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SHORT REPORT

Explaining sex differences in mental rotation: role of spatial activity experience

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Abstract Males consistently outperform females on mental rotation tasks, such as the Vandenberg and Kuse (1978) Perceptual and Motor Skills, 47(2), 599–604, mental rotation test (MRT; e.g. Voyer et al. 1995) in Psychological Bulletin, 117, 250–265. The present study investigates whether these sex differences in MRT scores can be explained in part by early spatial activity experience, particularly those spatial activities that have been sex-typed as masculine/male-oriented. Utilizing an online survey, 571 ethnically diverse adult university students completed a brief *demographic survey*, an 81-item *spatial activity survey*, and the *MRT*. Results suggest that the significant relation between *sex of the participant* and *MRT score* is partially mediated by the *number of masculine spatial activities* participants had engaged in as youth. Closing the gap between males and females in spatial ability, a skill linked to science, technology, engineering, and mathematics success, may be accomplished in part by encouraging female youth to engage in more particular kinds of spatial activities.

Keywords Mental rotation · Sex difference · Spatial activity · Spatial thinking

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Mental rotation, the ability to mentally rotate and orient three- and two-dimensional objects or images in space, is a process critical to a host of tasks, including identification of individual letters of the alphabet for reading (Rusiak et al. 2007), orientation and navigation in unfamiliar environments (Linn and Petersen 1985), map-reading (Shepard and Hurwitz 1984), and perhaps even as some have suggested, success in science, technology, engineering, and mathematics (STEM) disciplines (Lubinski 2010; Wai et al. 2009). Research consistently shows significant sex differences in mental rotation skill, with males outperforming females (Linn and Petersen 1985; Maccoby and Jacklin 1974; Voyer et al. 1995). Explanations for this sex difference have ranged from underlying biological/hormonal causes (Gaulin and Hoffman 1988; Halari et al. 2005; Hausmann et al. 2000; Silverman et al. 1999) to use of different attentional/cognitive strategies (Hugdahl et al. 2006; Linn and Petersen 1985) to social/experiential factors (Baenninger and Newcombe 1989, 1995). In the present study, we consider and test the latter explanation, that men outperform women on a mental rotation task, specifically the Vandenberg and Kuse *mental rotation test* (MRT; 1978), because of experiential factors. In particular, we explore whether sex differences on the MRT are explained in part by the number of spatial activities participants have engaged in as youth.

Some argue that engagement in spatial activities, particularly those that are male/masculine sex-typed activities (e.g. mechanical drawing, building models, carpentry), may provide the opportunity to utilize the very same skill set used to solve mental rotation tasks (Newcombe et al. 1983; Sherman 1967, 1974). Indeed, there is some evidence to suggest that participation in these early spatial experiences may contribute to sex differences in spatial ability. For example, Newcombe and colleagues (1983) find a significant correlation between spatial visualization ability, as measured by the Differential Aptitude Test (DAT), and participation in spatial activities, as measured by an 81-item spatial activity questionnaire. Some have argued that spatial thinking is composed of several distinct and differentiated abilities including, spatial visualization, spatial perception, and spatial orientation (e.g. Hegarty and Waller 2004; Lohman 1996; Thurstone 1950), and thus, different tests are measuring different underlying processes. The space relations' subtest of the DAT is largely thought of as a spatial visualization task, as it requires the ability to visualize a three-dimensional object from a two-dimensional pattern. To date, no research has examined whether past spatial activity participation, particularly those spatial activities sex-typed as male/masculine, explains sex differences in mental rotation performance, a process largely thought to measure one's spatial orientation ability (i.e. ability to anticipate or recognize the appearance of an object after it has been rotated). The present study explores whether participation in masculine spatial activities mediates the sex difference in MRT scores and thus adds to the existing body of research on the impact of early spatial experiences on spatial ability. Given that research has demonstrated a link between spatial ability and achievement in STEM fields (Lubinski 2010), understanding the causes of the sex difference in spatial ability is of paramount importance to ensure equal representation of the sexes across the STEM disciplines.

Method

Participants

The final sample consisted of 571 students (M_{age} = 22.37 years, SD = 5.5 years; 166 male, 405 female) from a Southeastern University. Twenty additional participants (<4 %) were eliminated from the sample, as their study completion times were two standard deviations from the mean ($M_{completion\ time}$ = 36.50 min, SD = 57.05). Participants represented an ethnically (72 % Hispanic/Spanish/Latino) and racially (68 % White; 12 % Black; 20 % mixed-race) diverse group.

