A Meta-Analytic Review of the Relation Between Spatial Anxiety and Spatial Skills

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Abstract

Spatial skills are key predictors of achievement in science, technology, engineering, and math (STEM) disciplines, despite being acquired through everyday life and not formally taught in schools. Spatial skills include a diverse group of abilities broadly related to reasoning about properties of space such as distance and direction. Recently, more research has investigated the link between spatial skills and spatial anxiety, defined as a fear or apprehension felt when engaged in spatial thinking. There has yet to be a meta-analytic review summarizing these findings. Thus, the goal of this pre-registered meta-analytic review is to provide an estimate of the size of the relation between spatial anxiety and spatial skills while considering several moderators (grade/age group, sex, spatial skills measure/subtype, spatial anxiety measure/subtype, geographical region of sample, publication type/year, and risk of bias). Analyzing 283 effect sizes accumulated from research conducted between 1994 and 2020, we found a small, negative, and statistically significant (r = -.14) correlation between spatial anxiety and spatial skills. Results showed that effect sizes including mental manipulation anxiety, scalar comparison anxiety, and navigation skill were often significantly stronger than effect sizes including measures of other subtypes. The magnitude of the relation was not significantly different in children and adults, though effect sizes tended to be weaker for younger samples (r = -.08). Our results are consistent with previous findings of a significant relation between spatial anxiety and skills and this work bridges a gap in the existing research, lending support to future research efforts investigating spatial cognition.

Keywords: meta-analysis, spatial anxiety, spatial skills, spatial cognition

Public Health Significance Statement

The present meta-analytic review finds a small-to-moderate association between spatial anxiety and spatial skills, indicating that people who report higher feelings of anxiety toward spatial situations tend to have worse spatial skills. The relation is stronger when mental manipulation and scalar comparison anxiety are measured, as well as when navigation skills are assessed. Given that spatial anxiety is experienced by many individuals across a variety of ages, its association with spatial skills makes it a critical factor to consider for improving spatial experiences like driving and navigating, as well as improving science, technology, engineering, and math (STEM) achievement and career participation.

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Spatial reasoning, like many of the skills that humans possess, develops throughout the lifespan. It is the basic function that allows for the successful navigation of the physical world (Vasilyeva & Lourenco, 2010). Despite spatial cognition being comprised largely of skills that are learned through everyday life, rather than subjects taught in school, research has shown spatial skills to be key predictors of achievement and attainment in science, technology, engineering, and math (STEM) disciplines (e.g., Atit et al., 2021; Hawes et al., 2022; Shea et al., 2001; Uttal et al., 2013; Wai et al., 2009; Wai et al., 2010). Given that spatial skills are malleable and can be trained (Lerner, 2006; Lowrie et al., 2017; Uttal et al., 2013), it is imperative to understand the factors that relate to spatial skills (Hawes et al., 2022). Existing research suggests one factor might be spatial anxiety, defined as nervousness when engaged in spatial thought, which has been shown to negatively relate to spatial skills (e.g., Geer, 2019; Lawton, 1994; Lyons et al., 2018). Understanding the magnitude of the relation between spatial anxiety and spatial skills, as well as factors that may impact this relation, can increase our understanding of how emotions play a role in spatial thinking and guide future research and intervention efforts. In this preregistered meta-analytic review, we aim to (a) estimate the average effect size of the relation between spatial anxiety and spatial skills and (b) examine if this relation differs based on demographic factors, measurement factors, or publication quality or status.

Definition of Spatial Skills

Spatial thinking encompasses a diverse group of skills that are vital to everyday life, and for achievement in STEM disciplines (Vasilyeva & Lourenco, 2010). The common element that connects subtypes of spatial skill is that they all involve reasoning about properties of space that are captured by concepts including distance and direction (Vasilyeva & Lourenco, 2010). Due to the diverse nature of the skills involved, it is difficult to organize spatial tasks according to specific spatial abilities (Gunderson et al., 2012). Instead, there are broad categories often used in the literature, specifically under two theoretical frameworks: a three-factor framework suggested by Linn and Petersen (1985) and a four-factor framework suggested by Uttal et al. (2013).

The first framework, proposed by Linn and Petersen (1985), describes spatial cognition as comprised of three subtypes: mental rotation, spatial perception, and spatial visualization. Mental rotation refers to the ability to hold images in one's mind while simultaneously mentally rotating them (Ganley & Vasilyeva, 2011; Uttal et al., 2013; Vandenberg & Kuse, 1978). Spatial perception refers to the ability to observe spatial relations with respect to the orientation of one's own body despite distracting information (Linn & Petersen, 1985; Uttal et al., 2013). Spatial visualization refers to the ability to successfully navigate through complicated, multistep manipulations of spatially presented information (Linn & Petersen, 1985; Uttal et al., 2013). For a more detailed explanation of these subcategories, as well as example tasks, see Table 1.

The second framework, suggested by Uttal et al. (2013), proposes that spatial cognition can be defined by a four-factor structure that is created by crossing the distinction between intrinsic (the relation of components that define a single object) and extrinsic (the relation between a group of different objects) with the distinction between static (fixed object) and dynamic (moving object). Uttal and colleagues posit that spatial skills can be classified into four subtypes using this system: imagery/intrinsic-static (includes Linn & Petersen's spatial visualization), mental manipulation/intrinsic-dynamic (includes Linn & Petersen's mental rotation), scalar comparison/extrinsic-static (includes Linn & Petersen's spatial perception) and navigation/extrinsic-dynamic (not directly mentioned in the Linn & Petersen, 1985 framework). For a more detailed explanation of these sub-categories, as well as example tasks, see Table 1.

Due to the fact that the Uttal et al. (2013) framework allows for more nuanced categories through the inclusion of spatial navigation/extrinsic-dynamic subtype, in the present meta-analytic review we report findings from analyses with the subtypes of spatial skills from the Uttal et al. framework as a potential moderator of the relation between spatial anxiety and spatial skills. Results from analyses with the subtypes of spatial skills from the Linn and Petersen (1985) framework can be found in the supplemental materials.

Definition of Spatial Anxiety

Spatial anxiety, defined as fear or apprehension felt when engaged in spatial thinking, has been shown to relate to poorer performance on spatial tasks (Geer, 2019; Kremmyda et al., 2016; Lawton, 1994; Lyons et al., 2018; Ramirez et al., 2012). Spatial anxiety is also closely related to other forms of anxiety including math anxiety, general anxiety, and test anxiety (Ferguson et al., 2015; Geer, 2019; Lyons et al., 2018; Malanchini et al., 2017). Some researchers use the term *wayfinding anxiety* interchangeably with spatial anxiety (e.g., Lawton & Kállai, 2002; Malanchini et al., 2017) and, therefore, the present meta-analytic review incorporates articles that measure wayfinding anxiety as well though we will continue to refer only to spatial anxiety.

Existing work posits that, like spatial skills, spatial anxiety may have a complex structure with multiple subtypes; however, capturing these adequately with spatial anxiety scales has proven difficult (4 factors, Geer, 2019; 1 factor, Lawton, 1994; 3 factors, Lyons et al., 2018; 2 factors, Malanchini et al., 2017). The first spatial anxiety scale developed included items focused only on anxiety about spatial navigation (Lawton, 1994). Navigation anxiety relates closely to the extrinsic-dynamic subtype proposed by Uttal et al. (2013). The Lawton scale was the most commonly used measure of spatial anxiety in the literature for over 20 years. In 2017, Malanchini and colleagues expanded upon the Lawton scale by including an additional subtype which they classified as rotation/visualization (mental manipulation, Lyons et al., 2018; intrinsic-dynamic; Uttal et al., 2013).

In an effort to better address the complexity of spatial anxiety, Lyons et al. (2018) used exploratory factor analysis conducted within the spatial framework set forth by Uttal et al. (2013) to develop a new spatial anxiety scale. They found that items loaded onto three factors that fit well with three of Uttal et al.'s categories: imagery (intrinsic-static), mental-manipulation (intrinsic-dynamic), and navigation (extrinsic-dynamic), but that the fourth factor, scalar comparison (extrinsic-static), was not represented in their items. Recently, Geer (2019) developed a revised version of the Lyons scale that refined the construct of spatial anxiety by removing items that tapped into other anxieties (i.e., items that prompted a fear of being lost rather than anxiety about navigation itself) or were about specific content areas (e.g., science concepts) by using expert reviews and cognitive interviews. Geer also added items to measure the theorized fourth subtype of spatial anxiety (scalar comparison), that the scale developed by Lyons et al. had not captured, leading to a revised scale that included Uttal et al.'s four subtypes.

Relation between Spatial Skills and Anxiety

Existing research has demonstrated a relation between spatial anxiety and spatial skills (Geer, 2019; Kremmyda et al., 2016; Lawton, 1994; Lyons et al., 2018; Ramirez et al., 2012). This relation has been found in samples of varying ages (grades 1-5, Lauer et al., 2018; college students, Geer, 2019, Lyons et al., 2018; non-student adults, Muffato & De Beni, 2020) and is present for both men and women (Lawton, 1994). Less work has considered the directionality of the causal link between spatial anxiety and spatial skills, but the relation is likely bidirectional and may follow one of two main mechanisms, like other domain specific anxieties (i.e., math anxiety; Ashcraft et al., 2001). Specifically, the link may be rooted in avoidance and/or the way that both anxiety and skills each deplete cognitive resources.

The first mechanism, experiential avoidance, suggests that individuals may be unwilling to tolerate situations that elicit negative emotions (e.g., anxiety), and therefore avoid tasks that cause such feelings (Berman et al., 2010). Thus, individuals who experience anxiety when confronted with a spatial task may avoid future situations that involve spatial skills. This avoidance could serve to decrease opportunities to improve those skills, thus leading them to maintain their lower spatial skills. These lower spatial skills may lead to the development of domain-specific spatial anxiety over time, as one reflects on their poor performance. Thus, potentially creating a cyclical reaction such that poor spatial skills lead to increased spatial anxiety, leading to increased avoidance of spatial activity, and ultimately leading to minimized the chances for spatial skills to improve. Unlike other areas such as math, many spatial experiences are almost entirely avoidable in real life settings, allowing for this cycle to continue across the life span. For example, the creation of GPS mapping systems allows individuals with anxiety about navigation to avoid using their own navigation abilities and instead rely on technology. The same can be said for those who avoid mental rotation/mental manipulation tasks such as completing jigsaw puzzles, as these are leisure activities that can be easily forgone.

A second potential mechanism for the link between spatial anxiety and spatial skills suggests that spatial anxiety depletes cognitive resources associated with working memory, thereby contributing to poorer performance on spatial tasks. If this is the mechanism for this relation, we would expect that spatial anxiety creates thoughts and concerns that tax the working memory of the individual when they are faced with a spatial task. Thus, they become overwhelmed and either unable to complete the task or unable to do so as quickly or effectively as they might have if they had not been anxious. In this case, the added stress on working memory caused by spatial anxiety would lead to poorer spatial skills, which has been demonstrated in similar constructs such as math anxiety (e.g., Justicia-Galiano et al., 2017). Both avoidance and working memory may help account for the relation between spatial anxiety and spatial skills. Specifically, when faced with a spatial task that increases anxiety, it is possible that due to the impact on working memory, an individual might become overwhelmed by a spatial situation and avoid that feeling again in the future.

