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The Impacts of Anxiety and Motivation on Spatial Performance:
Implications for Gender Differences in Mental Rotation and Navigation

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ABSTRACT

Despite extensive research on gender differences in spatial cognition, the potential roles of affective and situational factors in accounting for these differences remain relatively understudied. Here we discuss the impacts of spatial anxiety and motivation in mental rotation and navigation tasks, particularly their roles in explaining the gender performance gaps. We highlight the distinction between approach and avoidance motivation, as well as interactions between anxiety and motivation. Attention, working memory, and response strategy are discussed as mechanisms by which anxiety and motivation may affect performance on spatial tasks. Implications for a broader approach that also considers other psychological variables, such as confidence, are discussed.

KEYWORDS: spatial reasoning; gender differences; affect; anxiety; motivation

1 Introduction

Gender differences have long interested the scientific community and general public alike. That males and females perform differently on particular cognitive tasks has important implications for theories of task performance and for practical considerations related to individual differences. Much discussion has concerned the reliability of gender differences across two types of spatial tasks: mental rotation and navigation. There has also been much consideration of the potential causes of these differences. Yet debate continues about why gender differences exist in these cases. The literature has been dominated by research attempting to answer the nature-versus-nurture question. Less attention has been paid to the psychological variables that affect performance in the immediate context and over the long term. Here, we draw on recent trends to evaluate how affective and situational factors impact cognition. We focus specifically on the roles of anxiety and motivation in accounting for gender differences in mental rotation and navigation tasks. Recent research has examined gender differences in anxiety and motivation in the context of spatial reasoning, but there has been little consideration of the different types of motivation (i.e., approach vs. avoidance), or the potential interactions between anxiety and motivation, which may be crucial to furthering our understanding of the gender differences in spatial performance.

2 Mental Rotation and Navigation

The ability to manipulate images in our minds incorporates processes related to visualization (also known as imagery), object representation, and spatial transformation. These processes come together on tasks of mental rotation, which may involve turning, flipping, and sliding objects in one's mind. In the classic task developed by Shepard and

Metzler (1971), participants viewed drawings of three-dimensional objects, presented as pairs of objects in different orientations, and they judged whether the objects were the same or different (Figure 1A). Objects are considered the same if it is possible to mentally rotate one object into congruence with the other and different if it is not, though there may be individual differences in the exact strategy adopted on this task (Figure 1A).

Navigation occurs when an organism traverses the external environment, and laboratory-based studies focus either on ongoing, or plans for subsequent, traversal. Drawing on general cognitive and specific spatial processes, navigation operates on the large-scale environment, either the real world, virtual space, or symbolic representations such as maps (Wolbers & Hegarty, 2010). Of particular interest to many studies is wayfinding, in which the goal of the participant is to localize a specific place, plan a route to a target location, and/or maintain one's orientation (Figure 1B).

Despite differences in task dynamics and putative neural mechanisms (Cona & Scarpazza, 2019; Zacks, 2008), converging evidence provides support for a male advantage on both mental rotation and navigation tasks. On mental rotation tasks, males tend to score higher and respond more quickly than females, beginning at about 6 years of age (Lauer et al., 2019). In the case of navigation, the male advantage is smaller than that for mental rotation and there is less clarity as to when it develops (Nazareth et al., 2019). Lourenco and colleagues (2011) found that when localizing a target object following disorientation, boys and girls (18-24 months) differed in how much they relied on the geometry of the surrounding space, at least when a salient landmark was present. Although this gender difference mimics that found in adults (Figure 1B), it is likely a smaller effect, and more research will be needed to ensure its reliability.

Previous accounts have often debated whether gender differences are due to nature or nurture, but recent proposals have moved beyond this debate and instead emphasize their interactions (Levine et al., 2016; Newcombe, 2020). Recently, there has also been increasing attention paid to the potential role that affective and situational factors, such as anxiety and motivation, may have on task performance. Although task performance is dependent on one's ability (and one's ability is often characterized by task performance), these two constructs are not interchangeable. Task performance also depends on decision variables, which may be independent of ability, and which may depend on affective and situational factors (Lerner et al., 2015). In other words, even if two people are equally competent at mental rotation or navigation, one person may still approach the task differently, and perform worse, than another because of differences in anxiety, motivation, confidence, mood, and so on.