Materials and procedure

Participants were asked to complete online, in a fixed order: (1) a brief *demographic survey* consisting of questions about their race/ethnicity, sex, and socioeconomic/educational backgrounds; (2) Newcombe et al. (1983) *spatial activity survey*; and (3) Vandenburg and Kuse's (1978) *mental rotation test* (MRT). All materials were created and administered through Qualtrics, a survey creation and data management program.

The *spatial activity survey* asked participants to indicate whether they had ever participated in 81 different spatial activities (40 sex-typed masculine; 21 sex-typed feminine; 20 neutral) from 3 to 18 years of age. The *number of masculine spatial activities* was tallied for each participant (*Range* = 0–40), as were the number of "*other*" *spatial activities* (i.e. sum of feminine + neutral spatial activities; *range* = 0–41).

The *MRT* consisted of 3 practice items in which feedback about their answer was provided and 20 test items where no feedback was provided. For all items, participants were shown one target figure and four test figures, two of which were the same as the target figure but rotated in some way, and were asked to choose two that matched the target figure. To solve the task, participants mentally rotated the figures to find the two correct items that matched the target figure. *MRT scores* ranged from 0 to 20.

Results

Replicating the work of others, males ($M = 11.14$, SD = 5.52) significantly outperformed females ($M = 8.06$, SD = 4.94) on the MRT, $t(569) = 6.52$, $p \leq 0.001$, $d = 0.59$, and males ($M = 16.17$, SD = 7.41) participated in significantly more masculine/male spatial activities than females ($M = 9.80$, SD = 6.13), $t(569) = 10.60$, $p \leq 0.001$, $d = 0.94$.

All three variables of interest, *sex of participant*, *number of masculine spatial activities*, and *MRT scores*, were significantly and positively correlated with each other (Fig. 1a), meeting the prerequisite for a mediation analysis (rs > 0.21, ps ≤ 0.05; controlling for "*other*" *spatial activities*). Regression analysis established that *sex of participant* significantly predicted their *MRT scores* ($\beta = 0.58$, $t = 6.52$, $p \leq 0.001$). Figure 1b shows the strength of this direct effect (path *c*) of *sex of the participant* on *MRT scores*. When the *number of masculine spatial activities* was included as a potential mediator, the path coefficient (c') was reduced ($\beta = 0.48$, $t = 4.92$, $p \leq 0.001$) suggesting that *sex of participant* influences *MRT scores* via *number of masculine spatial activities* (Fig. 1c). Entering *"other" spatial activities* in the model as a covariate revealed no significant effect on *MRT scores* (*"other" spatial activities*, $\beta = 0.80$, $t = 1.23$, $p = 0.22$). This model accounted for 8 % of the variance (based on R^2) on *MRT scores*. A bias-corrected bootstrapping procedure (Preacher and Hayes 2004) provided a 95 % confidence interval of −0.19 to −0.22, which does not cover zero. This provides statistical support that the reduction in the direct effect of *sex of participant* on *MRT scores* was significant and indicates a partial mediation of *MRT score*.