Although the present work cannot distinguish between which of these mechanisms may or may not be accurate, it is essential that we examine what the field currently knows about the relation between spatial anxiety and spatial skills, as well as what may moderate this relation, to highlight gaps in existing research and inform next steps for the field. Importantly, despite extensive research on spatial cognition, including several meta-analyses (e.g., the relation between spatial and math skills, Atit et al., 2021; the malleability of spatial skills, Uttal et al., 2013; the effect of spatial training on spatial and math performance, Hawes et al., 2022; the magnitude of sex differences in spatial abilities, Lauer et al., 2019, Voyer et al., 1995), there has yet to be a meta-analytic review to summarize the relation between spatial anxiety and spatial skills.

Potential Moderators of the Relation Between Spatial Anxiety and Spatial Skills

Based on existing research, the relation between spatial anxiety and spatial skills has been theorized to vary depending on a number of sample and study factors. In the present meta-analytic review, we will assess if publication bias, sex, grade level/age group, geographical region of sample, spatial anxiety measure, spatial anxiety and spatial skill subtype, spatial skills measure, publication year, and risk of bias serve to moderate the relation between spatial anxiety and spatial skills.

Publication Bias

When conducting any systematic or meta-analytic review, it is essential to consider the tendency for published effect sizes to be systematically different, typically stronger, than those from unpublished work (Dickersin, 2005; Song et al., 2000). To combat potential publication bias in the overall estimate of the relation, we included grey literature by including unpublished work, theses/dissertations, and effect sizes that were not included in published manuscripts but were recovered through author queries. To test for the potential influence of publication bias on the relation between spatial anxiety and spatial skills, we examined publication type as a moderator.

Sex Differences

Sex differences favoring males in spatial performance have been found consistently in the literature (e.g., Geer & Ganley, 2022; Geer et al., 2018; Lawton, 1994; Linn & Petersen, 1985; Tarampi et al., 2016; Voyer et al., 1995). Despite a plethora of research examining sex differences in spatial ability, less work examines sex differences in spatial anxiety, though existing research suggests females tend to report higher spatial anxiety (Geer, 2019; Lawton, 1994). There is also a lack of research examining if the *relation* between spatial anxiety and spatial skills is stronger or weaker based on sex. It is unclear if we should expect the relation to be stronger for males or females, even though researchers find sex differences in each construct separately. To assess if sex impacts the strength of the relation between spatial anxiety and spatial skills, sex of the sample has been included as a moderator for the present meta-analytic review.

Grade Level/Age Group of Sample

Research on spatial cognition has been conducted in a variety of age ranges (e.g., grades 1-5, Lauer et al., 2018; college students, Geer, 2019, Lyons et al., 2018; non-student adults, Muffato & De Beni, 2020). Based on existing work, it is possible that children might not experience domain-specific anxieties in the same way as adults (Geer, 2021; Lauer et al., 2018). Children may not have had enough spatial experiences to develop domain-specific anxieties; for example, children generally do not have to do much navigation in their day to day lives, since their caretakers often navigate to and from school, home, the store, etc. Thus, outside of more general anxiety, their anxiety about space may not be strongly related to how they perform on spatial tasks. Research with young children has elicited mixed findings regarding whether spatial anxiety and spatial skills are related (Geer, 2021; Lauer et al., 2018; Ramirez et al., 2012). No existing work has examined whether there are differences in the magnitude of the relation between spatial anxiety and spatial skills based on the age of the sample, however given that spatial anxiety seems to be less domain specific in children, it may also be less strongly related to spatial skills at younger ages. Thus, we will test whether there are impacts of grade level/age group of sample on the strength of the relation between spatial anxiety and spatial skills.

Geographical Region of Sample

Because the work done on spatial cognition has been conducted in many different countries (e.g., Canada, Huang & Voyer 2017; Hungary, Kállai et al., 2000; Italy, Carbone et al., 2019; Spain, Munoz-Montoya et al., 2019; USA, Lawton, 1994), it makes sense to test if the geographical region of the sample may impact the strength of the relation between spatial anxiety and spatial skills. Following this logic and the fact that this moderator is common in meta-analysis (i.e., Barroso et al., 2021), we include this factor as a moderator in our analyses.

Spatial Anxiety Measures and Subtypes

Recent research has aimed to identify a structure of spatial anxiety that is more complex, to account for the various skills that make up spatial cognition (Geer, 2019; Lyons et al., 2018; Malanchini et al., 2017). Based on this research, it is possible that the spatial anxiety scale used and the subtype of spatial anxiety measured could impact the strength of the association between spatial anxiety and skills. Specifically, since each spatial anxiety measure incorporates different subtypes of spatial anxiety (i.e., Lawton, 1994 only measures navigation whereas Geer, 2019 measures four subtypes), we may see differences in the relation between spatial anxiety and skill based on the scale used. Recent work suggests there may be stronger relations between spatial anxiety and skills for subscales of spatial anxiety such as mental manipulation and navigation when compared with imagery (Geer, 2019; Lyons et al., 2018). This is perhaps because mental manipulation and navigation anxiety subscales are tied closely to the components that make up mental manipulation and navigation skills respectively. To address this, the measure used and type of spatial anxiety measured have been included as moderators in the present meta-analytic review.

Spatial Skill Measures and Subtypes

Theory on spatial cognition suggests that these skills can be divided into several subtypes (Linn & Petersen, 1985; Uttal et al., 2013) that are assessed through a variety of spatial tasks (e.g., Embedded Figures task, Lyons et al., 2018, adapted from Ekstrom et al., 1976; Mental Rotation Task, MRT, Peters et al., 1995, Vandenberg & Kuse, 1978; Crystal Slicing Test, Ormand et al., 2013). Based on work examining the relation between different subtypes of spatial anxiety and skills (Geer, 2019; Lyons et al., 2018), we would expect that the type of skill measured would potentially impact the relation between spatial anxiety and skills. The spatial measure used is worth examining because it is possible that some measures of spatial skill trigger more anxiety based on the complexity of the task. For example, mental rotation tasks involve imagining an object and rotating it in your mind to assess something about the object (i.e., to match it to a target object). A task with moving components like this may be more cognitively involved than tasks with no moving components, therefore leading to a potential increase in spatial anxiety. Assessing which subtype of spatial skill is measured, incorporating the Uttal et al. (2013) framework, is necessary since specific subtypes may be more or less associated with spatial anxiety. Thus, the present meta-analytic review aims to include both the specific spatial tasks used and subtypes of spatial skill as potential moderators for the relation between spatial anxiety and spatial skills.

Matching Anxiety and Skill Subtypes

Since most spatial tasks measure only one subtype of spatial skill, it is possible that certain spatial measures may be more aligned with specific subtypes of spatial anxiety. Thus, we believe that the relation between spatial anxiety and spatial skills may be significantly stronger when there is a *match* between the subtype of anxiety and skill that is measured (i.e., navigation anxiety and navigation skill are measured). There is some evidence of this in existing research, with both Geer (2019) and Lyons et al. (2018) finding stronger relations between some of the spatial tasks that measured subtypes that matched with the subscales of their spatial anxiety measures. Thus, we will examine if the relation between spatial anxiety and spatial skills differs depending on whether there is a match between the anxiety and skill subtype measured.

Publication Year

Because this is the first meta-analytic review on the relation between spatial anxiety and spatial skills, we include publication year as a potential moderator of this relation.

Risk of Bias

To assess whether effect sizes from included studies are truly reflective of the relation they examine, meta-analyses have begun to account for the methodological rigor of included studies (e.g., Hjetland et al., 2017). Study quality can vary greatly and in a systematic review or meta-analysis it is vital that we account for the potential influence of risk of bias on the reported effect size(s). Each selected article received a quality score based on the criteria outlined by Hjetland et al. (2017), and this score was used as a moderator in the present meta-analytic review.

Present Study

Though there is an abundance of research on the relation between spatial anxiety and spatial skills, there has yet to be a meta-analytic review summarizing the existing work and comparing the effect sizes reported across studies based on critical moderators. The goal of the present meta-analytic review is to examine what the existing research can tell us about the relation between spatial anxiety and spatial skills. We would like to know 1) the size and statistical significance of the overall relation between spatial anxiety and spatial skills, and 2) if the strength of the relation differs depending on the sex of the sample, grade level/age group of the sample, geographical region of the sample, spatial anxiety scale used, spatial anxiety subtype assessed, spatial skills measure used, spatial skill type measured, matching spatial anxiety and spatial skill subtype, publication year, publication type, or risk of bias. By considering these moderators, the results will give insight into when the relation between spatial anxiety and spatial skills may be especially strong.

Based on existing research, we expect to find that the overall average weighted effect size of the included studies will demonstrate a significant negative correlation between spatial anxiety and spatial skills, such that those who report higher levels of spatial anxiety will tend to score lower on spatial tasks. Research shows that there are often systematically stronger correlations reported in published compared to unpublished studies. Therefore, we expect to find a significant moderation effect with evidence for publication bias. Based on existing research and a meta-analysis in a similar domain (math anxiety and performance, Barroso et al., 2021), we expect that there will be little difference in the magnitude of the relation between spatial anxiety and skills for all-male samples and all-female samples. For age, based on existing research examining domain specific anxieties in children (e.g., Geer, 2021; Lauer et al., 2018), it is possible that we may see weaker relations between spatial anxiety and spatial skills for younger children.

Based on past research, we expect that relations between spatial anxiety and spatial skills may be stronger when mental rotation/manipulation (Linn & Petersen, 1985; Uttal et al., 2013) and navigation (Uttal et al., 2013) anxiety or skills are measured because these subtypes incorporate movement, making them more complex. For the matching anxiety and skills moderator, we expect to find stronger relations between spatial anxiety and skills when the effect size includes measures of the same subtype (e.g., navigation anxiety and navigation skill). Due to limited knowledge about how geographical region, spatial anxiety scale, and risk of bias may impact the relation between spatial anxiety and skills, we do not have specific hypotheses.

Methods

Transparency and Openness

This meta-analytic review was pre-registered through Prospero, an international register of systematic reviews coordinated by the National Institute for Health Research (York, United Kingdom). The timestamped preregistration can be found on the Prospero website (Geer et al., 2020) https://www.crd.york.ac.uk/prospero/display_record.php?RecordID=169980. We also created an OSF page (Geer et al., 2023) with our data, R code, codebook, and a comprehensive excel sheet that includes all studies that were excluded from the present meta-analysis with reasons for why each was excluded: https://osf.io/sdpve/.

Study Search and Selection

The search for relevant articles consisted of two techniques. The first technique was modeled after existing meta-analyses in similar fields of research (Barroso et al., 2021; Lauer et al., 2019; Ma et al., 1999). We conducted an online database search across three journal databases that focus on literature in psychology, education, and medicine: APA PsycInfo, Educational Resources Information Center (ERIC), and Medline, as well as two broader databases that include literature from many sources: Web of Science and Google Scholar. To remain consistent with the search terms and Boolean operators across databases, we used the ProQuest platform for each search. We queried any available document that contained our search terms, including both peer-reviewed publications and grey literature, such as theses, dissertations, reports, and conference proceedings. The selected year criteria for these searches were any documents or publications available in July 2020, when the search was conducted.

