International Journal of Gender, Science and Technology
http://genderandset.open.ac.uk

Selected papers presented at the 7th Network Gender & STEM Conference, 18-20 July 2024 in Heidelberg, Germany

In association with

NETWORK GENDER & STEM educational and occupational pathways and participation

Performance and Emotion in the STEM Field – Relationship Between Spatial Anxiety and Mental Rotation with Polyhedral Stimuli

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ABSTRACT

Mental rotation is a critical spatial skill often linked to gender differences favouring men, contributing to the gender gap in STEM fields. Traditional cube figures in mental-rotation tests have been criticized for gender bias due to their association with male experiences, like construction toys. This study investigates whether gender-neutral polyhedral figures can reduce performance differences and their association with spatial task anxiety. We assessed 106 German participants (34 men, 72 women) on a mental-rotation task using unfamiliar polyhedral stimuli and also measured their spatial anxiety and perceived certainty and task difficulty. Results showed no gender differences in mental-rotation performance, neither in accuracy nor reaction time. However, men reported greater certainty in their responses and perceived the test as easier. Women reported higher anxiety only in spatial-orientation and visualization tasks, with no gender differences in overall spatial anxiety or anxiety related to mental rotation. Unlike prior findings with cube figures, mental-rotation performance was unrelated to overall spatial anxiety or mental-rotation anxiety. These findings suggest that gender-neutral stimuli, unlike stereotypically male ones, do not inherently advantage men. They highlight the importance of using unbiased stimuli to assess cognitive performance in STEM without reinforcing gender stereotypes.

KEYWORDS: gender differences, spatial anxiety, mental rotation, gender-neutral stimuli

Performance and Emotion in the STEM Field – Relationship Between Spatial Anxiety and Mental Rotation with Polyhedral Stimuli

INTRODUCTION AND THEORETICAL BACKGROUND

Women continue to be underrepresented in STEM fields and this remains particularly pronounced in the so-called GEMP fields, i.e. Geosciences, Engineering, Mathematics/ Computer Science/ Economics, and Physical Science (Ceci, 2018). This disparity has a critical impact on women's participation in today's key areas of the green, energy and digital transitions— where gender gaps in land ownership, employment, leadership, pay and digital inclusion persist and risk deepening existing inequalities (OECD, 2024).

It is widely acknowledged that gender differences in participation in STEM can be attributed to multiple factors. One important factor is gender stereotypes that shape girls' interest and confidence from an early age, often resulting in the underestimation of their abilities and less support in STEM domains (Makarova et al., 2019; Wang & Degol, 2017). In addition, structural barriers in academic and professional environments of GEMP disciplines, such as long working hours and a competitive culture, may discourage women from pursuing or remaining in these fields (Wang & Degol, 2017). These barriers can be particularly challenging when combined with societal expectations regarding the compatibility of family and career, which may complicate many women's return to work after maternity leave (Ceci & Williams, 2011; Wang & Degol, 2017).

In addition to these factors, cognitive ability is also discussed as a factor in the gender gap (Newcombe, 2017; Quaiser-Pohl & Lehmann, 2002; Reilly et al., 2017; Wang & Degol, 2017). Although empirical studies show no fundamental biological differences in general intelligence between men and women, gender differences appear in certain cognitive sub-areas (Halpern, 2000). In the context of STEM, one cognitive ability that deserves special attention is spatial reasoning. Spatial reasoning refers to the cognitive abilities involved in representation, manipulation and transformation of spatial information (Wai et al., 2009). The subcomponent of mental rotation, which is defined as the ability to mentally rotate three-dimensional objects (Linn & Petersen, 1985), is of particular interest as men tend to outperform women in standardised mental rotation tests. Such findings are relatively inconsistent in childhood, but very robust in adulthood (Lauer et al., 2019; Voyer et al., 1995). These age-related effects emphasise that, even in the absence of general cognitive differences, interactions among socialisation processes, task characteristics and test materials can create performance gaps. This is particularly relevant in STEM disciplines, where spatial skills are essential for success. For example, mental-rotation skills support visualizing technical drawings and three-dimensional structures, manipulating spatial representations in engineering and architecture, and reasoning about molecular or geometric forms; as a result, they are considered a key factor in the success in many STEM disciplines (Castro-Alonso & Uttal, 2019). Furthermore, mental-rotation ability is not only considered a central competence for the natural sciences (Castro-Alonso & Uttal, 2019) but also plays an important role when starting a career, as it is tested in many standardised recruitment tests (Shea et al., 2001; Wai et al., 2009). In their overview, Castro-Alonso and Atit (2019) provide evidence for the use of the common Mental Rotation Test, which was originally developed by Vandenberg and Kuse (1978) and subsequently redrawn by Peters et al. (1995) in various STEM disciplines.