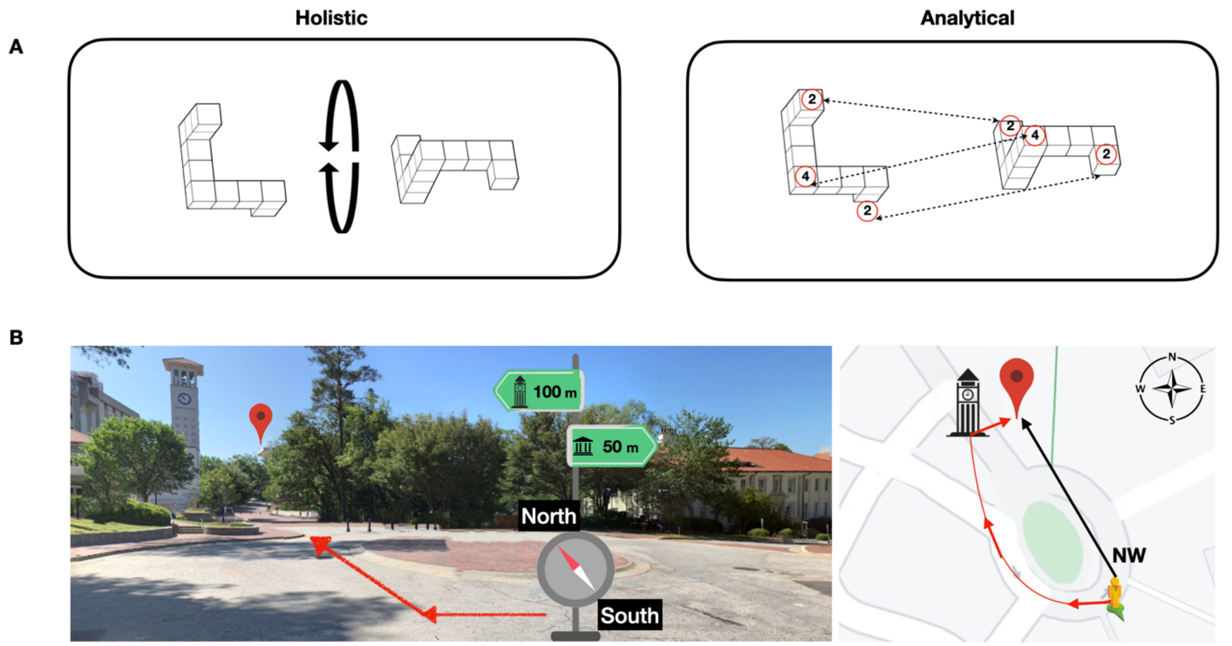

Figure 1. A: When performing a mental rotation task, participants may adopt holistic or analytical strategies for deciding whether two objects are the same or different. A holistic strategy involves rotating the object as a single entity, so that a judgment of same or different for the object pair is based on the alignment between the whole objects. An analytical (or 'piecemeal') strategy involves comparing component parts of the objects (e.g., four parts in one segment of the object versus two parts in another segment), so that a same or different judgment is based on the match between the different object parts. Males and females may differ in the extent to which they adopt these strategies (Geiser et al., 2006; Wang & Carr, 2014), though research suggests that it may be most beneficial to be able to switch flexibly between strategies (Boone & Hegarty, 2017). B: Examples of a route-planning task, depicted in a real-world environment (left) and on a map (right). In both cases, participants need to maintain one's heading; however, participants may use either cardinal direction (e.g., northeast), distance (e.g., 100 m), and/or landmarks (e.g., clocktower) to solve the task. An example of a landmark-based strategy would be to go to the road sign and turn left, and then to go straight until getting to the clocktower, at which point turn right. An example of a distance and direction strategy would be to travel northwest for 100 m, and then turn east and continue for 20 m. Males and females may differ in the extent to which they adopt these navigation strategies, though it is usually more effective to use a combination of strategies (Coluccia & Louse, 2004).

3 Spatial Anxiety

Spatial anxiety is an apprehension (or fear) expressed towards spatial activities. Individuals who are spatially anxious experience worry when performing, or even anticipating, a spatial task. Like other fears, spatial anxiety shows some specificity. For example, anxiety associated with navigation has been found to dissociate from anxiety associated with manipulation (i.e., mental rotation) or imagery (Alvarez-Vargas et al., 2020; Lyons et al, 2018; Malanchini et al., 2017). There may be less specificity for mental rotation and imagery anxieties, given that mental rotation encompasses visualization, but, here too, the evidence suggests that there is anxiety for mental rotation *per se* (Alvarez-Vargas et al., 2020; Lyons et al., 2018). The specificity of spatial anxiety is interesting for theoretical reasons and dovetails with research showing that mental rotation and navigation are subserved by distinct neurocognitive mechanisms. There are also important practical implications; given the specificity of spatial anxieties, interventions designed to treat anxiety will likely require targeting the specific spatial anxiety.

