION

Our most notable findings in the present study are the Sex × SES interactions for the two spatial tasks. These interactions provide strong evidence that factors affecting spatial skill interact in a nonadditive manner. Additivity would predict the lowest level of spatial ability in low-SES girls; their spatial skills would suffer both because they are female and because of their low-SES status. This clearly was not the case, as performance levels of low-SES girls and boys did not differ. The Sex × SES interaction for the two spatial tasks provides constraints and challenges for an explanatory theory of this sex-related cognitive difference—any explanation for the male spatial advantage must also explain why it is absent in low-SES groups.

A possible explanation for the difference in the male spatial advantage across SES groups is that this advantage is more marked on difficult test items. In fact, sex differences on mathematics achievement tests are found only on more difficult items, perhaps because these items are higher in spatial content (e.g., Hedges & Nowell, 1995; Hyde, Fennema, & Lamon, 1990; Penner, 2003). Thus, if neither boys nor girls in the low-SES group in our study succeeded on the difficult items, this could account for the lack of a sex difference in the low-SES group. If this account were correct, we would expect a significant correlation between item difficulty and the magnitude of the male advantage. However, this was not the case for any SES group (aerial-maps task: $rs = -.14$, .07, and $-.10$ for the high-, middle-, and low-SES groups, respectively; mental rotation task: $rs = -.10$, $-.14$, and $-.04$ for the high-, middle-, and low-SES groups, respectively; all $ps > .05$). Moreover, according to the difficulty hypothesis, a male spatial advantage should emerge when low-SES children succeed at difficult items. To test this hypothesis, we compared the sex difference in spring of third grade for the low-SES group with the sex difference in fall of second grade for the higher-SES groups, when their performance levels were comparable (see Fig. 2). We found a sex difference for the higher-SES groups on both spatial tasks at the fall second-grade test point, but not a hint of a sex difference in the low-SES group on either spatial task at the spring third-grade time point.

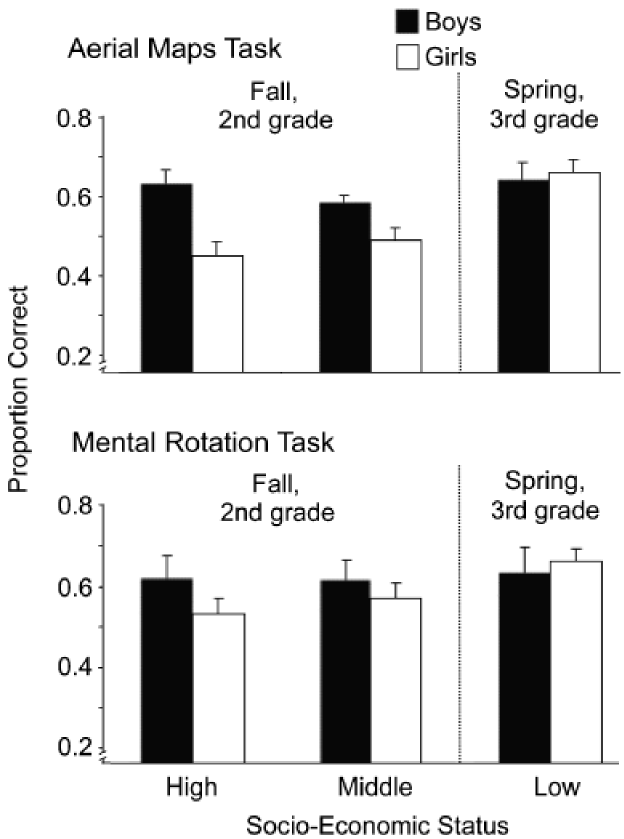

Fig. 2. Mean proportion correct (and standard deviation) on the aerial-maps task (top panel) and mental rotation task (bottom panel) for children of high and middle socioeconomic status (SES) in the fall of second grade and for children of low socioeconomic status in the spring of third grade.

An alternative explanation for the SES-related difference is that a differentially high level of engagement in the kinds of activities that promote the development of spatial skill is essential to the male spatial advantage. In lower-SES groups, these kinds of activities may be relatively unavailable to both boys and girls. Although little is known about what types of input can promote spatial skill, prior studies indicate that activities such as playing with Legos, putting puzzles together, and playing video games are correlated with spatial skill; further, boys spend more time on these activities than girls (e.g., Dorval & Pepin, 1986; Serbin, Zelkowitz, Doyle, Gold, & Wheaton, 1990; Subrahmanyam & Greenfield, 1994). Although low-SES children certainly engage in sex-typed play, they may have less access than other children to toys and games that promote spatial skill, as some of these toys and games are relatively expensive. Prior studies also indicate that freedom to explore the environment is correlated with the male-female discrepancy in spatial ability, and that boys spend more time exploring their neighborhoods than girls do (e.g., Entwisle, Alexander, & Olson, 1994). However, boys from low-SES backgrounds may not be given as much freedom to explore their neighborhoods as their higher-SES counterparts because of parental perceptions of danger in their environment (e.g., O'Neil, Parke, & McDowell, 2001). Thus, in high-SES environments, boys may engage more in spatially relevant activities than girls do, but in low-SES environments, boys and girls may engage in these activities at low and approximately equivalent levels. Such a pattern would provide a possible explanation for the Sex × SES interaction (e.g., Dickens & Flynn, 2001).

Although activities that promote spatial skill may be critical to the male spatial advantage, our findings do not distinguish between two potential causes for higher male engagement in these activities. One possibility is that boys engage in spatial activities more than girls do whenever such activities are available because of a biological propensity, and the other possibility is that boys engage more in these activities in certain cultural contexts because their environments make it more comfortable for them to do so. Of course, some combination of these two scenarios is possible. Thus, our findings do not rule out a role of biological factors in the male spatial advantage, but the finding of Sex × SES interactions for two spatial tasks poses a challenge for explanations that downplay the role of environmental effects.

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