In addition, it is not only actual performance that influences success in STEM, but also the perception and internalisation of societal ideas about gender differences in spatial-performance areas and associated stereotypes (Halpern et al., 2011; Wang & Degol, 2017). According to a global cognitive approach of gender development, these gender stereotypes and an associated low ability self-concept in spatial reasoning can contribute to women underestimating their own abilities in STEM areas, which in turn affects their choice of studies and careers, as well as their role model function for subsequent generations (Hofer et al., 2025; Neuburger et al., 2013; Reilly & Neumann, 2013; Wang & Degol, 2017). The implicit assumption by many women that spatial tasks are a male domain can lead to a fear of such tasks, as well as to so-called stereotype threat effects. These effects can result in poorer performance due to reduced working memory capacity and avoidance behaviour (Ramirez et al., 2012; Schmader & Johns, 2003). The way the test stimuli are designed is one factor that might lead to these stereotype-based effects. Research findings show that the shape of the stimuli used in the Mental Rotations Test contributes to them being perceived as masculine (e.g. Bartlett & Camba, 2023; Ruthsatz et al., 2019).

This study makes a valuable contribution to the current research landscape by investigating the relationship between gender, spatial anxiety and mental-rotation performance using gender-neutral polyhedral stimuli. For our study, the stereotyped nature of the stimulus material in mental-rotation tasks and the fear of spatial tasks play a particularly important role and are described in more detail below.

Influence of Stimulus Material on Gender Differences in Mental-Rotation Performance

Domain-specific gender differences in cognitive abilities are widely attributed to a psycho-bio-social framework that considers the interplay of multiple factors, including early gendered experiences, as they shape both ability development and gendered self-concepts (Bussey & Bandura, 1999; Halpern, 2000; Hausmann et al., 2009). One such factor is gender stereotypes. Gender stereotypes are socially shared beliefs about the character traits and attributes typically associated with a gender category (Weinraub et al., 1984). They act as cognitive schemas for processing information and can influence self-perception and mental-rotation performance in both the short and long term.

Within this psycho-bio-social causal structure, gendered childhood experiences and gender-stereotypical attitudes towards spatial tasks are of central importance, as they result not only in a performance gap and divergent ability self-beliefs (Bussey & Bandura, 1999), but also in neuronal structural differences and in different solution strategies (Newman, 2016). It is widely accepted in research that typically male toys and activities (e.g. construction toys, video games, technical experiments) promote mental-rotation skills more than typically female toys which promote comparatively more linguistic and social skills (Dinella & Weisgram, 2018; Liben et al., 2018). For example, frequency of play with construction toys correlates positively with mental-rotation performance (Brosnan, 1998; Jirout & Newcombe, 2015). Research also suggests that boys play with LEGO® more often and in a qualitatively different way than girls and therefore may better train their skills in handling constructed block figures (Liben et al., 2018). Studies have further shown that gender-congruent stimuli, modelled on objects from children's everyday world, are also associated with greater familiarity thus more efficient processing (Jansen et al., 2014; Ruthsatz et al., 2019).

Childhood experiences can be seen as a relevant factor, as they shape spatial strategies and gendered beliefs that persist into later life. However, recent studies increasingly suggest that typically male experiences do not confer an advantage for overall mental-rotation performance, but only for performance on specific tests that use items similar to construction toys, such as LEGO© (Bartlett & Camba, 2023; Ruthsatz et al., 2014). This research is important to consider when evaluating approaches to studying mental rotation. The classic study paradigm of mental-rotation ability is based on research by Shepard and Metzler (1971), in which the reaction time of test subjects when comparing a cube figure with a rotated version of the same cube figure or a distractor increases linearly with increasing angular difference. Based on this research, Vandenberg and Kuse's (1978) Mental Rotation Test, in which two identical and two mirrored or structurally different cube figures are compared with a target figure, is one of the most widely used tests today. In current research discourse, these classic Mental Rotation Test is criticised for potential gender bias and called for revision (Bartlett & Camba, 2023; Neuburger et al., 2012; Ruthsatz et al., 2014). Namely, the stereotypical nature of the cube figures, which correspond to masculine attributions, has been repeatedly demonstrated in studies as an explanation for boys' advantage due to greater familiarity with the test material (e.g. Lennon-Maslin et al., 2023; Ruthsatz et al., 2014, 2015). Boys' greater familiarity with cube figures contributes to an overall performance advantage, likely reflecting more effective solution strategies than those typically used by girls (Jansen et al., 2014; Ruthsatz et al., 2019). This perceived male advantage may be reinforced by the perception that mental rotation is a male-dominated skill, activating stereotype lift effects for boys and inducing stereotype threat effects for girls (Neuburger et al., 2014).