3.1 Gender differences in spatial anxiety

In general, high levels of anxiety result in poor task performance (Eysenck et al., 2007), and women report greater spatial anxiety than men for both mental rotation and navigation (Lawton & Kallai, 2002; Malanchini et al., 2017). Thus, it follows that women would perform worse than men. Indeed, the gender difference in spatial anxiety was recently found to partially account for why women scored lower than men on a mental rotation task (Alvarez-Vargas et al., 2020), suggesting that if spatial anxiety were comparable, the gender difference in mental rotation performance would be minimized.

Studies with children suggest that spatial anxiety develops during elementary school, with girls reporting greater anxiety than boys for wayfinding and block building activities (Lauer et al., 2018; Ramirez et al, 2012). But questions remain about *how* the relation between spatial anxiety and spatial performance develops. A possibility is that one's prior performance, or perceived competence, causes one's anxiety. In other words, individuals who experience poor performance on spatial tasks may become anxious because of a fear of performing poorly (again). In adults, the effects of prior experience have even been demonstrated within an experimental session. For example, participants performed better on a harder version of a mental rotation task when they completed an easier version first, suggesting that prior success enhances subsequent performance (Rahe et al., 2019). In children (4^{th}-graders), Rahe and Quaiser-Pohl (2020) found that feedback enhanced subsequent performance, indexed by reaction times (RTs), such that RTs were faster following a feedback condition, though this effect was only significant in boys. More research will be needed to test how prior experiences, including feedback conditions, affect subsequent anxiety in adults and children, and whether changes in performance are the result of spatial anxiety *per se*, since performance could instead reflect changes in motivation or other psychological factors (e.g., confidence).

Other research has focused on the possibility that spatial anxiety emerges prior to differences in task performance, such that one's pre-existing anxiety affects one's performance (e.g., higher anxiety causes worse performance). But why might anxiety exist in the first place? One suggestion is that spatial anxiety arises from cultural beliefs (i.e., stereotypes) about gender differences in spatial ability, independent of one's own ability. Gender stereotypes about spatial reasoning, and intelligence more generally, are pervasive across cultures, which even children endorse (Bian et al., 2017; Okanda et al., 2022; Vander Heyden et al., 2016).

Besides stereotypes, spatial anxiety can be attributed to other environmental stressors. For example, crimes against females are more prevalent compared to males, possibly leading to greater anxiety in unfamiliar environments. Indeed, cross-cultural research reveals that the feeling of personal safety accounts for the gender difference in navigation anxiety, at least in adults (Lawton & Kallai, 2002).

3.2 How does spatial anxiety affect performance?

There is much agreement that anxiety depletes cognitive mechanisms such as working memory (WM) (Eysenck et al., 2007; Maloney et al., 2014). Anxious individuals may engage in rumination, such as "Women aren't good at navigation" or "I'm not a spatial person," which may be difficult to suppress and, consequently, competes for WM resources required by the task (Moran, 2016). Relatedly, anxious individuals may be more vigilant about their performance and this self-monitoring may tax WM (Schmader et al. 2008).

WM comprises both verbal and visuospatial subtypes. In the case of mental rotation, there is evidence for visuospatial WM as a predictor of mental rotation performance (Levin et al., 2005). However, the evidence for verbal WM as a predictor of performance is more mixed (Christie et al., 2013; Kaufman, 2007) and may depend on task strategy.

On mental rotation tasks, females tend to be more reliant than males on an analytical strategy (e.g., Wang & Carr, 2014). It has been suggested that this strategy places a larger burden on verbal WM (whereas the holistic strategy may be more dependent on visuospatial

WM). If females engage in more verbal rumination than males, as has been suggested, then their performance is likely to be more impacted, given the preference for an analytical strategy. This is not to say, however, that a holistic strategy is immune to the effects of anxiety. Whereas rumination has been found to tax verbal WM, physiological arousal that accompanies anxiety appears to compete with visuospatial WM resources, which may be crucial to supporting a holistic strategy during mental rotation (Moran, 2016; Shackman et al., 2006).

