State anxiety influences sex differences in spatial learning

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Abstract. Past research shows consistent sex differences in survey-based spatial knowledge and wayfinding strategy. State anxiety may help to explain some of these differences. The current study tested if and how state anxiety influences sex differences in spatial learning during navigation. We used a virtual desktop spatial learning task and manipulated state anxiety between-subjects. Participants passively learned the locations of landmarks and then were tested using egocentric pointing and map landmark placement tasks. Results showed that males performed better than females overall, replicating past work. Further, state anxiety adversely affected pointing accuracy for females but not males. Males were more accurate in their cognitive maps and women's cognitive maps appeared to be more spatially compressed than men's across both anxiety conditions. Results are discussed in the context of how state anxiety might influence sex differences in the formation of survey representations dependent on spatial learning and assessment perspective.

Keywords: spatial memory, wayfinding, sex differences, anxiety

1 Introduction

Across numerous paradigms, individual differences are observed in spatial navigation tasks, often showing a male performance advantage in real and virtual environments [1, 2, 3]. While differences in abilities, strategies, and cue-use have been proposed to account for sex differences, our current study examined whether state anxiety affects sex differences in navigation. State anxiety can be defined as a subjective feeling of distress, often accompanied by physiological changes such as increased heart rate and/or skin conductance. Anxiety may be experienced during navigation in many circumstances, such as when one is late to a doctor's appointment, or lost in a new place. We expected state anxiety to affect sex differences in spatial learning given potential differences in neurobiological and behavioral stress responses in the context of spatial learning. For example, cortisol level at time of encoding positively predicts spatial memory in men, but predicts either no relationship or a negative relationship to memory in women [4]. Related research has found that spatial learning under stress impairs cognitive map formation in females, but not males [5, 6]. In contrast, similar research has found that stress did not affect male or female spatial learning performance as measured by an egocentric pointing task in a virtual environment [7]. Thus, although work exists testing an effect of state anxiety on sex differences in spatial learning, the direction and magnitude of the effect remains open to further investigation.

In the current study, we tested effects of state anxiety on a passive spatial learning task in a naturalistic, large-scale, outdoor virtual environment. We were particularly interested in the formation of survey knowledge—observer independent representations of the environment—because of its importance for efficient and flexible navigation and because it often shows sex differences [8]. Survey-based spatial knowledge supports flexible and global environmental representations of the relative spatial relationships, or configurations, between landmarks (as opposed to procedural, route-specific knowledge of landmark locations only). Men, more than women, tend to use distal (far-space) landmarks and a fixed allocentric coordinate system in learning of novel spaces that allows for efficient navigational shortcuts above and beyond previously traversed space, an indication of better survey spatial knowledge acquisition. Conversely, women often learn spaces in relation to proximal (near-space) landmarks and previously traversed routes [1, 9, 10, 11]. Self-reported spatial strategy and cue-use measures align with measures of wayfinding efficiency; orientation strategies and the use of distal-cues are more often reported by men, who navigate more effectively than women on average [12, 13, 14, 15, 16, 17]. Based on attentional control theory [18], if anxiety typically affects global processing and results in attentional narrowing, then we would expect greatest effects of anxiety on survey spatial representations—spatial memory that relies on a global understanding of the environment—and on females, who may not have a tendency to use strategies or cues that support these types of representations.

Our approach contributes to existing work on the effect of acute anxiety on sex differences in spatial learning in three primary ways. First, many navigation studies have used geometrically rigid mazes/environments, which may favor preferred male strategies and cue selection. The larger scale, more naturalistic environment utilized in the current study increases the potential generalizability and external validity of findings. Second, the current study used measures of spatial learning from both egocentric (pointing) and allocentric (cognitive map) perspectives. Inclusion of both types of measures is important, given prior work indicates individual differences in spatial memory formation and retention dependent on frame of reference [19]. Previous work has shown that consistency between perspectives used in learning and testing matters, finding advantages when study and test match (e.g., egocentric learning of routes and egocentric test such as direct navigation to targets) and costs when they do not [20, 21]. Currently, there is no consensus as to whether anxiety affects the use of different perspectives in spatial memory retrieval.