There have already been a number of studies comparing performance on mental-rotation tests using male and female stereotyped concrete objects (e.g. cars vs. dolls) and showing a clear performance advantage for men and boys with male stereotyped objects and no, reduced or even reversed gender differences with female stereotyped objects (e.g. Jansen et al., 2014; Rahe et al., 2021; Ruthsatz et al., 2015, 2019). Research comparing stereotypically female pellet figures with cube figures yielded mixed findings: some studies show gender effects only for cube figures (Ruthsatz et al., 2014), while others found smaller but persisting gender differences for pellet figures, too (Rahe et al., 2021; Rahe & Quaiser-Pohl, 2019). There are different explanations for these distinct results.

There is some evidence that the pellet figures are more difficult to work with. Even though the pellet figures are similar in shape to the cube figures, there are no edges or corners, so there is no visual grid for orientation during mental rotation

(Rahe & Quaiser-Pohl, 2019). In earlier studies, a higher degree of difficulty is associated with a greater gender effect favouring men (Voyer & Doyle, 2010; Voyer & Hou, 2006). In addition, former results showed an age effect. While studies with younger children found gender differences only in the test with cube figures, but not with pellet figures (Ruthsatz et al., 2014), older samples also showed gender differences in the tests with pellet figures, suggesting that gender effects become more generalised or pronounced with age (Rahe et al., 2021). This developmental trajectory suggests that the shape of the stimuli has an influence on the gender effect, but that this influence is associated with a greater increase in performance in boys compared to girls (Neuburger et al., 2011; Rahe & Quaiser-Pohl, 2019).

Taking both explanations together, men's improvement in performance on mental rotation taks could also be due to an increased internalisation of gender stereotypes with increasing age and, thus, also to a stereotype-lift effect. This would be the case if the test itself, regardless of the type of stimuli, indicates that it is a male domain (Iriberri & Rey-Biel, 2017). Closely related to the effects of stereotype lift and stereotype threat is the possibility that a mental-rotation test can also induce anxiety about spatial tasks in women, and thus, impair performance through negative emotions and shifts of attention (Derakshan & Eysenck, 2009).

Spatial Anxiety

Spatial anxiety is the discomfort or emotional apprehension that individuals experience when performing spatial tasks (Lawton, 1994; Ramirez et al., 2012). It can be divided into fear of navigation tasks, mental rotation, and visualisation (Alvarez-Vargas et al., 2020; Lyons et al., 2018).

In addition to the effect of stereotypes, the abstractness of stimuli may contribute to increased anxiety in spatial tasks. The geometric shapes of the cube figures have a relationship to mathematical fields (Mix et al., 2016). Although spatial and mathematical anxiety are conceptually distinct constructs, empirical studies suggest they can be related, particularly in girls, potentially due to gender differences in self-concept and internalised beliefs about mathematical competence (Muzzatti & Agnoli, 2007; Rahe & Quaiser-Pohl, 2023). A recent study with children shows age and gender effects: preadolescents had a lower mathematical self-concept than younger children, and girls had a lower mathematical self-concept compared to boys (Lennon-Maslin & Quaiser-Pohl, 2024). In addition, lower mathematical self-concept was associated with reduced accuracy on mental-rotation tasks. Although this study focused on mathematical self-concept, these findings are relevant, as self-concept can affect both spatial anxiety and performance in mental-rotation tasks involving geometric shapes. Furthermore, Ramirez et al. (2012) used the abstract stimuli of the PMA-MR and showed that some children (ages 5.40 to 8.84), especially girls, have already developed a fear of spatial tasks. Thus, abstract stimuli may induce higher spatial anxiety in girls, which can negatively affect attentional control and performance in mental-rotation tasks. This can be explained within the framework of Eysenck et al.'s (2007) attentional control theory, according to which abstract stimuli are likely to be perceived as a signal of a difficult task and as threatening. According to Eysenck et al. (2007), the basic central executive functions of working memory shifting and inhibition are most strongly affected by anxiety related to the specific task. Attempting to suppress distressing thoughts makes goal-directed attentional control more difficult, which can lead to increased susceptibility to distraction and thus more careless errors and slower processing. Ramirez et al. (2012) has shown that higher spatial anxiety is associated with lower mental-rotation performance, especially in girls with high working memory. Spatial anxiety adds an additional cognitive load on their working memory, reducing their overall capacity. Therefore, according to Ramirez et al. (2012), girls may adopt less working memory-intensive, but also less efficient strategies to solve mental-rotation tasks.