These types of effects have received less attention in the navigation literature, but at least some evidence suggests that women are more likely to rely on landmarks than cardinal direction for wayfinding, particularly when participants report greater spatial anxiety (Schmitz, 1999). More research, however, will be needed to determine whether wayfinding strategies are affected by anxiety related to navigation specifically and to what extent wayfinding strategies may relate to available WM resources and/or effects of attention (for further discussion, see Section 4.1).

4 Motivation

Yet anxiety cannot be the sole explanation of gender differences in spatial performance. After all, even when men and women perform comparably, women may still report higher spatial anxiety than men (Lyons et al., 2018; Liu & Lourenco, 2022). Next, we focus on motivation, which is characterized by effort (either exerted or planned) and goal activation (Elliot, 2008), and its potential role in accounting for spatial performance.

4.1 Toward a model of how motivation affects spatial performance

There is widespread agreement that motivation is distinguishable by type (Elliot, 2008; Scholer & Higgins, 2008). One type—approach motivation—is characterized by the desire to achieve a positive outcome, as when one is motivated by success. Another type—avoidance motivation—is characterized by the desire to avoid negative outcomes such as failure. The distinction between approach and avoidance motivation is well known, but their effects on spatial tasks have been relatively understudied.

In what follows, we draw on theories of attentional control (Eysenck et al., 2007), processing efficiency (Nieuwenhuys & Oudejans, 2012), and regulatory focus (Crowe & Higgins, 1997) to support predictions of how approach and avoidance motivation may differentially impact spatial performance. In Figure 2, we highlight attention, working memory, and response strategy as potential mechanisms in this process. To the extent available, we discuss studies within the literature on spatial cognition that support the predictions of our model, particularly as they relate to strategy selection and flexibility of responses. We also make explicit where additional research will be needed to validate the roles of attention and working memory on spatial performance.

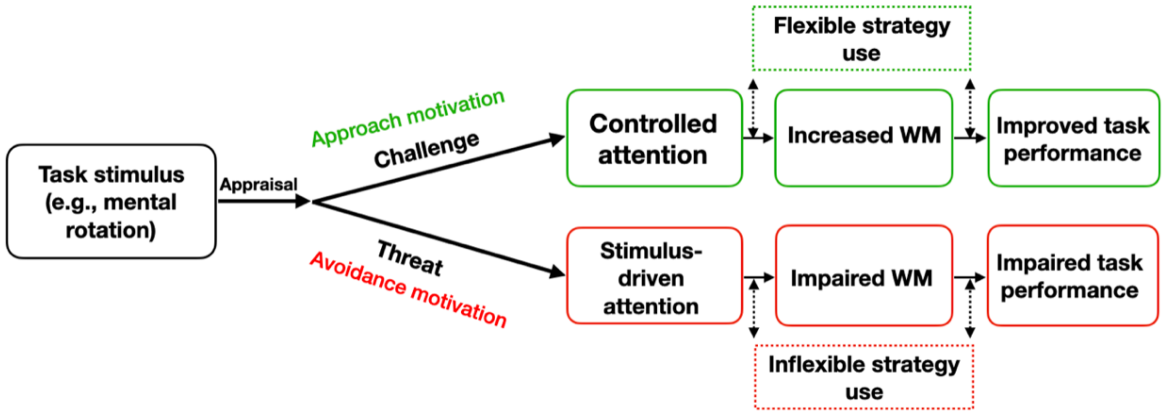

Figure 2. A proposed model of the impact of motivation (approach and avoidance) on spatial performance, adapted from Vine et al. (2016). Participants begin a task with appraisal, executed implicitly or explicitly, by considering their interest, experience, and emotion, including anxiety (Blascovich, 2008; Schmader et al., 2009). If a task is appraised as a challenge, this generally triggers approach motivation. However, if the task appraisal is one of threat, this may trigger avoidance motivation. On this model, approach and avoidance motivation differentially affect attention, working memory, response strategy and, ultimately, performance on spatial tasks[1].

Approach motivation is typically accompanied by controlled attention towards the goal(s) of a task, including its reward structure and stimuli (Jones et al., 2009; Vine et al., 2015). Controlled attention, in turn, has been found to correlate positively with WM capacity (Engle, 2002). Avoidance motivation, however, is typically accompanied by attention that is primarily stimulus-driven (Bless & Fiedler, 2006). Stimulus-driven attention, in turn, has been found to tax WM, especially when stimulus features are irrelevant to the task (Eysenck et al., 2007). Avoidance motivation may also be accompanied by attention that is self-oriented, but perhaps only when anxiety (or physiological arousal) is high (cf. Beilock & Carr, 2001). If self-oriented attention leads to excessive self-monitoring, or rumination, about task performance (Hester & Garavan, 2005), performance may become impaired, either by disrupting processing or inducing escape behaviors (Kelley et al., 2017).