To conduct an exhaustive search through our query of online databases, we took several steps to develop an inclusive list of search terms. We used the APA PsycInfo Thesaurus, knowledge of the field of study, and search terms employed by meta-analyses in similar research areas (i.e., math with math anxiety, Barroso et al., 2021; gender differences in spatial reasoning, Lauer et al., 2019) to develop this list. We included the following search terms, making sure to select for articles that included both the term ‘spatial skills’, or a related term, and the term ‘spatial anxiety’ (denoted by the connecting AND): (spatial OR visuospatial or “mental rotation”) AND (“spatial anxiety”). We searched for these terms anywhere in a document. The second search technique we used to procure relevant studies was emailing the Cognitive Development Society (CDS) listserv and requesting that researchers with unpublished data on the relation of spatial anxiety and spatial skills provide their data/write-up to be included.

Inclusion Criteria

Studies were eligible to be included if they met the following criteria. First, included studies had to have quantitative data on the relation between spatial anxiety and spatial skills; this led to the exclusion of review articles, corrections to existing manuscripts, etc. Second, the included studies needed to involve human participants. Third, studies had to measure spatial skills or performance using a relevant spatial task. Measures of self-reported spatial skills (e.g., perceived spatial skills, such as the Santa Barbara Sense of Direction Scale, SBSOD; Hegarty et al., 2002) did not meet this criterion. Fourth, studies had to measure spatial anxiety using a relevant spatial or wayfinding anxiety scale/measure. Measures of self-reported spatial confidence or other such constructs did not meet this criterion.

As a fifth inclusion criterion, studies had to either report a zero-order correlation coefficient between spatial anxiety and spatial skill or have collected data that made the calculation of a zero-order correlation possible. If the relation was not reported in the manuscript, but data were collected, or if multivariate regression coefficients were reported, zero-order correlations were requested from authors via email. Sixth, if a study tested an intervention, we only included effect sizes if data were available for both spatial anxiety and spatial skill *prior* to the intervention. The final inclusion criterion was that studies were only included if both spatial anxiety and spatial skill were measured in the same group of people (e.g., a correlation between spatial anxiety of parents and the spatial skills of their children would not meet this criterion).

Screening and Coding Procedures and Included Studies

Figure 1 displays a flowchart of the article selection process. The database search yielded a total of 1736 relevant documents. We excluded 131 duplicate titles, making the final count 1605 independent documents found through the initial database search. These documents were then reviewed closely using the previously outlined inclusion criteria. At each round, questions regarding the screening and coding of specific articles were discussed as a group through a private, online messaging system and through ad hoc meetings as needed with the five coders resolving any questions unanimously. Training for each round of screening and coding consisted of reviewing the inclusion criteria as a group prior to each round and answering any questions that arose prior to the start of the round.

In Round 1, the 1605 included studies were split up so that that each article was screened by two of the five coders. Of these 1605 articles, 126 articles were identified as articles in languages other than English. For articles in languages other than English, we followed the coding procedures outlined in Busse et al. (2014). Using these procedures, 15 articles were removed for being 1 of fewer than 3 articles in that language (i.e., there was only 1 article in Czech, so that article was removed). For the remaining 1584 articles (of which 105 were in languages other than English), coders looked at the study titles and abstracts obtained from the online database search. For languages other than English, the titles and abstracts were translated into English. An excel file with all excluded articles and rationale for exclusion can be found on our OSF page (Geer et al., 2023): https://osf.io/sdpve/.

During Round 1, 1605 articles we started with were sorted into yes (48 articles), no (1454 articles; including the 15 that were excluded following Busse et al., 2014), and maybe (105 articles) categories based on the inclusion criteria. All articles in Round 1 were double coded and any disagreements were discussed among the entire group. After Round 1, initial author query emails were sent to a subset (27) of the authors of studies where the full text was unavailable. In these emails, we requested a full document version of the study. Of these author queries, we had a 33% response rate, receiving 9 full articles back. The remaining 18 articles were considered failed author queries and excluded from further rounds.

Round 2 began with 126 articles (including the 9 full-text documents we received from author queries) and consisted of two coders screening each full-text document (for languages other than English, the articles were translated into English) for each of the articles identified as "maybe" or "yes" from Round 1 (126 articles total). Coders categorized them into yes (73 articles) or no (53 articles) categories, again based on the inclusion criteria. If two coders' choices did not match for an article, these articles were discussed at a roundtable discussion among the coders to determine whether or not the study was included. Following Round 2 there were 73 included studies moving forward from our database search. References for all articles excluded during Round 2 or later can be found in the supplemental materials.

During Round 3, the coding phase, we coded the included articles from Round 1 and Round 2 (73 articles total). The following study information from each of the 73 studies was entered into a Qualtrics survey: correlation coefficients, sample size, sex, age and grade level, race/ethnicity, country, spatial anxiety scale used, spatial anxiety subtype, spatial task used, spatial skill subtype, and risk of bias factors. The studies were divided between all five raters to be coded. Each article was coded by two raters, and any disagreements or concerns were discussed as a group via a private, online messaging system or via round table discussions. From the coding process, an additional 5 articles were excluded leaving 68 articles that moved forward from Round 3 of Coding. This led to Round 4, which involved contacting the corresponding authors via email or other means (i.e., ResearchGate) if the effect size or sample size was not reported in an included study (n = 41). From these author queries, 10 articles were excluded due to failed author queries (i.e., the author did not have access to the dataset), 12 were excluded due to no response, and 2 were excluded due to no pretest data available in an experimental design. We received 17 replies (41%) with the needed effect sizes. During the coding process, we also received 6 additional studies from grey literature search through the CDS listserv were double coded for effect sizes, descriptive information, and information for moderators. Thus, there were 50 studies with a total of 283 effect sizes included in the present meta-analyses.

Inter-rater reliability. All the included studies in Round 3, which involved the coding of full articles for relevant study and effect size information, were coded by two coders. The index of agreement rate was calculated for all data extracted by coders for the inclusion variable (i.e., whether or not the article should be included), the number of effect sizes in each study, effect size, sample size, sex, race/ethnicity, country, grade level, spatial anxiety scale used, subtypes of spatial anxiety, spatial task, and spatial skill subtype.

First, we calculated the agreement rate for whether the coder decided, based on our inclusion criteria, to include the study in our meta-analytic review. If coders disagreed on the inclusion variable, the study was not included in the agreement rate calculation for the number of effect sizes and moderator variables. Next, we calculated the agreement rate for the number of included effect sizes between measures of spatial anxiety and spatial skill from each study as reported by each coder. Then, based on the final codes for each moderator (see below section on Coding Categories), we calculated the agreement rate for each of the moderator variables. It is worth noting that if there was a disagreement on the number of effect sizes, we were only able to code the agreement rate for effect sizes that overlapped between coders. Since we had different pairs of coders selected from five possible coders that each worked on a random subset of the studies from Round 3, the agreement rate was calculated for each pair of raters (10 pairs total). These rates were then averaged across rater pairs for each variable.

The average coder agreement rate across raters was 97% for the inclusion variable, 89% for the number of effect sizes, 100% for the effect size itself, and 99% for the sample size. Average agreement rates for the moderator variables ranged from 91% to 100%, with an average of 98.5%. To ensure accurate coding of variables from included studies, most included study variables were checked for accuracy by another coder or verified by the first author. Table S1 in the supplemental materials has agreement rates for each variable.

Details of study coding categories

For each effect size, demographic and measure information was recorded in an online Qualtrics survey and then coded for the moderator analysis into particular categories. The coding scheme is outlined below.

Publication bias. Publication status was categorized as: published (k = 180) and unpublished (k = 103; including theses, dissertations, manuscripts in preparation, conference proceedings/papers, raw data, grey literature, etc.). Since there may be a tendency for published studies not to report non-significant effect sizes that are not directly relevant to their primary research objectives, we also conducted a second, exploratory version of this moderator analysis. Specifically, any effect size that was not reported in a published manuscript and was retrieved via author query, we categorized as *unpublished*. For this version of the analysis, publication status was coded as: published effect size (k = 106) and unpublished effect size (k = 177).

Demographic information.

Sex. Information about the reported sex of each sample was entered by selecting if the sample for each effect size was all male, all female, a combined sample (i.e., the effect sizes are not reported for all male or all female samples), or not reported. Reported sex information was only used for moderator analyses if the samples were all male ($k = 24$) or all female ($k = 32$).

Grade level/Age group. Mean age, standard deviation of age, minimum age, and maximum age of each sample were recorded if reported in the study. However, because this was only recorded for a subset of the studies, moderator analyses were focused on grade level, which was more likely to be reported. Grade level(s) (i.e., year in school based on the U.S. system) of the sample for each effect size was selected from one or more of the following choices: kindergarten, grade 1, grade 2, grade 3, grade 4, grade 5, grade 6, grade 7, grade 8, grade 9, grade 10, grade 11, grade 12, community college, undergraduate, graduate students, adults (not specified as students), not reported/relevant, and/or not sure. The following subgroups were used: grades K-2 ($k = 6$), grades 3-5 ($k = 3$), grades 6-8 ($k = 0$), grades 9-12 ($k = 1$), undergraduate and graduate students ($k = 183$), and non-student adult samples ($k = 83$). However, due to the small number of samples in grades K-12, we also combined these into a school-age subgroup to use in analyses ($k = 12$) as well. There was a subset of effect sizes from multiple age groups that were nonconsecutive. These effect sizes were excluded as they could not be sorted into a specific age group ($k = 5$).

For samples with no reported grade level but with a reported age, we estimated the grade according to the average compulsory age for students entering each grade from the United States, based on the mean age or the highest category for the range of age if reported (Education Commission of the States, 2018). For samples that included participants from two or more consecutive grades we first estimated the grade based on mean age, if available. If the mean age was not reported, a mean grade was calculated based on the median grade of the total grade range reported, and subsequently coded into the grade category for the median grade (e.g., samples with students in grades 7 through 9 were calculated to be in grade 8 and coded as being in the grade category for grades 6 through 8).

Race/ethnicity. Race/ethnicity was entered as whether the sample associated with each effect size consisted of 75% or more White participants, Black participants, Hispanic/Latinx participants, Asian participants, the sample consisted of a racially diverse group (i.e., no race was more than 75% of the sample), or the racial or ethnic breakdown of the sample was not reported. It should be noted that for most effect sizes, studies did not report a racial/ethnic breakdown of their sample (k = 256, 90%). Of the studies that did report a breakdown by race/ethnicity, only two subgroups were represented: 75% or more Asian participants (k = 2) and racially diverse (i.e., no race was more than 75% of the sample, k = 25). Therefore, the race/ethnicity moderator was removed from analyses, as there was not enough information from our included studies to make this moderator analysis meaningful.

Geographical region. Information about the geographical region where the study was conducted was entered as the country or countries reported for the sample for each effect size, or as not reported. There were 9 countries represented; however, many effect sizes (k = 117, 41%) were from studies in the United States of America and 4 of the countries had fewer than 5 effect sizes from only 1 study. Thus, for the moderator analysis to be more meaningful, country information was recoded into continent (following methods by Barroso et al., 2021) leaving 3 continents represented: North America (k = 134), Europe (k = 134), and Asia (k = 15).

Publication year. Publication year was recorded for all published studies, theses, dissertations, and conference proceedings and included as a continuous moderator for analyses.

Measures information.

Spatial anxiety scale. Spatial anxiety measures were categorized as: Lawton (1994; *k* = 94); Malanchini et al. (2017; *k* = 12); Lyons et al. (2018; *k* = 14); Geer (2019; *k* = 48); Other Spatial Anxiety Scale (with space to specify; *k* = 95); researcher developed scale (*k* = 0) and Wayfinding Anxiety Scale (*k* = 20).