In adults, women typically report higher levels of spatial anxiety, partly driven by the fear of underperforming compared to men (Alvarez-Vargas et al., 2020; Arrighi & Hausmann, 2022). This anxiety not only affects working memory but also undermines self-efficacy and confidence in one's spatial abilities, which can negatively affect mental-rotation performance (Arrighi & Hausmann, 2022).

Moreover, spatial anxiety is closely tied to self-evaluation processes that shape gender differences in performance on mental-rotation tasks (Estes & Felker, 2012). These processes include academic self-concept, self-efficacy beliefs, and internalised gender stereotypes (Guizzo et al., 2019; Lennon-Maslin et al., 2024; Miola et al., 2021; Quaiser-Pohl & Jordan, 2004). Research shows that men generally have a more positive view of their spatial abilities, while women tend to be less confident in mental-rotation tasks (Arrighi & Hausmann, 2022; Cooke-Simpson & Voyer, 2007; Hofer et al., 2025). The tendency to underestimate one's own abilities is more pronounced among women, even after controlling for individual differences in personality traits associated with underestimation (Hofer et al., 2025). Such lower self-evaluation may exacerbate the effects of stereotype threat by increasing spatial task-related anxiety and reducing self-confidence, which in turn may negatively affect performance on mental-rotation tasks. Furthermore, it can also encourage avoidance of spatial tasks, reduce engagement in STEM fields and reinforce stereotype threat effects (Hofer et al., 2025; Rahe & Quaiser-Pohl, 2023). Given that abstract stimuli, especially the commonly used cube figures may already induce stereotype lift effects in men and threatening women, the presence of spatial anxiety and negative self-evaluation may further exacerbate differences in mental-rotation performance. However, previous studies with adults have only examined the relationship between spatial anxiety and mental rotation with male stereotyped cube figures, and it is unclear to what extent stereotypical content in test stimuli may increase or decrease anxiety during task performance (Osborne, 2007).

Aims and Hypotheses

As traditional cube figures in mental-rotation tests have been criticised for gender bias, the development of gender-neutral abstract stimuli as equivalents to cube figures is still a challenging issue, and there has been little research on it to date. To address this issue, some studies used polyhedral figures composed of cuboctahedra (Lennon-Maslin et al., 2023, 2024; Ruthsatz et al., 2025). These figures retain the geometric complexity required for mental-rotation tasks while allowing for easy replication of cube figures and remain a relatively unfamiliar shape, which reduces implicit biases associated with prior experience. In previous studies polyhedral figures have been confirmed to be perceived as gender-neutral by the participants in contrast to cube figures, which were perceived as typically male (Lennon-Maslin et al., 2023, 2024; Ruthsatz et al., 2025). The results so far are not yet entirely clear. While Ruthsatz et al. (2025) found no gender differences in reaction time for adults in mental rotation tasks with gender neutral stimuli, they did observe differences in accuracy, with women generally performing less accurately than men.

The aim of our study was to further investigate previous findings with adults by examining the use of polyhedral figures, with a focus on how these stimuli might affect gender differences in mental-rotation performance and its relationship with spatial anxiety. By using gender-neutral stimuli, we attempt to reduce external influences on test performance in order to assess whether spatial anxiety remains a significant factor when gender associations caused by the stimulus material are minimised. Understanding the role of spatial anxiety in mental-rotation tasks may provide further insight into how to support individuals with high spatial anxiety and promote more equitable spatial skill development.

Previous findings suggesting that the typically masculine features of cube figures and male-stereotyped objects may lead to a stereotype-lift effect in men's mental-rotation performance. However, studies with different stimuli have shown mixed results. Building on this previous research, we aimed to investigate whether participants of all genders perform equally well when tested with gender-neutral polyhedral figures (Research Question 1).

We hypothesised in line with Alvarez-Vargas et al. (2020) that gender differences in spatial anxiety would persist, with women more likely to report higher levels of spatial anxiety than men (Hypothesis 1). However, we expect no significant relationship between mental-rotation performance and either overall spatial anxiety or mental-rotation anxiety (Hypothesis 2). The second hypothesis is based on the idea that the use of gender-neutral polyhedral figures may reduce stereotypical associations and associated anxiety. Specifically, as these gender-neutral stimuli do not elicit strong gender-related expectations, the usual gender-specific cognitive impact of spatial anxiety on working memory (and consequently on mental-rotation performance) is likely to be reduced. Therefore, we expect spatial anxiety to have a smaller impact on performance in this context.

