

The Unexamined Influence: An Object's Perceived Gender on Spatial Reasoning Skills in Girls

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Abstract: Explanations for gender differences in spatial visualization and mental rotation typically center on lack of experience or cognitive deficits of females. Our research offers an alternative explanation for these differences—one rooted in the materials used for mental rotation tasks, informed by sociocultural approaches and posthumanist perspectives. Combining a gender sorting task and a mental rotation assessment, this study shows that students—regardless of gender—perceive consistent gender differences of everyday objects. Their ability to mentally rotate each object is related to their gender and the objects' perceived gender. Females perform significantly higher on mental rotation tasks that involve objects that are perceived as feminine, matching scores of males. Yet, the stereotypical mental rotation differences between females and males are seen only on objects perceived as neither feminine nor masculine. The perceived gender of materials included in educational design may shape mental rotation ability.

Introduction

Spatial reasoning skills play an important role in STEM fields (e.g., Uttal et al., 2013). For example, scores on spatial assessments are significant predictors of future attainment of STEM degrees and entering STEM professions (Wai et al., 2009). Yet, these skills are subject to consistent gender disparities favoring males, especially in three-dimensional mental rotation (3DMR; Linn & Petersen, 1985; Voyer et al., 1995). Despite views and societal perceptions that facility with spatial information is an innate talent (e.g., Wai et al., 2009), spatial skills can be taught and improved (Uttal et al., 2013). Women and young girls especially are disproportionately impacted by a lack of opportunities to develop spatial skills due to the stereotype that men are naturally more talented in 3DMR (e.g., Muenks et al., 2020). Rather than considering innate abilities as a source of gender differences in spatial reasoning and, in particular, 3DMR, there seems to be something about who is being invited to engage that may shape students' opportunities to engage in 3DMR practice.

The current study considers the traditionally feminine as its starting point, rather than viewing an increase in girls' engagement with stereotypically masculine activities as the only solution to the 3DMR gender gap. To determine the relationship between gender, material, and mental rotation (MR) performance, we asked: 1) *To what extent do students perceive gendered differences of everyday objects and does the gender identity of the respondent affect these outcomes?* 2) *To what extent does mental rotation of everyday objects vary in relation to students' gender identity and students' perceived gender of objects?* To answer these questions, we first introduced a gender sorting task and asked students (n=89) to sort everyday objects from very feminine to neither feminine nor masculine to very masculine. Then, to test whether students' ability to rotate objects varied by both the gender of the object and the gender of the students, we designed a MR assessment and administered it with another student group (n=51). Findings demonstrate that students perceive gender differences of everyday objects mostly consistently. Additionally, findings showed that MR ability is related to students' gender and objects' perceived gender: female students perform significantly higher on MR tasks that involve objects that are perceived as feminine, matching scores of their male peers. By contrast, stereotypical MR gender differences between females and males were seen in relation to objects that were perceived as neither feminine nor masculine. The results of the study offer an alternative explanation for gender differences and stereotyping in 3DMR tasks that is rooted in materials and not in the cognitive or psychological makeup of females. We argue that the perceived gender of objects included in educational design may shape MR ability.

Background: Mental rotation, gender, and materials

Mental rotation (MR) is an aspect of spatial visualization skills, which describes the ability to understand and imagine an object's spatial relationship to other objects (Linn & Petersen, 1985). These abilities involve the manipulation of visual information, which may include problems of navigation and calculation of shape, size, and fit (Gardner, 1993). MR, in particular, refers to imagining objects at different angles (Linn & Petersen, 1985). Typically considered a cognitive skill, MR is also regarded as a predictor for future career success and engagement with STEM fields (e.g., Humphreys et al., 1993; Wai et al., 2009). Assessments of MR are based on people

perceiving two-dimensional images as abstractions of three-dimensional figures through a MR experiment (e.g., French et al., 1963). The Mental Rotation Test (MRT) was designed to measure an individual's MR ability with cube shaped items (Vandenberg & Kuse, 1978).