Last, our study implemented a purely physiological (respiratory) manipulation of state anxiety. This manipulation was chosen to activate the sympathetic nervous system without introducing a confound of social stress or navigation-specific stress, and to test the hypothesis that male and female spatial memory would be differentially affected by high levels of stress. This high level of anxiety was targeted for manipulation due to work showing that anxiety at moderate levels of arousal sometimes increases performance [22], especially if reappraised as a positive emotion such as excitement or challenge [23, 24]. Overall, we aimed to test 1) whether anxiety would adversely affect women's spatial memory more than men's in a large-scale naturalistic virtual environment and 2) whether the effects of anxiety would generalize to two different spatial memory retrieval tasks. We predicted an overall performance advantage for men on both measures, replicating past work. Previous indications of adverse effects of anxiety on female's spatial performance, and the notion that anxiety decreases global processing, led us to predict that women's acquisition of survey knowledge would be further impaired relative to men with the addition of a state anxiety manipulation. Given that both pointing and cognitive map measures relied on the formation of survey knowledge, we also expected that the anxiety effects on women would generalize across both measures. However, given previously established effects on the greater costs on memory when tested from a different perspective than learning, it is also possible that we would find differential effects on anxiety as a function of testing method.

Method

1.1 Participants

107 University of Utah students aged 18 to 47, (M = 21 years) participated for course credit. All participants provided informed consent before participation. Sample size was determined a priori using a GPower 3.1.7 power analysis [25] with a conservative effect size based on past literature (power = .80, $\eta_p{}^2 = 0.10$).

Six participants were excluded from data analysis as outliers due to Cook's distance (a measure of statistical influence) exceeding three times the mean distance of the sample [26] for either cognitive map distance or the pointing outcome measures. Three additional participants were excluded due to procedural errors. 98 participants were included in the final data analyses (26 F and 26 M in the anxiety condition; 22 F and 24 M in the control condition).

1.2 Virtual Environment

The large-scale virtual spatial learning task and environment were implemented using Unity 5.0.1. The experiment was presented on a high resolution, 24-inch Dell LCD monitor, updating at a frame rate of 60 Hz. The display was located 1.07 m from the chair where participants sat. The virtual environment spanned 1500x1500 meters. There were six proximal landmarks present in the environment: a home, a truck, a well, a tent, a shed, and a column. Two separate spatial learning videos lasting 3 minutes 45 seconds each and containing 6 major (> 45 degree) turns were shown through this virtual environment [27, 28, 29]. Three landmarks were directly encountered on dirt roads followed through the environment in each of the spatial learning videos, though other landmarks were visible in the distance. There were also distal cues, such as the sun, a waterfall, a beach, and surrounding mountainous terrain (see Figure 1). Route learning order was counterbalanced.

Fig. 1. View of the virtual environment from above. The two spatial learning paths are depicted using solid and dashed lines (participants did not see this aerial view during learning). The map landmark placement test was shown from the same perspective, but did not include labeled landmarks or indication of the paths taken (solid and dashed lines).

1.3 Anxiety Manipulation

Participants in the anxiety condition performed restricted breathing through a small coffee-stirrer straw for two minutes prior to encoding. This method has been utilized in clinical studies to elicit the physiological aspects of a panic attack [30] and more recently used to test effects of anxiety on perceptual judgments [31][1]. Individuals in the control condition breathed through a large straw for the same amount of time. The subjective units of distress scale (SUDS), which provides a subjective measure of distress on a scale from 1 (very calm and relaxed) to 100 (very agitated and anxious) was recorded as a manipulation check [33].

[1] This method was utilized instead of the Trier Social Stressor Task since men and women differentially respond to the Trier stressor [32]. Additionally, the stress response from the Trier might have lasted until the experimental testing phase, and we were interested in testing the effect of anxiety on spatial encoding, not testing.

1.4 Covariates

Participants completed a Corsi block test of spatial working memory for use as a covariate using Psychology Experiment Building Language (PEBL) software [34]. This was chosen as a covariate because our question of interest was about sex differences in the effect of anxiety on acquisition of survey knowledge, and alternative theories have posited that spatial working memory may explain these differences [35]. There were no gender differences ($t(95) = 1.7$, $p = 0.09$) or anxiety manipulation group differences ($t(95) = -0.1$, $p = 0.93$) in spatial working memory as measured by the Corsi. In addition, self-reported video game use (hours per week) was measured for use as a covariate to control for familiarity with virtual environments and computer interfaces. There were gender differences in video games played per week ($t(54) = -3.5$, $p < .001$), but no anxiety manipulation group differences ($t(91) = 0.3$, $p = 0.77$) in video games played per week. Men reported an average of 4.8 hours played per week, while women reported an average of 0.7 hours played per week.