Considering that both feelings of anxiety and greater familiarity with gender-congruent stimuli are associated with differences in self-concept of spatial ability we questioned if gender-neutral stimuli influence participants confidence (Research Question 2). As women generally show lower self-confidence in mental-rotation tasks (Hofer et al., 2025), we expected them to report lower certainty in their responses (Hypothesis 3a). However, based on the results of a previous study (Ruthsatz et al., forthcoming), we anticipated that participants would find the test material equally difficult regardless of gender (Hypothesis 3b).

METHODS

Participants

The study has a total sample size of *N* = 110, with a gender distribution of *n*= 35 men and *n*= 75 women. No participants identified as non-binary. The age of the subjects ranged from 16 to 69 years, with a mean of 29.25 years (*SD* = 11.87). Participants were recruited from a range of educational and occupational backgrounds in Germany to ensure a diverse sample. One hundred and eight participants reported their employment status, including 45 who reported having a job or training. Forty-seven university students took part in the study and 16 people classified themselves as having other activities.

Participants were recruited via social networks of university students, and all individuals who responded to the invitation were initially included to maximize inclusivity and sample size. Participants aged 60 and older were later excluded from the main analyses to avoid potential confounding effects due to age-related declines in mental-rotation performance (Rahe et al., 2018). Younger participants, including the 16-year-old, were retained to maintain a larger sample and because they fall within the age group in which robust gender differences in mental-rotation tasks are expected, as outlined in the theoretical background section. The mean age of the remaining 106 participants (34 men, 72 women) was 16-57 years (M = 27.91, SD = 9.83). Due to missing data on the M-SAS, two male participants were excluded from the spatial-anxiety analyses, resulting in a final sample of n = 104 (32 men, 72 women) for these analyses.

Mental-Rotation Test

A 26-item mental-rotation test with polyhedral figures based on the shape of the cube figures designed by Vandenberg and Kuse (1978) was administered. The test and stimulus design are described in detail in (Ruthsatz et al., forthcoming). On each trial, participants had to decide whether a given pair of comparison items was rotated or mirrored (see Figure 1) as quickly and accurately as possible. Performance was measured in terms of accuracy and reaction time.

Figure 1. *An Example Item of the Mental-Rotation Test with Gender-Neutral Cuboctahedral Polyhedrons.*

Self-Assessment

A self-report scale adopted from Rahe and Quaiser-Pohl (2019) was included to assess participants' subjective experience. Participants rated their perceived performance on a scale from 'uncertain' (=1) to 'very certain' (=6). They also rated the difficulty of the task on a scale from 'very difficult' (=1) to 'very easy' (=6). These measures were designed to explore the relationship between objective performance and self-perceived ability.

Modified Spatial Anxiety Scale (M-SAS)

Spatial anxiety was measured using the Modified Spatial Anxiety Scale (M-SAS) by Alvarez-Vargas et al. (2020), which is a revised and expanded version of the Spatial Anxiety Scale by Lawton (1994). It consists of three subscales with 18 items: eight items measuring navigation anxiety (e.g., “trying a new route that you think will be a shortcut, without the benefit of the map"), seven items measuring mental-rotation anxiety (e.g., "building a Lego Architecture® Empire State building using the instructions") and three items measuring visualisation anxiety (e.g., "moving all of your furniture from a larger space into a smaller space"). Participants were asked to rate how much being in the 18 described situations bothered them on a 4-point scale, where 1 = not at all, 2 = mildly, 3 = moderately, and 4 = severely. We computed an overall M-SAS score by summing responses across all 18 items (range: 18–72), with higher scores indicating greater spatial anxiety. In addition, we calculated three subscale scores: navigation anxiety (8–32), mental-rotation anxiety (7–28), and visualization anxiety (3–12).

The M-SAS was translated into German using a rigorous procedure described by Harkness (2003). To ensure linguistic and cultural appropriateness, two independent translations of the scale and a facilitated discussion to compare the translations and refine discrepancies were conducted. The entire translation process was documented to ensure transparency and replicability. By using this rigorous translation method, we aimed to ensure that the German version of the M-SAS accurately captured the constructs of spatial anxiety while maintaining comparability with the original scale. The reliability and validity of the M-SAS were examined in detail by Alvarez-Vargas et al. (2020). However, since the test was translated in the current study, reliability was checked again. A good Cronbach's alpha = .837 was revealed. Thus, there is evidence that this is a standardized and reliable test instrument to analyse spatial anxiety in a German sample.