It was long considered that practice of spatial skills does not lead to long term improvement (e.g., Sims & Mayer, 2002). Thus, findings that boys outperform girls in MR assessments (e.g., Voyer et al., 1995, Linn & Petersen, 1985; Neuburger et al., 2011) can lead to highlight deficits over training effects and possible assessment bias. However, efforts to reduce inequities related to educational and career access have shown that repeatedly mentally rotating objects, including administration of assessments, can lead to improved performance (Uttal et al., 2013). The learnability of spatial visualization skills, especially MR, is hopeful in relation to gender differences and points to inquire to what extent aspects of instruction and gender play a part in MR assessment.

We take a perspective that understands gender as performance (Butler, 1990), we conceptualize gender as a construct that exists beyond humankind, but there are features of tools that send cues to individuals. The strong emphasis on contextual materiality resonates with recent studies that highlight the non-neutral role that a diversity of materials and representations play in producing what can be learned (e.g., Kuby et al., 2017; Peppler, Rowsell, & Keune, 2020). These lines of research suggest that materials and tools are non-neutral and play an active part in shaping domain knowledge (Keune, 2020). The gender associations of tools and material are increasingly important in terms of what people can learn and how people participate. With the present study, we aimed to understand how materials relate to MR ability for female and male students.

Methods

The research was conducted at a Midwestern charter school with two separate cohorts of students (ages 10-18). The gender sorting included 89 students (39 female, 48 male, and 2 gender non-binary) and the MRT assessment included 51 students (15 female, 33 male, and 3 gender non-binary).

The *gender sorting* prompted students to sort everyday objects (e.g., lemon, doll, hammer) based on a mutually exclusive spectrum of five gender categories (i.e., very feminine=5, somewhat feminine=4, neither feminine nor masculine=3, somewhat masculine=2, and very masculine=1). The scale enforced a gender binary also because the prevalent orientation within MR positions females at a deficit. The task had 32 objects, 30 everyday (e.g., dress, box, truck, etc.) and two building block objects from spatial visualization assessments (i.e., MRT and PSVT:R). To probe how students' perception of the objects' gender and students' gender identity related to students' MR scores, we administered a *modified MRT assessment* with the objects from gender sorting, 30 everyday objects and nine MRT items. Based on the original MRT assessment, items of our modified assessment showed the target object above four perspectives of the object, including two mirrored options and two correct rotations (Figure 1). To answer an item correctly, students had to select both correct rotations.

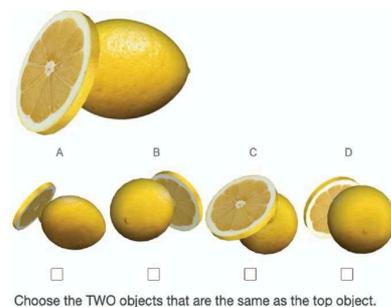


Figure 1. Modified MRT assessment item with everyday object.

Data analysis

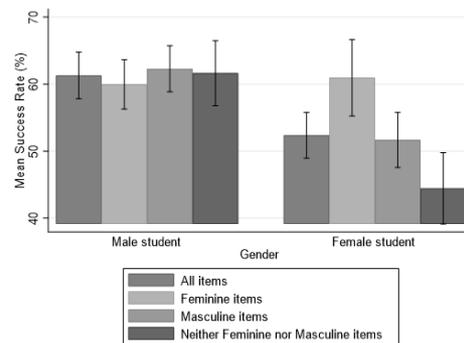
Using a two-sample t-test, we divided the participants in two groups based on their gender to test whether gender sorting was independent of students' gender for any of the 32 objects. For each object, if the mean sorting score by female students was different to that by male students, we rejected the null hypothesis of equal means between genders. A p-value of the two-sample t-test lower than 0.00156 (i.e., the Bonferroni-adjusted p-value of 0.05/32) meant that gender sorting varied based on student gender.