1.5 Procedure

After completion of informed consent, a baseline SUDS measure was obtained. Then, the first breathing task was completed with either a large or small straw, depending on anxiety condition. After the manipulation, a follow-up SUDS measure was taken. Then, the first route video through the environment was shown to participants from an egocentric perspective. Participants moved through the environment at 5 m/s. Following spatial learning, participants were asked to accurately point to the unseen locations of each major environmental landmark from their stopping point on the path. They moved a crosshair on the screen using an Xbox controller to indicate the direction of a particular landmark (see Figure 2). They pointed twice to each landmark in random order for a total of six trials.

Fig. 2. Pointing test location in the virtual environment. Spatial learning paths through the environment were also viewed from this perspective without the appearance of the instructions and crosshair.

The spatial learning and testing procedure was then repeated once: the breathing task was performed a second time, a second video was played of a different path through the same environment, and a second series of pointing tests was completed. After this test, participants were asked to mark locations of major landmarks on a top-down map of the environment (see Figure 1) as accurately as possible using the same controller. Finally, participants completed the Corsi task and were debriefed about the purpose of the experiment before leaving.

2 Results

2.1 Anxiety Manipulation Check

A 2 (sex) x 2 (anxiety condition) ANOVA was used to check the anxiety manipulation using the mean difference between SUDS ratings. Anxiety condition was significantly related to a change in SUDS from baseline, F(1, 94) = 45.0, $p < .001$, ${\eta_p}^2 = 0.32$. Individuals in the anxiety condition (*M* = 25, *SD* = 20.20) became significantly more anxious following the anxiety manipulation than individuals in the control condition (*M* = 1, *SD* = 13.74) (see Figure 3).

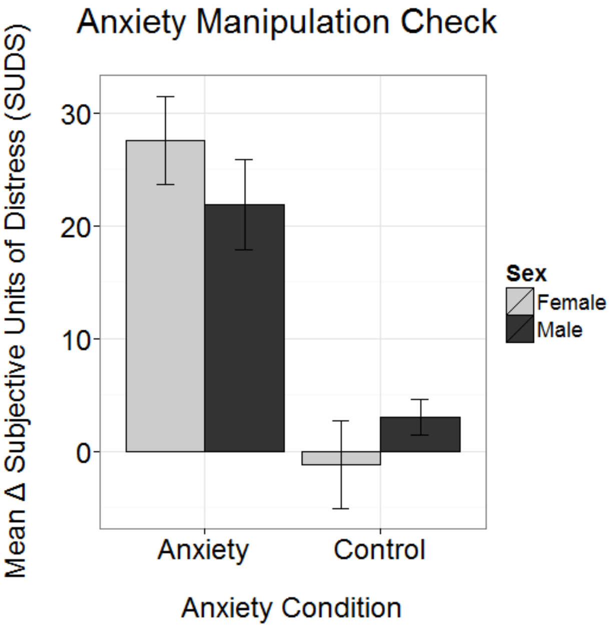

Fig. 3. Change in subjective units of distress ratings across anxiety conditions. Error bars indicate ± 1 SE. A positive value indicates that self-reported anxiety increased from baseline.

There were no differences in SUDS ratings between males and females (F(1, 94) = 0.1, $p = 0.77$, ${\eta_p}^2 = 0.001$) and no interaction between anxiety condition and sex (F(1, 94) = 1.9, $p = 0.16$, ${\eta_p}^2 = 0.02$).

Individuals were allowed to suspend the breathing task if uncomfortable, so a 2x2 ANOVA was used to determine if time (in seconds) spent breathing differed by sex. Overall, breathing was shorter in the anxiety condition (*M* = 55.7, *SD* = 33.8) than the control condition (*M* = 115.1, *SD* = 18.35), but male and female breathing time in the anxiety condition did not differ, F(1, 94) = 0.53, $p = 0.47$, ${\eta_p}^2 = 0.006$.