Procedure

The data collection for this study was conducted via an online platform, SoSci Survey, which facilitates the creation of web-based questionnaires. The procedure began with a brief introduction in which participants were informed that the study focused on the assessment of mental-rotation skills. For optimal readability, it was emphasised that participants should ideally complete the survey on a device with a larger screen and, if using a smartphone, it should be positioned in landscape mode. Participants were also reminded that their participation was voluntary and that they could withdraw at any time.

After agreeing to the informed consent form and privacy policy, participants were introduced to the mental-rotation task. To ensure understanding, they first completed six practice trials, followed by immediate feedback on their performance. Once they were familiar with the task format, they were instructed to complete the subsequent 26 test items as quickly and accurately as possible, without receiving any feedback during the test phase. After completing the task, participants completed a self-report questionnaire that included questions about their age, employment status and gender identity (male, female, non-binary). The study concluded with the administration of the M-SAS to assess spatial anxiety, and participants were asked to indicate the type of device they had used to complete the study (smartphone, tablet, laptop or desktop computer).

RESULTS

The data analyses were conducted using SPSS® 29 software. First, the dataset was checked for outliers, but no outliers were found for either accuracy or response time. The next step was to examine whether the type of technical device used (laptop, tablet, smartphone, computer) influenced the participants' performance in the test. Two independent ANOVAs for accuracy and reaction time showed no significant differences between participants using different devices (all $p > .1$). Therefore, the type of device used was not considered in the subsequent analysis. All descriptive results are presented in Table 1.

Mental-Rotation Performance

There were no significant gender differences in mental-rotation performance. Specifically, no differences were found for accuracy, $t(104) = -0.117$, $p = .907$, or reaction time, $t(104) = 0.028$, $p = .978$, as shown in Figure 2 and Figure 3.

Figure 2. *Accuracy in the Mental-Rotation Test (Error Bars: ± 2 SE).*

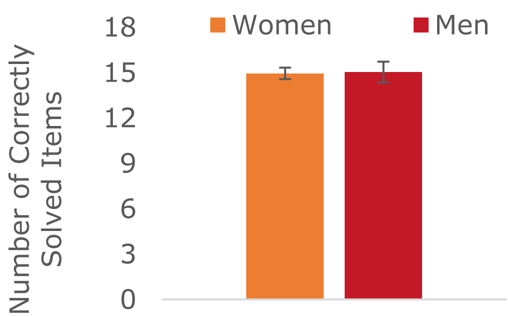

Figure 3. *Reaction Time in the Mental-Rotation Test (Error Bars: ± 2 SE).*

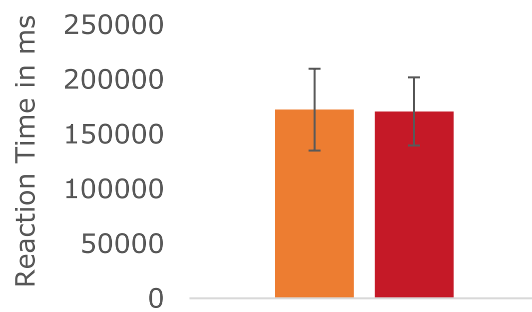

Table 1. *Descriptive Results.*

	N	*M*	*SD*
Accuracy			
Men	34	15.03	4.03
Women	72	14.94	3.22
Reaction Time			
Men	34	170709.94	181472.00
Women	72	172337.59	314991.32[1]
Certainty			
Men	34	3.15	1.234
Women	72	2.53	1.233
Difficulty			
Men	34	2.79	1.12
Women	72	2.26	1.05
Overall Anxiety			
Men	32	39.88	8.08
Women	72	39.82	8.84
Mental-Rotation Anxiety			
Men	32	15.53	4.72
Women	72	14.42	4.64
Navigation Anxiety			
Men	32	17.59	4.37
Women	72	19.50	4.94
Visualisation Anxiety			
Men	32	6.94	2.56
Women	72	5.90	2.26

[1] One participant had an unusually long reaction time to one item, probably because of a brief interruption. All of this participant's other responses were within the normal range. Sensitivity analyses excluding this response did not alter the results, so it was retained.

Spatial Anxiety

Hypothesis 1 regarding spatial anxiety was partially confirmed by an independent samples *t*-test: women reported significantly higher levels of anxiety than men on navigation tasks, $t(102) = 1.929$, $p = .028$, $d = 0.401$, and visualisation tasks, $t(102) = -2.271$, $p = .013$, $d = -0.473$. However, no significant gender differences were found in overall spatial anxiety or anxiety related to mental-rotation tasks, all $p > .05$. Confirming Hypothesis 2, mental-rotation performance was not related to either overall spatial anxiety or mental-rotation anxiety, all $p > .05$.