The success rate score for the MR assessments was represented with *four* variables (i.e., all, feminine, masculine, and neither feminine nor masculine items). We compared *different* success rates to test whether MR varied in relation to students' gender and students' perceived gender of objects. Specifically, we calculated Cohen's d and Hedges's g estimates to test the null hypothesis that the mean success rate score of male students

was equal to the mean success rate score of female students. If we reject the null hypothesis, Cohen's *d* and Hedges's *g* estimates show the difference of means in terms of the pooled standard deviation of both gender groups. The expected effect size is between 0.40 and 0.75 (see Uttal et al., 2009 for a review).

Results

Taking all three conditions together, students performed a total of $n=85-87$ sortings per object on a scale from 1 (very masculine) to 5 (very feminine). Students sorted 16 objects as more feminine, 4 objects as neither feminine nor masculine, and 12 objects as more masculine. Overall, a two-sample *t*-test showed that none of the everyday objects was sorted differently in relation to the students' gender identity (i.e., $p\text{-value} > 0.00156$).



Note: the error bars represent the standard errors of each mean success rate score.

Figure 2. Mental rotation scores related to gender identity of respondents and perceived gender of assessment items.

Across all items, female students' MRT scores were lower than those of their male peers (see Figure 2). Where male students rotated on average 61.28% of items correctly, female students rotated 52.36% of items correctly. However, the difference between the average male and average female student scores was not statistically significant ($p\text{-value} 0.12$). Across all items, female students performed best on items with feminine objects. By contrast, male students performed best on items with masculine objects and worst on feminine objects. Nevertheless, the average score of female and male students for feminine objects was not statistically different ($p\text{-value} 0.88$). On feminine items, female students performed only slightly above their male peers on average. When objects are considered feminine, gender differences in MR scores disappear.

Most interestingly, female students' MR scores were significantly negatively affected when objects were neither feminine nor masculine ($p\text{-value} 0.038$). On average, on neither feminine nor masculine items, male students scored 61.62% correctly and female students only 44.44%. Male students outperformed female students between 65% and 67% of a pooled standard deviation for the mean success rate score of neither feminine nor masculine items (Table 1, column 4). While the absence of a control group may overestimate the effect size, this large effect is within the range that other studies with similar designs found (Uttal et al., 2013).

Overall, the effect size analysis presented that for objects that were sorted as neither feminine nor masculine, the overall gender difference in MR scores was consistent with the results typically found in MR assessments (Voyer et al., 2006). These results suggest that objects that seem gender neutral favor male students in MR assessment, reproducing gender differences.

Table 1: The effect size of MR scores comparing male and female students.

	All items	Feminine items	Masculine items	Neither feminine nor masculine items
Cohen's <i>d</i>	0.49	-0.05	0.57 ⁺	0.67 [*]
Hedges's <i>g</i>	0.48	-0.05	0.56 ⁺	0.65 [*]

Note: Bootstrap standard errors with 1000 repetitions: + $p < 0.10$, * $p < 0.05$, ** $p < 0.01$, *** $p < 0.001$

Discussion and implications

When asking students to sort everyday objects across students' perceived societal gender stereotypes, female and male students sorted the objects predominantly similarly across all object conditions. Regardless of gender

identity, students categorized the gender of everyday objects consistently. The results suggest that students' gender identity did not largely affect students' perception of the genderedness of objects. These results further suggest that gender associations may be inherent to educational assessments and could risk introducing a bias.

The findings demonstrate that objects that students consider as neither masculine nor feminine can explain differences in MR scores related to student gender. Gender perception of objects seems to matter for how well a rotation task is performed. The results contribute to a possible explanation that gender differences are related to power and positionality of gendered objects rather than cognitive makeup. For example, where male students may consider masculine objects for them and, therefore, possible to rotate, female students may disassociate with these objects. The differences in students' scores are important because assessment designs may be based on false assumptions that gender neutral items eliminate gender-related assessment bias.

We see potential for considering everyday objects for the design of MR assessments. Especially feminine items seem promising for reducing possible gender differences in MR. This study considered gender on a binary scale, which reduces the wide spectrum of possible gender identities and gender perceptions. Thus, we consider it as important that future studies are conducted with a larger sample size of gender non-binary students and to consider ways to break out of gender binaries in the gender sorting and assessment results.

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