2.2 Survey Spatial Knowledge tested from an Egocentric Perspective (Pointing Task)

For the pointing task, the absolute value of the difference between participants' answers and the correct angle was calculated for each trial and averaged across trials to yield the overall error score [8, 36, 37]. Guessing with no knowledge of the environment would yield an average score of 90°. The pointing errors of six participants were above the 90° threshold (maximum = 109.0°). These were left in the analysis since it was expected that anxiety would greatly affect pointing judgments and these values did not exceed the previously mentioned Cook's distance outlier threshold (three times pointing mean). There was large variability in performance overall, for both females (*M* = 51.6°, *SD* = 27.6, range = 95.9, n = 48) and males (*M* = 32.3°, *SD* = 14.5, range = 72.7, n = 50).

A two-way ANCOVA was conducted to test whether sex, anxiety condition, and the interaction between sex and anxiety condition significantly predicted pointing error while controlling for video game experience (hours played per week; $F = 0.004$, $p = 0.95$) and visuo-spatial working memory (Corsi block span; $F = 0.23$, $p = 0.63$). Males performed better than females on pointing, $F(1, 92) = 20.0$, $p < .001$, $\eta_p^2 = 0.18$. Participants in the anxiety condition (*M* = 45.4°, *SD* = 27.2) did not perform differently than controls (*M* = 37.7°, *SD* = 18.91) on the pointing task, $F(1, 92) = 2.8$, $p = 0.09$, $\eta_p^2 = 0.03$. However, there was a significant interaction between sex and anxiety condition, $F(1, 92) = 5.9$, $p = 0.016$, $\eta_p^2 = 0.06$ (see Figure 4).

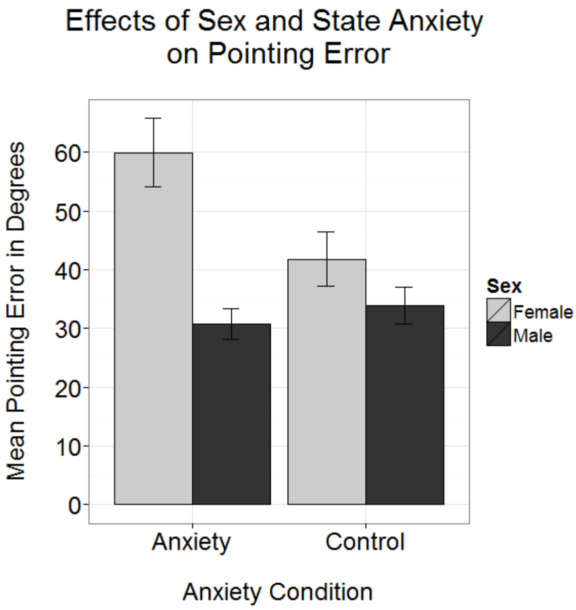

Fig. 4. Interaction between sex and anxiety condition predicting mean pointing error. Error bars indicate ± 1 SE.

Post-hoc t-tests (Bonferroni-adjusted alpha at .025) revealed that females in the anxiety condition made greater pointing errors than females in the control condition (Mean difference = 18.2°, *SE* = 6.2, *t* = 2.9, p = 0.02, 95% CI [6.0, 30.4]), while males in the anxiety condition did not perform differently from males in the control condition (Mean difference = -3.1°, *SE* = 6.1, *t* = 0.5, *p* = 0.96, 95% CI [-14.9, 8.8]).

2.3 Survey Spatial Knowledge tested from an Allocentric Perspective (Cognitive Map Formation)

A second measure of survey knowledge included assessing participants' cognitive maps after both paths were completed. Bidimensional regressions were conducted using the 'BiDimRegression' package for R software [38]. Bidimensional regression allows for comparison of two dimensional datasets and is a useful tool for assessing cognitive map accuracy [39]. Actual landmark locations (independent variable) predict remembered landmark locations (dependent variable). Bidimensional regression calculates a squared correlation coefficient (r^2) between remembered locations and actual locations, which describes the proportion of variance in the "real" map captured by individuals' cognitive maps.

Bidimensional regressions were conducted for each individual's cognitive map, and an ANCOVA mirroring the pointing analysis was conducted to determine if gender and anxiety predicted variance (r^2) captured by individuals' cognitive maps (akin to Weisberg et al., 2014). Similar to pointing, neither spatial working memory measured by Corsi block span (F = 0.01, p = 0.92) nor video game hours played per week (F = 0.32, p = 0.57) predicted mapping ability above and beyond gender and anxiety condition. Males (M = 0.90, SD = 0.13) performed better than females (M = 0.77, SD = 0.25) on cognitive map formation, F(1, 92) = 10.86, p = .001, $\eta_p{}^2$ = 0.18. Participants in the anxiety condition (M = 0.84, SD = 0.21) did not perform differently than controls (M = 0.83, SD = 0.20), F(1, 92) = 0.07, p = 0.79, $\eta_p{}^2$ = 0.03. Finally, there was no interaction between sex and anxiety condition, F(1, 92) = 1.67, p = 0.20, $\eta_p{}^2$ = 0.06. Overall, while the predicted gender difference was found, these results did not match the pattern of results from pointing accuracy analyses, as there was no interaction between anxiety condition and gender.