Spatial anxiety subtype. Spatial anxiety subtypes were categorized across the Linn and Petersen (1985) framework and the Uttal et al. (2013) framework. Because the categories of Linn and Petersen map closely onto the Uttal et al. categories and the pattern of results was similar across frameworks, all coding procedures and results regarding the Linn and Petersen (1985) framework can be found in the supplemental materials. For the Uttal et al. framework, the spatial anxiety subtype codes were imagery/intrinsic-static anxiety (*k* = 18); mental manipulation/intrinsic-dynamic anxiety (*k* = 18); scalar comparison/extrinsic-static anxiety (*k* = 12); navigation/extrinsic-dynamic anxiety (*k* = 196); multiple subtypes (*k* = 25); and other/unclear subtype (*k* = 4).

Spatial skill task. The subgroups for spatial skill task were mental rotations tasks (*k* = 44); spatial orientation tasks (*k* = 22); road map tasks (*k* = 19); virtual reality navigation tasks (*k* = 23); water level tasks (*k* = 6); plum line/van and bulb tasks (*k* = 4); embedded figures tasks (*k* = 18); hidden patterns tasks (*k* = 4); crystal slicing tasks (*k* = 4); researcher developed tasks (*k* = 23); and other spatial measures (*k* = 116). For each of these options there was a space that could be used to specify what specific task was used.

Spatial skill subtype. Spatial skill subtypes were categorized across the Linn and Petersen (1985) framework and the Uttal et al. (2013) framework. Coding procedures and results regarding the Linn and Petersen framework can be found in the supplemental materials. For the

Uttal et al. framework, spatial skill subtypes were imagery/intrinsic-static (*k* = 30); mental manipulation/intrinsic-dynamic (*k* = 69); scalar comparison/extrinsic-static (*k* = 24); navigation/extrinsic-dynamic (*k* = 141); visuospatial working memory (*k* = 17); and multiple subtypes (*k* = 2). Table 1 lists definitions and examples of each category.

Risk of bias. Following methods employed by Hjetland et al. (2017), the subsequent information was obtained from each study to assess its risk of bias: sampling procedures: random (score of 0) or convenience (score of 1); sampling procedures: unselected (score of 0) or selected (score of 1); test reliability: reported for both measures (score of 0), reported for either spatial anxiety or spatial skills (score of 1), or not reported (score of 2); floor or ceiling effects: no floor/ceiling effects (score of 0) or floor/ceiling effects on one or more measures or not enough information reported to tell (score of 1); missing data: handled using methods such as full information maximum likelihood (FIML) estimation (score of 0) or handled using listwise deletion/not mentioned (score of 1); latent variables: used (score of 0) or not used (score of 1); sample size: 150 or more (score of 0), between 70-150 (score of 1), or under 70 (score of 2). These scores were summed for each study and ranged from 0-9, with higher scores indicating a higher risk of study bias. This was included as a continuous moderator for analyses. The distribution of scores was as follows: score of 3 (*k* = 2), score of 4 (*k* = 15), score of 5 (*k* = 31), score of 6 (*k* = 82), Score of 7 (*k* = 80), score of 8 (*k* = 42), and score of 9 (*k* = 9).

Data Analysis Plan

Overall average effect size

We used Pearson's *r* correlation coefficient as the effect size for this meta-analytic review under the assumption that the effect size would be based on variables using scales that were continuous rather than rank-ordered or categorical. Pearson correlation coefficients were converted to Fisher's *Z*-scores to approximate a normal distribution of the population effect sizes (Cohn & Becker, 2003). Due to varying sample and measure characteristics used to assess spatial anxiety and spatial skills, the sample of included studies was considered to come from a random sample. Therefore, the overall average effect size model was fitted as a random-effects model. For random-effects models, the true effect size that a study estimates is considered to be random and made up of the true estimate plus the sampling error variance and between-studies variance. Once the true effect size estimate was calculated, we transformed to overall Fisher's *Z* score back to Pearson's *r* correlation coefficient for interpretation and reporting purposes.

We conducted multilevel meta-analyses to model the nested structure of the data, as several of the included studies reported multiple effect sizes (i.e., dependent samples). This technique accounts for sampling variance of the extracted effect size (Level 1), variance between effect sizes from the same study (Level 2), and variance between studies (Level 3; Hox, 2010). To conduct these multilevel meta-analyses, the metafor package from the statistical program R was used with the restricted maximum likelihood estimation method (Viechtbauer, 2010). For more detailed information on our data analysis plan, including more information about how we assessed publication bias, please see the supplemental materials.

Results

Study Characteristics

The 50 studies included in the present meta-analytic review provided 283 correlation coefficients (averaging 5.66 correlations per study) from 67 samples with 23,132 participants. Of the 50 included studies, 36 were peer-reviewed publications and 14 were non-peer reviewed (theses/dissertations, conference proceedings/papers, manuscripts in preparation, raw data, grey literature, etc.). These studies were conducted from 1994 to 2020 with an increase in frequency

(41 of the included studies were conducted after 2010). These studies were conducted across 9 countries and 3 continents; however, 4 of the countries were represented by only 1 study. All of the included studies were written in either English (48) or Italian (2). Based on our risk of bias scale that refers to the quality of the included studies, most of the included studies scored quite high on this scale (*M* = 7, with scores ranging from 0 to 9) indicating greater risk for bias. Many of these higher bias scores were due to lack of clarity of reporting (e.g., unclear sampling strategy, unreported reliability information) or factors that limit almost all psychological studies (e.g., not having a randomly selected sample).

Only 9 of the studies reported effect sizes separately for male and female samples, with 41 studies reporting on the relation in the full sample. The participants ranged in age from young children to older adults, with 49 studies reporting specific age information on their participants. There were 6 studies with participants under 18 years old (3 studies on first through second graders, 2 studies on third through fifth graders, and 1 study with ninth through twelfth graders). There was 1 additional study with three samples spanning multiple grades ranging from kindergarten through fourth grade that was included for the age moderator when groups were collapsed for participants under the age of 18 years old. For adult samples, there were 31 studies reporting on undergraduate and graduate students and 12 reporting on non-student adult samples (most often older adults).

Most studies (31) employed an established measure of spatial anxiety, with 22 using the Lawton (1994) scale, 1 using the Malanchini et al. (2017) scale, 3 using the Lyons et al. (2019) scale, 1 using the Geer (2019) scale, and 4 using various Wayfinding Anxiety Scales. The most commonly measured spatial anxiety subtype was navigation. Most studies (35) used at least one known measure of spatial skill, with many studies using more than one spatial skill measure.

Specifically, of these 35 studies using known measures of spatial skill, 25 used a Mental rotation task, 12 used a Spatial orientation task, 4 used a Road map task, 6 used a Virtual reality navigation task, 2 used a Water level task, 1 used a Plum line/van and light bulb task, 5 used an Embedded figures task, 1 used a Hidden patterns task, and 1 used a Crystal slicing task. The most commonly measured subtype of spatial skill was mental manipulation. An excel file and code book with all study information, including descriptive factors and effect sizes, can be found on our OSF page (Geer et al., 2023) at https://osf.io/sdpve/.

Overall Average Correlation Between Spatial Anxiety and Spatial Skills

The average correlation between spatial anxiety and spatial skills was small, negative, and statistically significant (r = -.14, p < .001, 95% CI [-.17, -.11]). As indicated by the Q statistic and I^2 statistic, there was a significant amount of unexplained variance across the range of effect sizes included in the calculation of the overall average effect size (Q = 855.44, p < .001, df = 282, I^2 = 67.03), suggesting these effect sizes did not come from the same population and validating our use of a random-effects model. An analysis to assess the need for three-level modeling versus a more simplified two-level model confirmed the necessity for a three-level model (see the supplemental materials for more details).

Publication bias

Publication status. We ran two versions of this moderator analysis. In the first, effect sizes for published articles were considered published even if they were retrieved via author query, because the data were published in a manuscript. In the second, effect sizes were only considered published if the actual effect size was in a published manuscript (i.e., effect sizes retrieved from author queries were coded as unpublished). For the first version, both effect sizes from published articles (k = 189, r = -.16, 95% CI [-.19, -.12]) and unpublished effect sizes (k =

94, r = -.11, 95% CI [-.15, -.06]) had significant average effect sizes for the relation between spatial anxiety and spatial skills. This version of the moderator analysis for publication status was not significant ($F(1, 281) = 2.81$, $p = .095$), suggesting that when effect sizes obtained from author queries are considered *published* there is no publication bias. For the second exploratory version, the overall correlations for both published effect sizes (k = 115, r = -.17, 95% CI [-.21, -.14]) and unpublished effect sizes (k = 168, r = -.11, 95% CI [-.14, -.07]) remained significant. However, this version of the moderator analysis for publication status was significant ($F(1, 271) = 9.39$, $p = .002$), suggesting that when effect sizes that are not included in a published manuscript are sorted as *unpublished* there is publication bias in our sample.

Visual inspection of the funnel plot of the effect sizes by their standard errors (black dots in Figure 2), with higher standard errors at the bottom of the plot, indicated that the spread of the effect sizes was not perfectly symmetrical; however, the distribution of dots suggests there are no specific effect sizes missing. Many of the dots were located around the line denoting the overall average correlation (r = -.14), suggesting that many of the effect sizes in the meta-analytic sample represent reporting small-to-moderate negative effect sizes obtained from studies with various sample sizes. While there was no obvious visual asymmetry, many of the dots are concentrated in the small-to-moderately significant areas of the funnel (as indicated by the shaded diagonal lines in Figure 2) this would suggest the cause of the asymmetry may be more likely to be due to factors other than publication bias, such as variable study quality (e.g., Peters et al., 2008). The Egger test for plot asymmetry was not significant (z = -0.84, 95% CI [-2.94, 1.17], p = .399), suggesting, in line with the visual symmetry in the funnel plot, that there is not a statistically significant amount of asymmetry in the present meta-analytic review. The trim-and-fill analysis indicated that there are no effect sizes potentially missing and needed to fill in the sparse areas of the funnel plot (see Figure 2, missing effect sizes would be indicated by *white* dots). This result suggests that after adjusting the funnel plot to be symmetrical, the adjusted overall correlation coefficient would remain statistically significant and similar in magnitude to the original overall correlation coefficient, r = -.14, 95% CI [-.16, -.13], p < .001.

Moderation Effects of Demographic and Measure Characteristics

We conducted moderator analyses to examine if demographic or measure characteristics might explain variation in the relation between spatial anxiety and skills. Table 2 contains model results for overall and moderator analyses. For all pairwise comparisons, the direction (positive vs. negative) of the regression coefficient (b) is based on the order of categories in the test. The regression coefficient is the difference between the effect size of the first category and the second category (First effect size – Second category effect size). Thus, a positive result means that the first category has a stronger negative relation (e.g., –.20 – (–.10) = .30) and a negative result means that the first category has a weaker negative relation (e.g., –.10 – (–.20) = –.10).

Moderation Effects of Demographic Characteristics

Sex. Figure 3 contains a plot for effect sizes across demographic characteristics. The relation between spatial anxiety and spatial skills was statistically significant for the two subgroups in the sex moderator of samples with all male participants (k = 24; r = -.15, 95% CI [-.22, -.08]) and samples with all female participants (k = 32; r = -.08, 95% CI [-.12, -.05]). The omnibus test indicated that the average effect size for males was not statistically different from the average effect size for females (F(1, 54) = 2.93, p = .093).