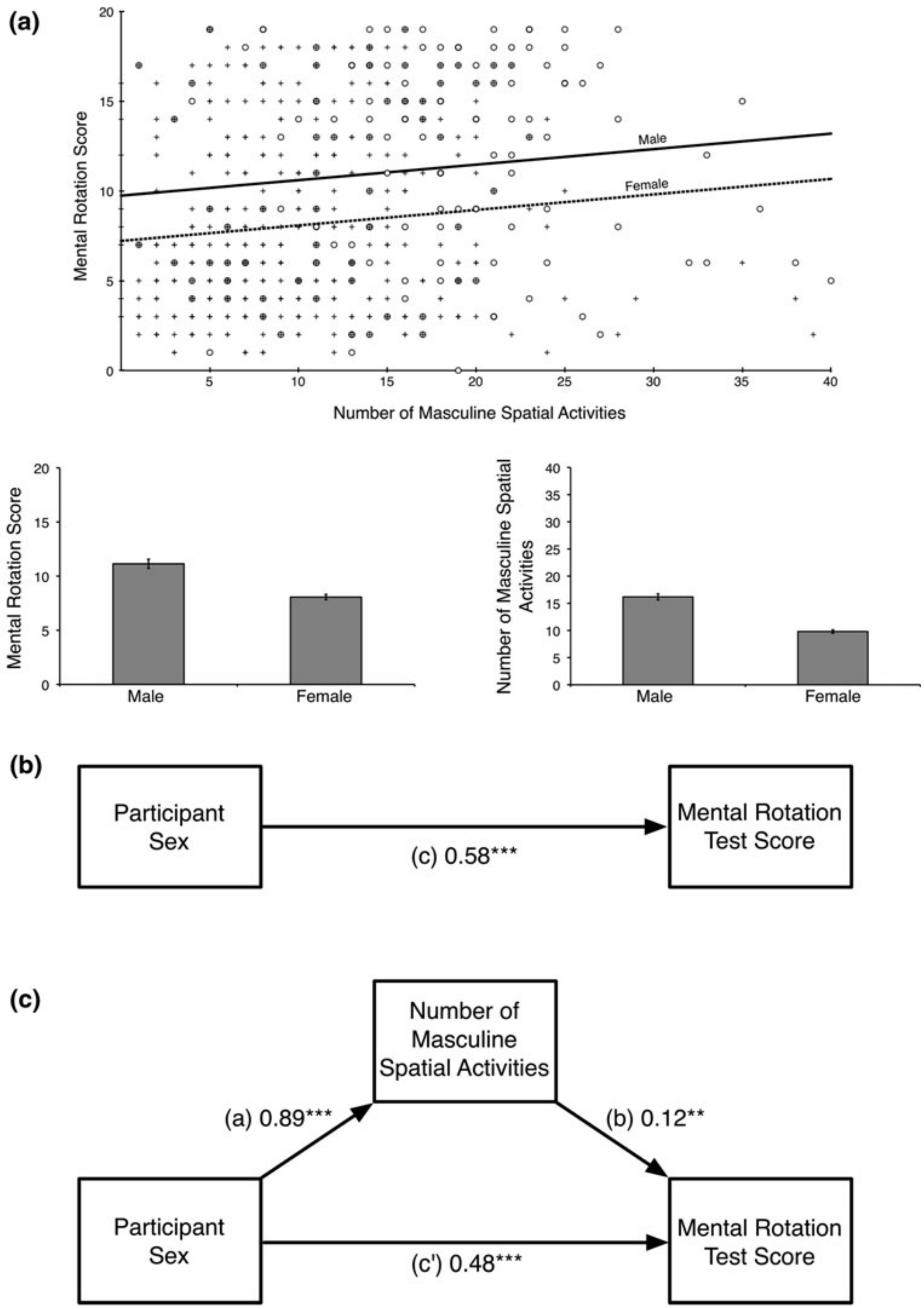

Fig. 1 Scatterplot and bar graphs **a** showing: (*1*) the relation between *number of masculine spatial activities* and *MRT scores* (*top*, °males, ⁺females; $r = 0.21$, $p \leq 0.001$), (*2*) the relation between *sex of participant* and *MRT scores* (*bottom left*; $r = 0.28$, $p \leq 0.001$), and (*3*) the relation between *sex of participant* and *number of masculine spatial activities* (*bottom right*; $r = 0.66$, $p \leq 0.001$), after controlling for "other" spatial activities. The mediation analysis revealed that the direct effect ***c*** of *sex of participant* on *MRT scores* **b** is significantly reduced when *number of masculine spatial activities* is included as a potential mediator **c**; *c*'). These results suggest that *number of masculine spatial activities* accounts for part of the relation between *sex of participant* and *MRT scores*. **b**, **c** report the β as a standardized regression coefficient. ($n = 571$, $*p \leq 0.05$, $**p \leq 0.01$, $***p \leq 0.001$)

Discussion

Taken together, the results indicate that the relation between *sex of the participant* and *MRT score* was partially mediated and explained by the *number of masculine spatial activities* participants had engaged in as youth. Further, *"other" spatial activities*, including feminine and neutral spatial activities, did not significantly impact *MRT scores*, nor did this variable significantly alter the relation between *sex of participant*, *number of masculine spatial activities*, and *MRT scores*.

While we replicate the sex difference in MRT scores, with males outperforming females, our mediation analysis suggests that there is malleability in spatial skill (cf. Newcombe 2010). Reducing the gap between male and female spatial skill may be facilitated by early spatial experience. Though we interpret our results with caution, as they are correlational in nature, encouraging female youth to engage in more "masculine/male-oriented" spatial activities (i.e. model building; carpentry), and those spatial activities utilized in K-12 science/math courses (i.e.

building electronic circuits), may be one effective way of reducing this sex difference. Reducing the sex difference in spatial skill is an important and urgent issue to address, as this ability relates to future STEM success (Shea et al. 2001; Wai et al. 2009).

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