While the ANCOVA supported an overall advantage in accuracy for males compared to females, we were also interested in characterizing the patterns of these differences. To explore these differences, we ran bidimensional regressions on the data collapsed across individual participants for each sex x anxiety condition (4 groups). The resulting parameters are presented in Table 1 and further discussed in the next section.

Table 1. Bidimensional regression parameters. *indicates p < .05, ** indicates p < .001 for α1 and α2, and test whether these values are significantly different from zero. θ values greater than 0 indicate counterclockwise rotation relative to the real map; θ values less than 0 indicate clockwise rotation relative to the real map. Φ values greater than 1 indicate expansion of the cognitive map relative to the real map; values less than 1 indicate contraction.

	Female control	Male control	Female anxiety	Male anxiety
Parameters				
$\alpha_{1,}$ horizontal displacement	51.4	-20.8	108.9*	26.5
$\alpha_{2,}$ vertical displacement	267.3**	160.6**	325.3**	167.0**
θ, angle displacement	-7.6	-6.3	-7.2	-4.7
Φ, scaling	0.79	0.89	0.73	0.91
r^2	0.68	0.87	0.53	0.85

3 Discussion

The goal of the current study was to test whether state anxiety (induced during learning) would differentially affect male and female formation of survey spatial knowledge. To test this hypothesis, we utilized a passive, large-scale outdoor virtual environment spatial learning task with a straightforward, short-lasting physiological manipulation of stress that allowed for testing the influence of anxiety on spatial encoding, separate from social pressure and/or task demands. Our results support the hypothesis that anxiety influences sex differences in spatial learning, with the important caveat that perspective of assessment matters. Males performed better than females on two converging measures of spatial learning that draw on responses from either egocentric or allocentric perspectives [2, 8, 33]. Importantly, female performance was adversely affected (i.e., increased pointing error) with the induction of anxiety, whereas male performance was not. This result is consistent with previous work showing that women's spatial memory is impaired by state anxiety [4, 5, 6]. The inconsistent influence of anxiety across two survey spatial measures provides evidence for an effect of anxiety on spatial learning dependent on assessment method when learning the environment from an egocentric perspective.

Conflicting results between the pointing and cognitive map analyses raise interesting questions about how the formation of allocentric representations might differ depending on sex, state anxiety, and learning assessment methods. The finding that anxiety only adversely affected women's pointing is consistent with previous work finding differences as a function of match between learning and testing, as environments were learned from the same egocentric perspective as the pointing test. Given that women prefer egocentric, route-based strategies [12, 13, 14, 15], anxiety may have only adversely affected the testing method that aligned with this preference. However, it may also be that anxiety differentially affected women's pointing because the pointing response measure immediately followed the learning phase whereas the map test came at the end of the study when state anxiety level could have decreased. As it stands, we cannot determine whether the inconsistent effect of anxiety on women between the map measure and pointing measure were due to timing or due to perspective because these two factors were confounded in the current study, opening the door for future work that further explores these factors. Future work might implement environment learning from a map-like perspective, and/or where map assessments precede pointing assessments. Both are critical factors to consider given anxiety's effects on attention to global features and the changing nature of anxiety over time [18]. Most importantly, manipulating these factors would help to assess whether anxiety affects pointing because of its alignment with learning perspective, or whether the persistence of the stress manipulation differentially affected the first task (pointing) more than the second (map formation).