Grade level/age group. The subgroups for testing grade level as a moderator were grades K-2 (k = 6), grades 3-5 (k = 3), grades 6-8 (k = 0), grades 9-12 (k = 1), undergraduate and graduate students (k = 183), and non-student adult samples (k = 83). The relation between spatial anxiety and spatial skills was only statistically significant for undergraduate and graduate student samples (*r* = -.16, 95% CI [-.20, -.13]) and non-student adult samples (*r* = -.12, 95% CI [-.16, -.08]). The omnibus test for grade level was not significant, *F*(4, 271) = 1.09, *p* = .364, indicating no significant difference in the relation between spatial anxiety and spatial skills for these groups. When we collapsed the K-12 groups across school-age children and adolescents (grades K-12; *k* = 12; *r* = -.08, 95% CI [-.15, -.02]) we found that the relation between spatial anxiety and spatial skills was significant for all three subgroups of the grade level moderator. The omnibus test for broader grade levels was not significant, *F*(2, 275) = 2.43, *p* = .090, indicating that there were no statistically significant differences between groups.

Geographical region. The relation between spatial anxiety and spatial skills was significant across all three subgroups of the continent moderator (*p*s < .001): North America (*k* = 134, *r* = -.14, 95% CI [-.19, -.10]), Europe (*k* = 134, *r* = -.14, 95% CI [-.18, -.10]), and Asia (*k* = 15, *r* = -.12, 95% CI [-.16, -.08]). The omnibus test for this moderator analysis was not significant, *F*(2, 280) = 0.22, *p* = .806, indicating no statistically significant differences in the strength of the spatial anxiety - spatial skills relation between samples from these continents.

Publication year. The moderator analysis for the continuous moderator of publication year was not statistically significant (*F*(1, 281) = .09, *p* = .760), suggesting year of publication does not relate to the strength of the relation between spatial anxiety and spatial skills.

Moderation Effects of Measure Characteristics

Spatial anxiety scales. Figure 4 contains a plot of average effect sizes across subgroups for spatial anxiety measure and subtype characteristics. The relation between spatial anxiety and spatial skills was significant for all subgroups for this moderator: Lawton (1994) scale (*k* = 94, *r* = -.16, 95% CI [-.21, -.10]), Malanchini (2017) scale (*k* = 12, *r* = -.12, 95% CI [-.16, -.07]), Lyons (2018) scale (k = 14, r = -.16, 95% CI [-.22, -.09]), Geer (2019) scale (k = 48, r = -.20, 95% CI [-.23, -.17]), Wayfinding Scales (k = 20, r = -.13, 95% CI [-.24, -.01]), and Other scales (k = 95, r = -.13, 95% CI [-.16, -.09]). The omnibus test for the spatial anxiety measure used was not statistically significant, $F(5, 277) = 0.36$, p = .879.

Spatial anxiety subtype. For moderators that include spatial subtype distinctions (spatial anxiety subtype, spatial skill subtype, spatial anxiety and spatial skill match), we present results from the Uttal et al. framework. Findings for the Linn and Petersen (1985) framework were largely consistent with those for Uttal et al. and are reported in the supplementary materials. See Figure 4 for a plot comparing subtypes of spatial anxiety from the Uttal et al. framework. The spatial anxiety subtypes were Imagery/intrinsic-static anxiety (k = 18, r = -.07, 95% CI [-.16, .02]), mental manipulation/intrinsic-dynamic anxiety (k = 18, r = -.22, 95% CI [-.27, -.18]), scalar comparison/extrinsic-static anxiety (k = 12, r = -.26, 95% CI [-.32, -.21]), navigation/extrinsic-dynamic anxiety (k = 205, r = -.15, 95% CI [-.18, -.12]), multiple subtypes (k = 26, r = -.11, 95% CI [-.15, -.06]), and other/unclear subtype (k = 4, r = -.13, 95% CI [-.34, .08]). The average effect size for the relation between spatial anxiety and spatial skills was significant for all subgroups (ps < .001) except for the imagery anxiety subtype (p = .112) and the other/unclear anxiety subtype (p = .230) subgroups. The omnibus test for this moderator analysis was statistically significant, $F(5, 277) = 4.70$, p < .001.

Pairwise comparisons indicated several statistically significant differences between spatial anxiety subtypes (see Table 3). Effect sizes that included spatial anxiety scales measuring imagery anxiety (r = -.07) had statistically significantly lower magnitude correlations than did effect sizes with scales assessing mental manipulation anxiety (r = -.22, b = -0.10, p = .003) and scalar comparison anxiety (r = -.26, b = -0.10, p = .004). Effect sizes with a scale measuring mental manipulation anxiety (r = -.22) had statistically significantly higher magnitude correlations than did effect sizes that included scales assessing navigation anxiety (r = -.15, b = 0.08, p = .004) and multiple subtypes of anxiety (r = -.11, b = 0.12, $p < .001$). Effect sizes that included spatial anxiety scales measuring scalar comparison anxiety (r = -.26) had significantly higher magnitude correlations than did effect sizes with scales assessing navigation anxiety (r = -.15, b = 0.14, $p < .001$) and multiple subtypes of anxiety (r = -.11, b = 0.16, p = .011).

Spatial skill measure. Figure 5 contains a plot of average effect sizes across different spatial skill measures. The categories for this moderator analysis were mental rotations tasks (k = 44, r = -.16, 95% CI [-.20, -.12]), spatial orientation tasks (k = 22, r = -.15, 95% CI [-.23, -.07]), road map tasks (k = 19, r = -.20, 95% CI [-.25, -.14]), virtual reality navigation tasks (k = 23, r = -.16, 95% CI [-.28, -.04]), water level tasks (k = 6, r = -.12, 95% CI [-.25, .01]), plum line/van and light bulb tasks (k = 4, r = -.20, 95% CI [-.27, -.14]), embedded figures tasks (k = 18, r = -.12, 95% CI [-.18, -.05]), hidden patterns tasks (k = 4, r = -.21, 95% CI [-.27, -.14]), crystal slicing tasks (k = 4, r = -.15, 95% CI [-.22, -.09]), researcher developed tasks (k = 23, r = -.12, 95% CI [-.24, .01]), and other tasks (k = 116, r = -.13, 95% CI [-.17, -.10]). The relation between spatial anxiety and spatial skills was significant for all task categories (ps < .05) except for water level tasks (p = .070) and researcher developed tasks (p = .079). The omnibus test for this moderator analysis was significant, $F(10, 272) = 3.23$, $p < .001$.

Pairwise comparisons indicated several statistically significant differences between spatial skills measures (see Table S2 in the supplemental materials). Effect sizes that included embedded figure tasks (r = -.12) had statistically significantly lower magnitude correlations than did effect sizes that included mental rotation tasks (r = -.16, b = 0.14, $p < .001$), spatial orientation tasks (r = -.15, b = 0.10, p = .021), road map tasks (r = -.20, b = 0.12, $p < .001$), plum line/van and light bulb tasks (*r* = -.20, *b* = 0.12, *p* = .012), and hidden patterns tasks (*r* = -.21, *b* = -0.12, *p* = .011). Effect sizes that used crystal slicing tasks (*r* = -.15) had statistically significantly lower magnitude correlations than did effect sizes that included mental rotation tasks (*r* = -.16, *b* = 0.14, *p* = .030), spatial orientation tasks (*r* = -.15, *b* = .14, *p* = .005), and road map tasks (*r* = -.20, *b* = 0.09, *p* = .034). Effect sizes that used water level tasks (*r* = -.12) had statistically significantly lower magnitude correlations than did effect sizes that used spatial orientation tasks (*r* = -.15, *b* = 0.12, *p* = .011) and road map tasks (*r* = -.20, *b* = 0.09, *p* = .022). Effect sizes that used mental rotation tasks (*r* = -.16) had significantly stronger correlations than did effect sizes that used other spatial skill tasks (*r* = -.13, *b* = 0.05, *p* = .039). There were no other significant differences.

Spatial skill subtype. For this moderator, we again report results using the Uttal et al. (2013) framework for subtypes of spatial skills with the Linn and Petersen (1985) results available in the supplementary materials. Figure 5 contains a plot of average effect sizes across different spatial skill subtype characteristics. The spatial skill subtypes were imagery/intrinsic-static skill (*k* = 30, *r* = -.13, 95% CI [-.16, -.10]), mental manipulation/intrinsic-dynamic skill (*k* = 69, *r* = -.15, 95% CI [-.18, -.11]), scalar comparison/extrinsic-static skill (*k* = 24, *r* = -.14, 95% CI [-.21, -.06]), navigation/extrinsic-dynamic skill (*k* = 141, *r* = -.16, 95% CI [-.20, -.12]), visuospatial working memory skill (*k* = 17, *r* = -.09, 95% CI [-.15, -.02]), and multiple skills (*k* = 2, *r* = -.05, 95% CI [-.21, .10]). Except for spatial tasks that measured multiple skill subtypes (*p* = .501), the average effect sizes for all groups was significant (*p*s < .05). The omnibus test for this moderator analysis was statistically significant, $F(5, 277) = 2.91$, *p* = .014. Pairwise comparisons indicated effect sizes with tasks intended to measure navigation skill (*r* = -.16) had statistically significantly higher magnitude correlations between spatial anxiety and spatial skills than did effect sizes with tasks intended to measure imagery skill (*r* = -.13, *b* = -0.07, *p* = .007) and scalar comparison skill (*r* = -.14, *b* = -0.06, *p* = .020; see Table 4).

Spatial anxiety and spatial skill subtype match. We next conducted exploratory (i.e., not preregistered) analyses to examine whether correlations were stronger when the same type of spatial anxiety and spatial skill were measured. We present results using the Uttal et al. (2013) framework and report results from the Linn and Petersen (1985) framework in the supplemental materials. Figure 5 contains a plot of average effect sizes across different spatial skill measure and subtype matches and mismatches.

We first compared effect sizes that measured imagery anxiety and skill (*k* = 5, *r* = -.08, 95% CI [-.16, .00]), effect sizes that measured imagery anxiety and another spatial skill subtype (*k* = 13, *r* = -.08, 95% CI [-.18, .02]), and effect sizes that measured another spatial anxiety subtype and imagery skill (*k* = 22, *r* = -.14, 95% CI [-.18, -.10]). The average effect size was only significant for effect sizes with another spatial anxiety subtype and imagery skill ($p < .001$). The omnibus test for this moderator was not statistically significant, $F(2,37) = 0.69$, $p = .506$.

We next compared effect sizes that measured mental manipulation anxiety and mental manipulation skill (*k* = 6, *r* = -.28, 95% CI [-.35, -.20]), effect sizes that measured mental manipulation anxiety and another spatial skill subtype (*k* = 12, *r* = -.20, 95% CI [-.24, -.15]), and effect sizes that measured another spatial anxiety subtype and mental manipulation skill (*k* = 63, *r* = -.13, 95% CI [-.17, -.10]). The average effect sizes for all groups were significant (*p*s < .001). The omnibus test for this moderator analysis was statistically significant, $F(2,78) = 4.49$, $p = .014$. Pairwise comparisons indicated that effect sizes for both mental manipulation anxiety and skill (*r* = -.28) had higher magnitude correlations than did effect sizes that measured other types of spatial anxiety and mental manipulation skill (*r* = -.13; *b* = 0.14, *p* = .004; Table 5).