Self-Assessment

The third hypothesis was partially supported by an independent samples *t*-test: As expected in Hypothesis 3a, men reported greater certainty in their answers than women, $t(104) = -2.413$, $p = .009$, $d = -0.502$. Contrary to our expectation regarding Hypothesis 3b, men also found the test easier than women, $t(104) = -2.377$, $p = .019$, $d = -0.495$.

DISCUSSION

Our study aimed to clarify the effects of gender-neutral test materials on mental-rotation performance and to examine the role of spatial anxiety in relation to these stimuli. The results provide important indications for a fairer assessment of spatial skills in STEM-related contexts.

Disappearance of Gender Differences in Mental-Rotation Performance

We found no gender differences in mental-rotation performance, neither in accuracy nor in reaction time. This finding with gender-neutral test material stands in contrast to a robust body of literature reporting male superiority in mental-rotation tasks, particularly those using cube figures or objects stereotypically associated with male domains (Voyer et al., 1995). The absence of gender differences in our study supports the growing argument that at least part of the previously observed performance gap may be attributable to the nature of the test stimuli rather than inherent ability differences (Bartlett & Camba, 2023). The performance advantage of men, as has often been demonstrated with gender congruent stimuli, could not be shown with the unfamiliar polyhedra used in this study.

This is highly relevant for STEM fields, where mental-rotation skills are often seen as an indicator of future success (Castro-Alonso & Uttal, 2019). Test materials with cube figures are not gender-neutral and may inadvertently favour individuals with prior experience or familiarity with these stereotyped materials (i.e., men). As a result, these tests can reinforce gender disparities in self-selection, perceived competence, and performance expectations in STEM domains. Our results highlight the role of test stimuli and suggest that gender-neutral alternatives, such as polyhedral figures, can help reduce these biases.

However, the assumption that gender-neutral alternatives, such as polyhedral figures, can effectively reduce gender biases in performance should be investigated further.. For example, the lack of time limit may also be a contributing factor as to why the test showed no gender differences. A time limit has been shown to affect performance and gender differences in mental rotation, as women in particular seem to be disadvantaged by speed tests and are less confident in their approach (Goldstein et al., 1990; Voyer, 2011). Additionally, the relatively high difficulty of the polyhedral stimuli should be considered, as it may have influenced performance differently to what was anticipated. While they are similar in complexity to cube figures, they do not have exactly the same visual characteristics, which could affect task processing in a similar way as to what was already found with pellet figures (Rahe & Quaiser-Pohl, 2019).

Differences in Spatial Anxiety, Confidence and Task Difficulty

With regards to spatial anxiety, the results provide a nuanced picture: contrary to Hypothesis 1 and previous findings with the original version of the M-SAS (Alvarez-Vargas et al., 2020), we found no significant gender differences in either overall spatial anxiety or mental-rotation anxiety. Women only reported higher levels of anxiety in spatial orientation and visualisation. This finding adds complexity to the assumption of a global gender difference in spatial anxiety. It may indicate that women internalise anxiety more strongly in subdomains traditionally coded as masculine or related to navigation and manipulation in space, while not necessarily feeling anxious about mental rotation per se.

In line with Hypothesis 2, we found no correlations between spatial anxiety and mental-rotation performance. According to Arrighi and Hausmann (2022) spatial anxiety may not have occurred in the test situation because the mental-rotation task had no time constraint. However, this is contradicted by the fact that Alvarez-Vargas et al. (2020) found a relationship between spatial anxiety and mental-rotation performance in a test with cube figures that also had no time limit. Thus, the nature of stimulus material might explain the results. The use of gender-neutral polyhedral figures may have led to less activation of gender-role expectations, thereby reducing stereotype-related anxiety, particularly for women. The unfamiliar polyhedron might have attracted the subjects' attention due to its neutrality. This would compensate for an avoidance motivation (Lourenco & Liu, 2023). This finding supports the growing view that spatial anxiety is situationally influenced and that task design and stimulus framing play a key role in its activation. From a STEM education perspective, this highlights the importance of designing learning and testing environments that minimise anxiety-inducing cues and promote confidence across genders.