Moreover, and especially relevant to the proposed model, approach motivation has been associated with response flexibility (Calcott & Berkman, 2014), whereas avoidance motivation may promote less flexibility, including reliance on a prepotent response strategy (Seibt & Förster, 2004). This distinction aligns well with regulatory focus theory, wherein 'promotion' and 'prevention' foci engender differential types of information processing. When there is a promotion focus, the processing style is typically considered 'abstract' or 'holistic', and generally accompanied by exploratory behaviors and flexibility of responding (Friedman & Förster, 2001). When there is a prevention focus, the processing style is typically considered 'analytical', and generally accompanied by less novelty seeking and reduced response flexibility (Roskes et al., 2012).

On mental rotation tasks, there is evidence that both women (Moè et al., 2009; Moè, 2016) and girls (high schoolers; Moè, 2021) benefit from instructions and practice with a holistic strategy, which involves training on whole object (mental) rotation (Figure 1A). There is also evidence that female participants benefit from motivation-specific training, in which instructions promote effort attribution and beliefs about success (Moè & Pazzaglia, 2010). Less clear from these studies, however, is whether training a holistic task strategy affects motivation or whether motivation training affects response strategy.

The prediction from our model is that approach motivation should encourage a holistic strategy and response flexibility. Partial support for this prediction comes from a 'global-local' spatial task, in which approach motivation (induced by a self-control exercise) was associated with a holistic matching strategy (Crowell et al., 2014). Specifically, participants with higher approach motivation exhibited a stronger global bias (matching figures according to the global shape of the target stimulus) compared to a local bias (matching figures according to the local features of the target stimulus). Unknown, however, is whether approach motivation was also associated with greater response flexibility on this task. Future research might test this possibility by manipulating the relevance of each strategy and assessing whether there is greater flexibility under approach than avoidance motivation.

On mental rotation tasks, a combination of holistic and analytical matching strategies is associated with better performance (Boone & Hegarty, 2017), but future research will be needed to test the specific link between response flexibility and approach motivation specifically. It has even been found that the physical enactment of approach motivation (i.e., an arm extension) ameliorates participants' mental rotation performance (Jansen et al, 2017). But, here, too, there are open questions about whether, and how, physical actions might impact strategy selection specifically or other putative mechanisms such as attention and working memory associated with motivation.

Our model also predicts a link between avoidance motivation and response inflexibility. Consistent with this possibility is evidence from a spatial learning task, in which the goal for participants was to localize a target object (Schwabe et al., 2007), akin to the goal in many navigation tasks. In this study, spatial learning occurred after either a stressful task, known for eliciting avoidance motivation, or a non-stressful (control) task. When stress was induced, participants showed greater reliance on the more rigid 'stimulus-response' strategy, in which they relied exclusively on an adjacent landmark to localize the target. By contrast, following the control task, participants were more likely to ‘map’ the space by representing the distal landmarks, a strategy that generally allows for greater flexibility in the sources of information used for localization (Cheng et al., 2007). Future research, however, will be needed to test directly how response strategies, and related mechanisms such as attention and working memory, compare on spatial tasks under conditions of avoidance versus approach motivation.

4.2 A consideration of motivation and anxiety interactions

Although higher anxiety is generally associated with avoidance motivation (e.g., Roskes et al., 2014), there are individual differences in anxiety level among those who experience approach or avoidance motivation, allowing for interactions between anxiety and motivation. Support for such interactions comes from research in the math domain, in which Wang and colleagues (2015) found that when motivation was high, math performance was better at moderate levels of anxiety (compared to high and low anxiety levels). This curvilinear relation between motivation and anxiety is akin to the well-known Yerkes-Dodson effect, wherein performance varies in curvilinear fashion with physiological arousal. When motivation was low, however, there was a negative linear relation, such that math performance decreased as anxiety increased (i.e., performance was best at low anxiety compared to moderate and high levels).