We next compared effect sizes that measured scalar comparison anxiety and scalar comparison skill (*k* = 2, *r* = -.26, 95% CI [-.35, -.17]), effect sizes that measured scalar comparison anxiety and another spatial skill subtype (*k* = 10, *r* = -.27, 95% CI [-.33, -.20]), and effect sizes that measured another spatial anxiety subtype and scalar comparison skill (*k* = 16, *r* = -.12, 95% CI [-.22, -.03]). The average effect sizes for all groups were significant (*p*s < .001). The omnibus test for this moderator was not statistically significant, $F(2,25) = 3.21$, $p = .058$.

Last, we compared effect sizes that measured navigation anxiety and navigation skill (*k* = 33, *r* = -.17, 95% CI [-.23, -.11]), effect sizes that measured navigation anxiety and another spatial skill subtype (*k* = 124, *r* = -.16, 95% CI [-.20, -.12]), and effect sizes that measured another spatial anxiety subtype and navigation skill (*k* = 20, *r* = -.23, 95% CI [-.34, -.11]). The average effect sizes for all groups were significant (*p*s < .001). The omnibus test for this moderator analysis was statistically significant, $F(2,174) = 5.77$, $p = .004$. Pairwise comparisons indicated that effect sizes that included scales that measured navigation anxiety and tasks that measure other types of spatial skill (*r* = -.16) had statistically significantly weaker correlations than did effect sizes that included scales measuring other types of spatial anxiety and tasks that measure navigation skill (*r* = -.23; *b* = -0.14, *p* < .001; Table 5).

Risk of Bias. The moderator analysis for risk of bias was not statistically significant, $F(1, 281) = 0.13$, $p = .716$. This suggests that risk of bias did not impact the strength of the relation between spatial anxiety and spatial skills.

Discussion

Spatial cognition allows for the successful navigation of the physical world and develops over the course of our entire lives (Vasilyeva & Lourenco, 2010). Spatial skills can be improved through training (Hawes et al., 2022; Lerner, 2006; Lowrie et al., 2017; Uttal et al., 2013) and are consistently linked with STEM achievement (e.g., Atit et al., 2021; Hawes et al., 2022; Shea et al., 2001; Wai et al., 2009; Wai et al., 2010), leaving room for spatial skills to serve as potential targets for interventions. Evidence suggests spatial anxiety is a detrimental correlate of spatial skills (e.g., Geer, 2019; Lauer et al., 2018; Lawton, 1994; Lyons et al., 2018). Thus, understanding the relation between spatial skills and anxiety may also help us better understand STEM achievement and career interest. In this preregistered meta-analytic review, we investigated the overall average relation between spatial anxiety and spatial skills and potential moderators of this relation. We found an average small, but statistically significant negative association (r = -.14) across 283 effect sizes. We also found that the relation between spatial anxiety and skills was significantly stronger when mental manipulation anxiety, scalar comparison anxiety, and navigation skill were measured compared to effect sizes including measures of other subtypes.

Overall Average Effect Size

Our overall finding of a small but significant negative association between spatial anxiety and spatial skills supports much of the existing work on this relation that suggests that increased levels of spatial anxiety are weakly linked with lower performance on a variety of spatial tasks (e.g., Geer, 2019; Lyons et al., 2018). The present work suggests that spatial anxiety is a small but important factor to consider when investigating spatial cognition, though it may not be a critical target for interventions aimed at improving spatial skills. It is possible that through its impact on math anxiety (e.g., Delage et al., 2022; Sokolowski et al., 2019), spatial anxiety has implications for STEM outcomes. In particular, existing research has established mental manipulation anxiety as a mediator of the sex difference in math anxiety (Delage et al., 2022). This mediating role may explain part of the existing gap in STEM representation for women versus men. Mental manipulation anxiety may contribute to this sex difference in math anxiety because many components of mathematics are inherently spatial in nature (i.e., reading a graph, geometry, number lines, etc.). Thus, an intervention aimed at decreasing spatial anxiety might decrease math anxiety and, by association, the avoidance of spatial situations within STEM subjects. This reduced avoidance may provide more opportunity for people, and women in particular, to practice STEM skills and improve them. Though the overall effect size is small, examining moderators helped us see which factors impact the strength of the relation between spatial anxiety and spatial skills and thus highlight better targets for intervention.

Moderators

Publication Bias

When we sorted effect sizes as published as long as they came from a published article (regardless of the effect size being *reported* in said published article) and sorted any other effect sizes as unpublished, we found no significant difference. This finding goes against what we might expect to find based on other meta-analyses (Barroso et al., 2021). However, in the second version of this analysis we focused on whether *effect sizes* were or were not published (i.e., effect sizes retrieved through author queries were considered unpublished) and found that published effect sizes had stronger effect sizes, on average, than did unpublished effect sizes, indicating evidence for publication bias. These results suggest that the *file drawer dilemma*, or the publication of only significant and/or strong relations, which is often discussed as an issue within social sciences, is an issue that researchers need to be aware of in this field of work (Rosenthal, 1979). Researchers should publish their results even if their findings are null, as it is critical that the field is aware of real findings, not just the ones deemed interesting because they are statistically significant.

Demographic Characteristics as Moderators

Sex. Existing research has found sex differences in both spatial skills (e.g., Ganley & Vasilyeva, 2011; Geer & Ganley, 2022; Levine et al., 1999; Levine et al., 2016) and spatial anxiety (e.g., Lawton, 1994), but has not yet examined potential sex differences in the magnitude of the relation between spatial anxiety and spatial skills. We did not find a significant impact of sex on the strength of the relation between spatial anxiety and spatial skills. The all-male subgroup had a significant, negative relation between spatial anxiety and skills that was similar to the overall average correlation coefficient, whereas the all-female subgroup had a smaller, but still significant, effect size. Most studies did not report effect sizes separately for all male versus all female samples (84%). Therefore, this moderator analysis was limited to a smaller subset of effect sizes within our samples. Thus, we would encourage future researchers to continue to investigate the possibility of a sex difference in this relation.

Grade level/Age group. The first version of the moderation analysis investigating if grade level group impacted the strength of the relation between spatial anxiety and spatial skills was not significant; however, the number of samples for the younger age groups was small (kindergarten through second grade, $k = 6$; third through fifth grade, $k = 3$; ninth through twelfth grade, $k = 1$). Due to the small number of effect sizes in each group, we ran an analysis that collapsed effect sizes for younger populations into one group, which allowed us to include two additional samples that included kids from more than one non-consecutive grade ($k = 12$). Although the results of this moderator analysis were not significant, there is a trend ($p = .090$) suggesting that the relation between spatial anxiety and spatial skills is *weaker* on average for children and adolescents ($r = -.08$), and especially weak for the kindergarten through second grade samples ($r = -.04$), compared with older populations such as college-aged students (r = -

.15) and non-student adults (r = -.12). Despite the results of this moderator being non-significant, we acknowledge how few studies there are in younger populations and how that may be making it difficult to detect any differences. Existing research suggests relations between domain-specific anxieties and their relative domains may be different, and for spatial anxiety specifically, weaker for children (Geer, 2021; Lauer et al., 2018). Taken together, the slightly weaker effect size for young populations paired with a distinct lack of research on this relation in younger populations highlighted by this meta-analytic review suggests that further research with children and adolescents is needed. Because the present meta-analytic review cannot determine the causal direction of the relation between these factors, it remains prudent to expand upon the research done examining the longitudinal development of the relation between spatial anxiety and skills, particularly in school-age children and adolescents.

Geographical region of sample. The magnitude of the relation between spatial anxiety and spatial skills is similar across the three continents represented. These findings and the lack of representation from many countries are similar to another meta-analysis on the relation between math anxiety and math performance (Barroso et al., 2021). Importantly, there is very little research examining the potential relation between culture or geographical location and spatial cognition, so this meta-analytic review has begun to bridge a gap in research on this topic. It should be noted; however, that only 12 countries were represented in our sample. Our findings suggests only that there is no difference in the strength of the relation between spatial anxiety and spatial skills across the continents included and there may be countries that are not represented in the current body of research that would change these results. Future research should investigate this possibility and examine potential cultural differences within countries with diverse populations.

Measure Characteristics as Moderators

Spatial anxiety measures. Despite there being several measures of spatial anxiety, each with their own respective subscales (navigation, Lawton, 1994; navigation and mental rotation/visualization, Malanchini et al., 2017; imagery, mental manipulation, and navigation, Lyons et al., 2018; imagery, mental manipulation, scalar comparison, and navigation, Geer, 2019), results showed no difference in the strength of the relation depending on the scale used. Because many of the reported effect sizes were from specific subscales within each of these measures, this result is not that surprising, and does not conflict with expectations.

Spatial anxiety subtype. For this moderator analysis we used spatial anxiety subgroups from the Uttal et al. (2013) framework, which included imagery/intrinsic-static, mental manipulation/intrinsic-dynamic, scalar comparison/extrinsic-dynamic, and navigation/extrinsic-dynamic as well as multiple subtypes of anxiety and other subtypes of anxiety not accounted for in the Uttal et al. (2013) framework. Spatial skills had stronger correlations with both mental manipulation anxiety and scalar comparison anxiety than with imagery anxiety, navigation anxiety, and multiple subtypes of anxiety. There are several factors that may contribute to this pattern of results. First, mental manipulation skill is among the most frequently measured skill subtypes, so it is possible that the relation between spatial anxiety and spatial skills is higher for effect sizes that included mental manipulation anxiety because many of these effect sizes also include a mental manipulation task. This contention was supported by results from the match versus mismatch analysis that showed a stronger relation when effect sizes included both mental manipulation anxiety and skills versus measuring another subtype of anxiety in relation to mental manipulation skill. Additionally, mental manipulation skill, in general, involves complex and dynamic movements that can be quite cognitively demanding; thus, it is possible that participants may find these particular spatial situations to be more anxiety-provoking. These results are particularly poignant, as existing research has established mental manipulation anxiety as a mediator of the sex difference in math anxiety (Delage et al., 2022) and this may be related to the gap in STEM representation seen for women compared with men.

Additionally, the relation between spatial anxiety and spatial skill is weaker when the effect size included navigation anxiety compared to when the effect size included mental manipulation anxiety or scalar comparison anxiety. This may suggest that navigation anxiety scales may also be tapping into other anxieties that are not about spatial experiences (e.g., a fear of being lost). For example, the Lawton (1994) scale which has been the most commonly used spatial anxiety scale by far, measures navigation anxiety and has items that ask about being *lost* in an unfamiliar city. In a study by Geer (2019) participants in cognitive interviews suggested that these items made them fearful because being lost is dangerous, rather than being fearful because they had to *navigate*. Therefore, it is possible that navigation anxiety scales are tapping into anxieties that fall outside the purview of spatial anxiety. It is also important to note that a fair number of the effect sizes for navigation anxiety come from samples of non-student adults and, despite the difference not being significant, these effect sizes were lower on average than those for undergraduate and graduate student samples, which make up most of the included samples (k = 183).