Interestingly, while there were no gender differences in mental-rotation performance, men rated the task as easier and reported significantly higher certainty in their answers compared to women, despite comparable accuracy. This pattern indicates that women tended to underestimate their own performance. This finding supports Hypothesis 3a and aligns with existing research that has consistently shown that women tend to underestimate their performance in STEM-related tasks despite performing equally well (Hofer et al., 2025). Such self-perception biases can have a long-term impact on self-efficacy, motivation, and academic self-concept (Cooke-Simpson & Voyer, 2007; Estes & Felker, 2012). In the context of STEM subjects, this means that even when performance gaps are absent, gendered differences in how competence is perceived may still influence participation and career trajectories.

Furthermore, it suggests that abstract geometric features may induce greater uncertainty in women, but this is not due to overall spatial anxiety and does not directly translate into poorer mental-rotation performance. This could reflect the internalisation of gender role expectations: women may feel less confident in mathematical tasks because these domains are still associated with male competence in societal discourse. However, when the task is framed in a gender-neutral way– without stereotypically masculine cues– these anxieties may not impair performance to the same extent.

Hypothesis 3b was not supported as women perceived the task as more difficult than men did. As no gender differences were found in spatial anxiety, this difference in perceived task difficulty is unlikely to be a result of increased anxiety. Instead, it may be related to women's generally lower confidence in their abilities, as reflected in the self-assessment results, or to the stimuli's abstract geometric nature, which may have seemed complex and unfamiliar. This persistent discrepancy between self-confidence and performance highlights the presence of internalised gender-specific self-concepts that operate independently of actual abilities or task-related anxiety. These findings align with theoretical frameworks emphasising the role of self-beliefs in relation to specific task abilities (Bussey & Bandura, 1999; Hofer et al., 2025). Even when performance is objectively equal, subjective perceptions of competence may be influenced by long-standing societal expectations and gender-specific beliefs about cognitive abilities, potentially affecting motivation, engagement and persistence in STEM fields. This finding underlines the importance of considering not only the gender fairness of stimulus material, but also addressing gendered expectations and confidence levels in educational settings. Otherwise, gender disparities in STEM subjects may persist due to internalised doubts and lower self-efficacy.

Limitations and Future Research

Determining whether mental-rotation tests can induce anxiety about spatial tasks independently of gender stereotypes remains challenging. Even if the stimuli are perceived as gender-neutral, the task of mentally rotating them may still trigger stereotype-threat or -lift effects if the task itself is perceived as typically masculine. Although no gender differences in test performance were found, the overall very low accuracy scores suggest that the polyhedral figures used in this study may have been more challenging than the traditional cube figures commonly used in mental-rotation tasks. This raises the possibility that the increased task difficulty may have affected the performance of participants of all genders, potentially masking more subtle effects. In addition, this high task difficulty may also have contributed to the absence of a significant relationship between spatial anxiety and mental-rotation performance, as generally demanding tasks can reduce variance and obscure subtle individual differences. To more accurately assess the respective effects of gender-neutral polyhedral figures and stereotypically masculine cube figures on performance and the presence or absence of gender differences, future research should directly compare them within the same experimental design with and without time constraints. Conducting the experiment in a controlled laboratory environment would be ideal to better account for psychological or situational factors that may have influenced participants' subjective difficulty ratings despite identical task conditions. Additionally, the sample included a higher proportion of women than men, which could restrict the applicability of the findings relating to spatial anxiety to populations with a more balanced gender distribution.

CONCLUSION

Our findings provide meaningful insights into how the design of cognitive test materials can influence both performance outcomes and participants' self-perceptions. We found that gender differences in mental-rotation performance disappeared when gender-neutral polyhedral figures were used. This contrasts findings of previous studies using cube figures that show men often outperform women. The findings of our study suggest that such differences may not reflect inherent ability, but rather may be driven by gender-specific associations of the stimulus materials. Furthermore, no significant relationship was observed between spatial anxiety and mental-rotation performance, and no gender differences in mental-rotation anxiety were found. While the use of gender-neutral stimuli may have contributed to this outcome, the alternative explanations considered in the section on limitations cannot be ruled out.

In conclusion, our study raises critical questions about the fairness of mental-rotation tests with cube figures, given that our results with gender-neutral polyhedral stimuli yielded contrasting findings, despite their structural similarity. If cube figures systematically favour men, then reliance on these tasks to interpret gender differences in STEM should be reconsidered. Overall, our findings emphasise the importance of reducing implicit bias in cognitive assessments to promote equity.

ENDNOTES

Acknowledgements: We would like to thank Dilan Yaman for her valuable support in data collection. Tools such as DeepL and ChatGPT were used to refine the language and grammar of the article. The content and interpretations presented are entirely the author’s own.

Funding Statement: This study did not receive any funding.

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