Extending the findings of Wang and colleagues (2015), we propose that spatial performance may also depend on the relation between motivation and anxiety. Moreover, an intriguing possibility is that the effects may be modulated by the type of motivation. Indeed, we would offer the prediction that individuals who experience approach motivation may demonstrate a curvilinear relation between anxiety and performance, as in the Yerkes-Dodson effect. By contrast, those who experience avoidance motivation may demonstrate a negative linear relation, such that when anxiety is low, performance may be best, but with decreasing performance as anxiety increases. Nevertheless, despite the similarities between math and spatial domains (Hubbard et al., 2005; Lourenco et al., 2018), the interactions between anxiety and motivation, as proposed here, will need to be tested directly on spatial tasks such as mental rotation and navigation.

Preliminary support for an interaction between motivation and arousal (which may index anxiety) within the spatial domain comes from a virtual navigation task, which participants performed under conditions of approach or avoidance motivation (Murty et al., 2011). Performance was better when associated with approach motivation than avoidance motivation and, notably, greater arousal led to worse performance in the approach motivation condition, but not the avoidance motivation condition. However, a caveat is that, in neither case, was the relation between performance and arousal curvilinear, as in the Yerkes-Dodson effect. Thus, more research will be needed to test the differences between approach and avoidance motivation under varying levels of arousal and/or anxiety and across different spatial tasks.

More research will also be needed to examine whether, and how, the interactions between motivation and anxiety affect gender differences in spatial performance. Although female participants benefit from experimental conditions that boost motivation (Moè, 2016; Zander et al., 2020), it remains unknown to what extent motivation may explain the gender differences on spatial tasks. Preliminary support for such an effect comes from recent research from our lab using drift diffusion modeling, in which processing efficiency is indexed by the drift rate parameter and response style is indexed by the decision threshold parameter (Liu & Lourenco, 2022). We found that whereas highly motivated individuals exhibited no gender differences on these metrics, individuals who reported low motivation showed gender differences in both drift rates and decision thresholds. What remains unclear is the extent to which motivation might modulate the effects of anxiety, when they exist. We also did not distinguish between approach and avoidance motivation in this research, so additional studies will be needed to examine whether the type of motivation affects gender differences on spatial tasks.

5 Conclusion and Additional Considerations

We have described evidence that anxiety affects spatial performance. We have also discussed how different types of motivation may impact performance on mental rotation and navigation tasks. Finally, we have argued that interactions between anxiety and motivation may contribute to our understanding of gender differences in spatial tasks. We did not, however, consider why individuals may differ in their motivational states (or traits). Questions about developmental origins and experiential factors that give rise to approach versus avoidance motivation on specific tasks (or general traits) will need to be addressed empirically. Of potential relevance are the relations between motivation, anxiety, and other psychological factors such as confidence, which has been shown to differ among men and women on mental rotation tasks (Lemieux et al., 2019; Rahe & Jansen, 2021), even when performance is comparable (Estes & Felker, 2012), and which, like anxiety, may mediate the gender difference in mental rotation performance (Liu & Lourenco, 2022). Although not a direct measure of state-level confidence, there is also research on self-reported sense-of-direction that points to a potential gender difference in navigation-related confidence (Burte et al., 2018; Sholl et al., 2006). Future research would do well to assess how confidence interacts with anxiety and motivation to explain gender differences in spatial performance.

There has been increasing interest in the malleability of spatial reasoning, with studies demonstrating improvements in performance following practice and specific interventions (Hund & Nazarczuk, 2009; Uttal et al., 2013). These effects are generally taken to mean that participants get better at mental rotation or navigation—their ability is somehow enhanced. An open question, however, is whether these improvements may be better explained by changes in anxiety, motivation, and/or other psychological factors.

There are also open questions about how to target anxiety and motivation more effectively to improve spatial performance. Might reappraisal techniques that convert avoidance motivation into approach motivation, as appropriate given task demands, benefit performance? Might techniques designed to minimize anxiety (e.g., journal writing) prove effective on spatial tasks? Researchers concerned with interventions are sure to benefit from considering the impacts of anxiety, motivation, and other psychological factors on spatial performance.

Recommended Readings

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Footnote

[1] We have highlighted the relation between avoidance motivation and impaired WM because stimulus-driven attention is likely to tax WM resources required by spatial tasks such as mental rotation and navigation. However, there may be conditions in which performance is not impaired, such as when demands on WM are low and/or detection of stimulus features is imperative (Koch et al., 2008; Phelps et al., 2006). There is also evidence that as long as there is a match between global incentives related to regulatory focus and local incentives related to the task reward structure, avoidance motivation need not lead to worse performance (Maddox & Markman, 2010).

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