The only spatial anxiety scale that measures scalar comparison is the Geer (2019) scale. Because the researchers began with a pool of items from existing scales and some researcher-developed items that underwent screening by both experts in the field of spatial cognition and college-aged cognitive interviewees, this scale may more directly measure the subtypes of spatial anxiety, especially scalar comparison anxiety. This may therefore influence the strength of relations for this subtype of anxiety. Lastly, it is possible to attribute the weaker relation between imagery anxiety and spatial skills to the fact that there are only two spatial anxiety scales that include an imagery anxiety subscale (Geer, 2019; Lyons et al., 2018) which were only available for use in recent studies. Further, some research has discovered the imagery anxiety may be less related to other subtypes of anxiety (e.g., Lyons et al., 2018), suggesting it may be tapping into a more exclusive form of spatial anxiety that may be less related to spatial skills broadly. It is unclear why this pattern of results may emerge; however, it may have something to do with the content of these items. Specifically, some of these items may not prompt participants to think about truly spatial contexts. Because of the limited inclusion of imagery anxiety in extant research, further research is needed to truly expand upon the role of imagery anxiety as it relates to imagery skill and spatial skill more broadly.

Overall, these findings demonstrate that some spatial anxiety subtypes (i.e., mental manipulation, scalar comparison anxiety) have stronger links with spatial skills than other spatial anxiety subtypes (i.e., imagery, navigation). It is possible that items about mental manipulation anxiety are easier to conceptualize, for both researchers and participants, than the other subscales of spatial anxiety such as imagery which has only recently been introduced to research on spatial anxiety (Lyons et al., 2018; Geer, 2019). It is also possible that these subscales, most of which were developed more recently through more intensive scale development methods may be more well-suited for measuring spatial anxiety and its complexity. Future work should continue exploring the complexity of spatial anxiety and how its subtypes are related to spatial skill. Additionally, researchers should continue improving the quality of spatial anxiety measures, as measure quality likely plays a role in the magnitude of the relation between spatial anxiety and skill.

Spatial skill measures. We found that there is an effect of the spatial skill measure used on the relation between spatial anxiety and spatial skills. Effect sizes incorporating embedded figure tasks were significantly weaker than effect sizes for mental rotation tasks, spatial orientation tasks, road map tasks, plum line/van and light bulb tasks, and hidden pattern tasks. For this result, it is possible that the overall magnitude of the effect sizes that include embedded figures tasks was impacted by the inclusion of effect sizes that used reaction time as an outcome measure for these tasks, rather than an accuracy score based on the number of items correct. Specifically, reaction time might not be the best outcome measure for spatial skill, as some participants may be slow but perform better than a participant who rushes; however, this nuance is lost when the sole outcome measure is reaction time. Thus, this result might be hard to interpret with reaction times included as outcome measures for a subset of the effect sizes.

We also found that effect sizes for the relation between spatial anxiety and spatial skills that included water level tasks were significantly weaker than effect sizes that included spatial orientation tasks and road map tasks. The water level task was only used in two of the included studies with only six effect sizes total. Only one of the effect sizes was a *match* for anxiety/skill (i.e., both scalar comparison anxiety and skill). Despite the match versus mismatch moderator analysis not being significant for the scalar comparison subtype, the average effect size for the scalar comparison mismatch cases is on the lower end (r = -.12), which may have reduced the overall average effect size for the water level task given that most correlations were mismatches.

Lastly results showed that effect sizes that included crystal slicing tasks were significantly weaker than effect sizes that included mental rotation tasks, spatial orientation tasks, and road map tasks. The crystal slicing task was used for only one study and each effect size corresponded to a different subtype of spatial anxiety, only one of which was a *match* for what spatial skill was measured (mental manipulation). Therefore, it is possible that the crystal slicing task has weaker associations with spatial anxiety because there are so few effect sizes reported across such a wide range of anxiety subtypes (k = 4, rs = -.08 to -.21). Lastly, it is possible that the mental rotation, spatial orientation, and road map tasks have stronger relations with spatial anxiety because these tasks are relatively complex and require the participant to engage in spatial thought that involves moving components within the task which may tax their working memory more heavily. Overall, results suggest researchers should be mindful of the tasks selected for their studies and should select tasks that target the spatial skill and cognitive demand they are most interested in.

Spatial skill subtypes. For the spatial skill subtype moderator analysis, we found that effect sizes that included navigation tasks were, on average, stronger than those that included imagery and scalar comparison tasks. This may suggest that there is a link between the strength of the relation between spatial anxiety and spatial skill and how *avoidable* the task at hand is. It is easy to avoid, for example, a mental rotation task in day-to-day life (such as completing a jigsaw puzzle), but situations involving navigation skill are harder to avoid as they are central to our day to day lives (e.g., navigating the rooms of our house, the route to our job, the route across campus, etc.). Of course, there are exceptions to this rule (e.g., an individual can avoid using skill alone to navigate by using the GPS on their phone), but still navigation is a skill that we all use. Therefore, there is more common real-world application of navigation, which may be why this skill subtype has a stronger relation with spatial anxiety.

Another possible explanation for stronger effect sizes for navigation tasks is that these tasks include some form of motion, as is classified by the ‘dynamic’ distinction in the Uttal et al. (2013) framework, which may impact the relation between spatial anxiety and spatial skills more than tasks that do not involve moving components. Specifically, if we follow the theory of anxiety that suggests spatial anxiety taxes working memory, thus leading to poorer performance, it is possible that navigation tasks tax working memory more than do other tasks due to their dynamic nature, thus contributing to the poorer performance.

Match versus mismatch. Results for the imagery subtype of spatial anxiety/skill suggest no difference between effect sizes that use matched versus mismatched anxiety and skill measures. In line with existing research, this suggests that the imagery subtype of anxiety/skill may be more weakly associated with spatial cognition in general (Lyons et al., 2018). We found that effect sizes that included measures of mental manipulation anxiety and mental manipulation skill had statistically significantly stronger correlations than did effect sizes that included other types of spatial anxiety and mental manipulation skill. Results for scalar comparison anxiety/skill suggest there is no significant difference in the strength of effect sizes where the skill and anxiety subtype are matched versus mismatched. For the navigation subtype, effect sizes that included measures of navigation anxiety and other skill subtypes were weaker than those that measured other subtypes of anxiety with navigation skill. This suggests, perhaps, that navigation anxiety is not closely associated with all subtypes of spatial skill and that navigation skill, which may differentially tax working memory, thus depleting cognitive resources needed for the successful completion of the tasks, may be more strongly related with spatial anxiety in general, yet, oddly, not navigation anxiety specifically.

These results suggest, in line with existing work, that spatial anxiety is comprised of a complex set of subtypes and that some of these subtypes (such as mental manipulation anxiety) do tend to relate more strongly to their respective spatial skill (Geer, 2019; Lyons et al., 2018). Although these results give us no indication that matching anxiety and skill subtype matters for all subtypes, they do suggest we should measure multiple subtypes of spatial anxiety and skill to be thorough in our investigations of these relations. Future research should expand upon the existing work by examining anxiety subtypes outside of navigation, as much of the existing work in this field employed the original spatial anxiety measure that measured only navigation anxiety (Lawton, 1994). Given that anxiety scales including imagery (Geer, Lyons et al.), mental manipulation (Geer, Lyons et al., Malanchini et al., 2017), and scalar comparison (Geer) are all relatively new, the match sample sizes were quite small for these (*k*s = 5, 6, and 2, respectively). This could have led to missing some potential differences that exist that require additional research with these subtypes of anxiety.

The results of the match versus mismatch subtype moderator analyses, in particular the larger effect sizes seen when there is a match between anxiety and skill subtype for mental manipulation (r = -.28), when scalar comparison anxiety is paired with scalar comparison skill (r = -.26) or another skill (r = -.27), and when other anxieties and navigation skill is measured (r = -.23), suggest that these may be more appropriate targets for intervention. This is particularly true for navigation skill, as navigation ability is directly related to quality of life (e.g., the ability to get to and from one's school/job).

Risk of Bias

Risk of bias did not impact the strength of the relation between spatial anxiety and spatial skills, but overall, the research studies included in this meta-analytic review are of lower quality according to the scale we used (Hjetland et al., 2017). On the 0-9 scale, with higher numbers indicating more risk for bias, all effect sizes had a score of 3 or higher, with over 50% of the studies having a 7, 8 or 9. Due to this, the results here are a bit difficult to interpret. Though it would be ideal to only include studies with low risk of bias, given this distribution of risk of bias it would be difficult to do so for a meta-analytic review in this research area.

Limitations

One limitation of this work is that most included studies reported correlation coefficients for samples that are combined across sex, leading to a small number of studies that could be used in moderation analyses for sex differences in the relation between spatial anxiety and spatial skills. Future work should aim to report correlations for these populations separately so that future meta-analyses can further explore any potential sex differences in the strength of the relation between spatial anxiety and spatial skills. Alternatively, the current meta-analytic review could have chosen to code the percentage of each sample that was reported to be male/female and used the percentages as continuous moderators. This technique may have provided different results, though there was some concern that many studies would hover around 50% male, and this technique would, therefore, not have improved much compared to the current approach.

Another limitation of the present work was that our research team included mostly mono-lingual researchers. Some nuance of the results/discussion may have been lost in translation because these articles had to be translated to English to accommodate our research team. Due to the importance of improving open and equitable science, including articles written in languages other than English should be a focus. Future work should aim to engage collaborators who are multilingual and/or acquire external funding for meta-analytic reviews that would permit paying other researchers to complete coding in languages other than English.

Additionally, although the risk of bias measure used in this study had been used by other authors previously (Hjetland et al., 2017), there were aspects of it that did not suit the studies included in this meta-analytic review. For example, the item about convenience versus random sampling was difficult to use, because in psychology there is rarely ever a truly *random* sample. Further, many of the scores for high risk of bias reflected the fact that the information was not *reported* in the text of the study, not necessarily that what was reported suggested low quality or high risk of bias. The study quality may have been good for a study (e.g., good scale reliability, no floor/ceiling effects, missing data handled appropriately), but without that information being provided by study authors, there was no way for us to assess this. This introduces uncertainty which therefore increases the potential risk of bias. It is crucial to assess the quality of studies included in meta-analyses, but we feel that there were some difficulties with specific items on this scale in the context of social sciences and feel that this measure could be improved. More important, we encourage researchers to engage in more transparent reporting of their methodologies, either through open science practices (e.g., preregistrations, open data) or within the text or supplemental materials of their manuscripts, so that risk of bias and quality measures can more accurately assess what researchers did as opposed to the limited information they reported.

Another limitation of this meta-analytic review is that the search was conducted for available data or published articles between June 1994 through July 2020. Thus, we are missing studies published since our last search which may impact the findings. In an attempt to combat this dilemma, we solicited effect sizes from unpublished and ongoing studies from researchers and were able to include an additional 6 articles that may have been published in the time between our last search and the write up of these results. Even though this is a limitation of the present work, meta-analyses take substantial time to be completed following the search, because the screening and coding methods are extensive and often take months to complete.

Lastly, another limitation is that this meta-analytic review cannot directly test the causal direction of the relation between spatial anxiety and spatial skills nor any mechanism of this relation, therefore that gap in the literature must be addressed in future work. Specifically, future research should engage in studies that employ longitudinal data collection methods and/or develop possible manipulations to induce or reduce spatial anxiety or increase spatial skills in order to establish the causal direction(s) of the spatial anxiety and spatial skills relation. Despite these limitations, the present work is the first meta-analytic review to synthesize research on the relation between spatial anxiety and skills spanning over two decades, providing a significant contribution to the literature.