On the group level, the bidimensional regression scaling parameter (Φ) suggests that women may compress cognitive maps compared to men. Women's memory of metric spatial relations between landmarks were not as accurate as men's, even though men also showed a slight compression overall. What might explain why women demonstrated fairly large compression? Kosslyn has proposed a distinction between coordinate and categorical spatial knowledge [40] and recent work has tested for individual differences in these types of spatial encoding [41]. Our current result may reflect men's greater reliance on metric information compared to women's greater reliance on categorical information during spatial learning, consistent with results from Holden, Duff-Canning, and Hampson [42]. For example, in the current study, women placed landmarks more to the center of the map, around the visible locations of the dirt path. In addition, women in the anxiety condition were the only group who demonstrated a horizontal shift ($\alpha_{1,}$) of the cognitive map, compared to the physical layout of landmarks. Women in the anxiety condition tended to place landmarks generally closer to the water, biased to the side where most landmarks were located, which would also support an account of categorical encoding. It may be that categorical encoding is relied on as a more efficient cognitive strategy when working memory is consumed by task-irrelevant anxiety, but further testing is needed to address the role of cognitive mechanisms. In all, the bidimensional regression metrics supplementing r^2 provide additional information about the potential biases underlying individual differences in spatial learning and associated cognitive map formation.

3.1 Limitations

There are a few limitations related to the generalizability of the current study. First, the anxiety manipulation was not task specific. Breathing through a straw can be stressful, but does not necessarily have any functional relationship to spatial learning, navigation itself, or how anxiety might exert its influence outside of the laboratory, such as when someone feels lost while navigating. Future studies of the effects of anxiety on spatial learning could incorporate task-specific, threat-relevant stimuli, such as the presence of threat in the learned environment itself, or spatial-specific anxiety. For example, arousal alters estimates of vertical heights but not horizontal extents [43] and threatening stimuli, such as snakes, more easily draw attention than neutral stimuli [44]. An environment-specific threat may better elicit anxiety and test how anxiety affects spatial learning in a more ecologically valid way. Another possibility is that anxiety could affect spatial performance of men and women differently even when anxiety is not manipulated (via stereotype threat, for example) [45]. Future work that directly manipulates stereotype threat through planned instructions or scenarios could investigate this further in order to determine if type of anxiety matters.

Second, environments were learned passively rather than actively, but different mechanisms underlie passive and active navigation. For example, actively walking through an environment provides the proprioceptive and vestibular information necessary to form a metric survey representation of the traversed environment [46, c.f. 47]. Thus, the findings of the current study should only be generalized to passive spatial learning and not necessarily to the active spatial learning inherent to wayfinding. Future work would benefit from allowing individuals to actively learn the environment.

3.2 Future Directions & Open Questions

Despite these limitations, our findings provide initial evidence that state anxiety differentially affects male and female spatial learning and memory. Future research should test the underlying cognitive mechanisms of a sex-differentiated influence of anxiety on the formation and use of survey spatial representations. One potential mechanism may be that anxiety differentially affects attention in males and females, leading to individual differences in visual attention to environmental cues that could influence navigational strategies [15] or differences in the cognitive resources available for learning and memory [48, 49]. Future studies of the effect of anxiety on sex differences in spatial learning would benefit from eye tracking measures [50] to test whether anxiety differentially affects males and females' visual attention during spatial learning.

In addition, supplementary individual difference measures may help explain effects of anxiety on spatial learning. Recent work has shown that men high in trait anxiety and low in mental rotation ability navigate less effectively than other men [51]. Other trait variables, such as harm avoidance, can predict cautious exploration behavior, which leads to less accurate navigation [52]. More generally, individual differences exist in ability to integrate spatial knowledge from different routes traversed when navigating [34]. These trait-level individual factors could mediate sex differences in spatial learning performance.

In conclusion, the current study suggests that state anxiety should be considered when constructing and testing models of sex differences in survey spatial knowledge when learning under passive viewing conditions. In this case, a manipulation of state anxiety further exaggerated previously known sex differences in spatial learning, when knowledge was assessed from the perspective that the environment was learned. Work at the intersection between spatial cognition, emotion, and sex differences remains a large gap in the literature that merits further investigation, particularly since preliminary evidence across the fields of cognitive and neurobiological psychology suggest that emotional state may help to explain sex differences in spatial learning. This study serves as a first step for testing an influence of anxiety on spatial learning. Future research should investigate more subtle manipulations related to social factors and motivation using continuous measures of affective response and other individual differences across spatial tasks. A better understanding of the emotional underpinnings of sex differences in spatial performance could have far-reaching applications, from generating anxiety-based interventions for use with spatial tasks and tests during the lifespan (particularly during early development) to better understanding how different individuals navigate, learn, and remember spaces under stress.

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