Implications

The present study bridges a gap in the field of spatial cognition by providing the first meta-analytic review of the research on spatial anxiety and spatial skills. Even though there have been several meta-analyses in related areas (the relation between spatial and math skills, Atit et al., 2021; development of gender differences in spatial reasoning, Lauer et al., 2019; the malleability of spatial skills, Uttal et al., 2013; the magnitude of sex differences in spatial abilities, Voyer et al., 1995), this is the first to examine this relation. We found a significant, negative relation between spatial anxiety and spatial skills across existing research. Because spatial skills have often been linked to outcomes in STEM (e.g., Uttal et al., 2013; Shea et al., 2001; Wai et al., 2009; Wai et al., 2010), it stands that future work should continue to investigate the relation between spatial anxiety and spatial skills, as this relation may impact STEM domains directly or, perhaps, indirectly through other factors, such as math anxiety (e.g., Delage et al., 2022; Sokolowski et al., 2019).

Although the *overall* effect size for the relation between spatial anxiety and spatial skills is small, the effect sizes for some specific subtypes of spatial anxiety/skill were quite a bit stronger (e.g., effect sizes that include both mental manipulation anxiety and skill, r = -.28; effect sizes that include both scalar comparison anxiety and scalar comparison skill, r = -.26 or other skills r = -.27; effect sizes that include another anxiety and navigation skill, r = -.23). Given these stronger relations, it is possible that scalar comparison and mental manipulation anxiety are worth exploring as targets for interventions aimed at improving spatial skills, rather than other subtypes. Many of the effect sizes for both mental manipulation and scalar comparison anxiety are from more recent studies that have employed more intensive scale development methods and it is possible that this has led to spatial anxiety scales that are more effectively capturing the complexity of spatial anxiety (Geer, 2019; Lyons et al., 2018). This highlights the importance of scale development and how improving the quality of our measures may lead to more accurate research results. Further, only one scale has been used to measure scalar comparison anxiety (Geer, 2019), thus future work should aim to include this scale and explore if similar findings are seen in other populations. For the spatial skill subtypes, navigation skill had the strongest relation between spatial anxiety and spatial skill. This might suggest that navigation tasks that include some form of motion, as is classified by the 'dynamic' distinction in the Uttal et al. (2013) framework, may be more related to spatial anxiety than tasks that do not involve moving components.

Taken together, the results of the anxiety and skill subtype and match moderators suggest that interventions aimed at improving *specific* subtypes of both spatial anxiety *and* spatial skills, such as mental manipulation and scalar comparison anxiety and navigation skills, may have implications for improving quality of life. *Navigation* skills in particular are essential to quality of life, as these skills are necessary for the day-to-day life skills (i.e., getting to and from a job; driving; planning travel routes; etc.). Future research should aim to tease apart underlying factors that are linked to the magnitude of the relation between spatial anxiety and spatial skills.

Conclusions

Overall, we found a significant, small, negative relation between spatial anxiety and spatial skills, supporting the trend found in research on this topic. There was no significant sex difference in the magnitude of the relation between spatial anxiety and spatial skills, though there were few studies that reported effect sizes for samples that were all male or all female. There was no significant difference in the magnitude of the relation between spatial anxiety and spatial skills on the basis of age group; however, the pattern showed that the relation was weaker for school-aged children and adolescents than for undergraduate and graduate students and adults. Some subscales of spatial anxiety (i.e., mental manipulation, scalar comparison) related to spatial skills more strongly than did others (i.e., imagery, navigation). Some subtypes of spatial skills (i.e., navigation) were more strongly related to spatial anxiety than others (i.e., imagery, scalar comparison). The present work bridges a gap in the existing understanding of the relation between spatial anxiety and spatial skills as well as factors that may impact this relation. However, the present work cannot identify the mechanisms underlying the relation between spatial anxiety and spatial skills, thus the field would benefit from focused longitudinal studies aimed at identifying the direction of the relation between spatial anxiety and spatial skills. In particular, it would be beneficial to examine whether this relation is mediated by working memory skill or avoidance, in line with theoretical models of other domain-specific anxieties (e.g., math anxiety; Justicia-Galiano et al., 2017). Future research should expand upon existing work with an eye towards developing and testing structured interventions (such as randomized control trials) that may improve spatial and STEM outcomes.

Table 1.

Spatial Skill and Anxiety Subtypes, Definitions, and Example Tasks

Spatial Subtype	Definition	Example Skill Measures	Example Anxiety Items (common stem: *How much you would be made to feel anxious by…*)
Linn and Petersen (1985) Framework			
Mental Rotation	Ability to rotate/anxiety about rotating a 2- or 3-D figure rapidly and accurately in one's mind.	Mental Rotations Test	Having to rotate objects in your mind (Malanchini et al., 2017)
Spatial Perception	Ability to determine/anxiety about determining spatial relationships with respect to the orientation of one's body, in spite of distracting information.	Water Level Task, Plum line/Van and Light bulb task	No scale has been designed to measure spatial perception anxiety
Spatial Visualization	Ability to navigate/anxiety about navigating through tasks that involve complicated, multistep manipulations of spatially presented information.	Puzzle Tasks	Having to complete a complex jigsaw puzzle (Malanchini et al., 2017)
Uttal et al. (2013) Framework			
Imagery/Intrinsic-static	Ability to observe/anxiety about observing objects, paths, or spatial arrangements among distracting background information	Embedded Figures Task, Hidden Patterns Task	Playing a competitive game where one is asked to recall a visual detail about a scene that others are unlikely to have noticed (Geer 2019, Lyons et al., 2018)
Mental Manipulation/ Intrinsic-dynamic	Ability to combine/anxiety about combining objects into more complex patterns, visualizing or mentally transforming objects (often from 2D to 3D or vice versa), and/or mentally rotating 2D and 3D objects	Mental Rotations Task, Crystal Slicing Task	Tested on your ability to follow instructions for creating an origami design (Geer 2019, Lyons et al., 2018)
Scalar Comparison/ Extrinsic-static	Ability to understand/anxiety about understanding abstract spatial principles	Water Level Task, Plum Line/Van and Light bulb Task	Asked to find a location on a topographical map using information from the contour lines (Geer 2019, Lyons et al., 2018)
Navigation/ Extrinsic-dynamic	Ability to visualize/anxiety about visualizing an environment in its entirety or collection of objects from a different perspective	Spatial Orientation Task, Road Map Task, Wayfinding Tasks	Asked to follow directions to a location across town without the use of a map (Geer 2019, Lyons et al., 2018)

Table 2

Multi-level Model Results for Overall and Moderator Analyses

Moderator	*F(df1, df2)*	Between-study variance (Level-1)	Within-study variance (Level-2)	$Q_E(df)$	I^2
Overall	--	.0045	.0065	855.44(282)**	67.03%
Publication Status					
AQ as published	2.85(1, 281)	.0044	.0065	770.12(281)**	63.38%
AQ as unpublished	9.97(1, 281)*	.0042	.0062	772.85(281)**	63.51%
Sex	2.93(1, 54)	.0004	.0015	71.60(54)	23.18%
Age (5 groups)	1.43(3, 271)	.0048	.0060	616.76(271)**	55.41%
Age (3 groups)	2.43(2, 275)	.0048	.0058	629.36(275)**	55.99%
Geographical Region	0.22(2, 280)	.0045	.0069	696.73(280)**	59.53%
Publication Year	.09(1, 281)	.0045	.0067	820.17(281)**	65.62%
Spatial Anxiety Scale	0.36(5, 277)	.0044	.0072	601.23(277)**	53.10%
Spatial Anxiety Subtype	4.70(5, 277)**	.0035	.0068	682.97(277)**	58.71%
Spatial Skills Measure	3.23(10, 272)**	.0031	.0078	629.49(272)**	55.20%
Spatial Skills Subtype	2.91(5, 277)*	.0039	.0068	760.10(277)**	62.90%
Match vs. Mismatch					
Imagery	0.69(2, 37)	.0041	.0003	68.56(37)*	43.12%
Mental Manipulation	4.49(2, 78)*	.0047	.0029	184.78(78)**	56.71%
Scalar Comparison	3.21(2, 25)	.0041	.0123	66.43(25)**	59.36%
Navigation	5.77(2, 174)*	.0049	.0084	357.24(174)**	50.73%
Risk of Bias	0.13(1, 281)	.0045	.0065	783.43(281)**	64.00%

Note. *p < .05; **p < .001; F = omnibus test; df = degrees of freedom; Q_E = Residual Heterogeneity; I^2 = Heterogeneity Percentage; AQ = Author Query.

Table 3

Pairwise Comparisons of the Uttal et al. (2013) Spatial Anxiety Subtype Moderator

		95% CI		
Spatial Anxiety Subtype	*b*	LL	UL	*k*
Imagery vs. Mental Manipulation	-.10**	-.16	-.03	36
Imagery vs. Scalar Comparison	-.10**	-.18	-.03	30
Imagery vs. Navigation	-.02	-.08	.04	223
Imagery vs. Multiple	-.03	-.13	.06	44
Imagery vs. Other	-.06	-.32	.20	22
Mental Manipulation vs. Scalar Comparison	-.04	-.12	.03	30
Mental Manipulation vs. Navigation	.08**	.02	.14	223
Mental Manipulation vs. Multiple	.12***	.06	.19	44
Mental Manipulation vs. Other	.09	-.14	.33	22
Scalar Comparison vs. Navigation	.14***	.07	.21	217
Scalar Comparison vs. Multiple	.16*	.04	.29	38
Scalar Comparison vs. Other	.14	-.10	.38	16
Navigation vs. Multiple	.04	-.02	.11	231
Navigation vs. Other	.02	-.25	.28	209
Multiple vs. Other	-.03	-.27	.22	30

Note. $p < .05$*; $p < .01$**; $p < .001$***; CI = Confidence Interval; LL = Lower Level; UL = Upper Level. Each regression coefficient (b) is calculated by subtracting the second category effect size from the first category effect size. Thus, a positive b means that the first category has a stronger negative relation and a negative b means that the first category has a weaker negative relation.

Table 4

Pairwise Comparisons of the Uttal et al. (2013) Spatial Skill Subtype Moderator

		95% CI		
Spatial Skill Subtype	*b*	LL	UL	*k*
Imagery vs. Mental Manipulation	-.03	-.08	.02	99
Imagery vs. Scalar Comparison	-.01	-.07	.04	54
Imagery vs. Navigation	-.07**	-.11	-.02	171
Imagery vs. VSWM	.06	-.01	.14	47
Imagery vs. Multiple	.08	-.09	.25	32
Mental Manipulation vs. Scalar Comparison	.02	-.04	.08	93
Mental Manipulation vs. Navigation	.00	-.04	.04	210
Mental Manipulation vs. VSWM	.07	.00	.14	86
Mental Manipulation vs. Multiple	.09	-.11	.30	71
Scalar Comparison vs. Navigation	-.06*	-.11	-.01	165
Scalar Comparison vs. VSWM	.05	-.05	.14	41
Scalar Comparison vs. Multiple	.08	-.14	.30	26
Navigation vs. VSWM	.04	-.03	.10	158
Navigation vs. Multiple	.10	-.12	.32	143
VSWM vs. Multiple	.03	-.17	.23	19

Note. $p < .05$*; $p < .01$**; $p < .001$***; CI = Confidence Interval; LL = Lower Level; UL = Upper Level. VSWM refers to Visuospatial Working Memory tasks. Each regression coefficient (b) is calculated by subtracting the second category effect size from the first category effect size. Thus, a positive b means that the first category has a stronger negative relation and a negative b means that the first category has a weaker negative relation.

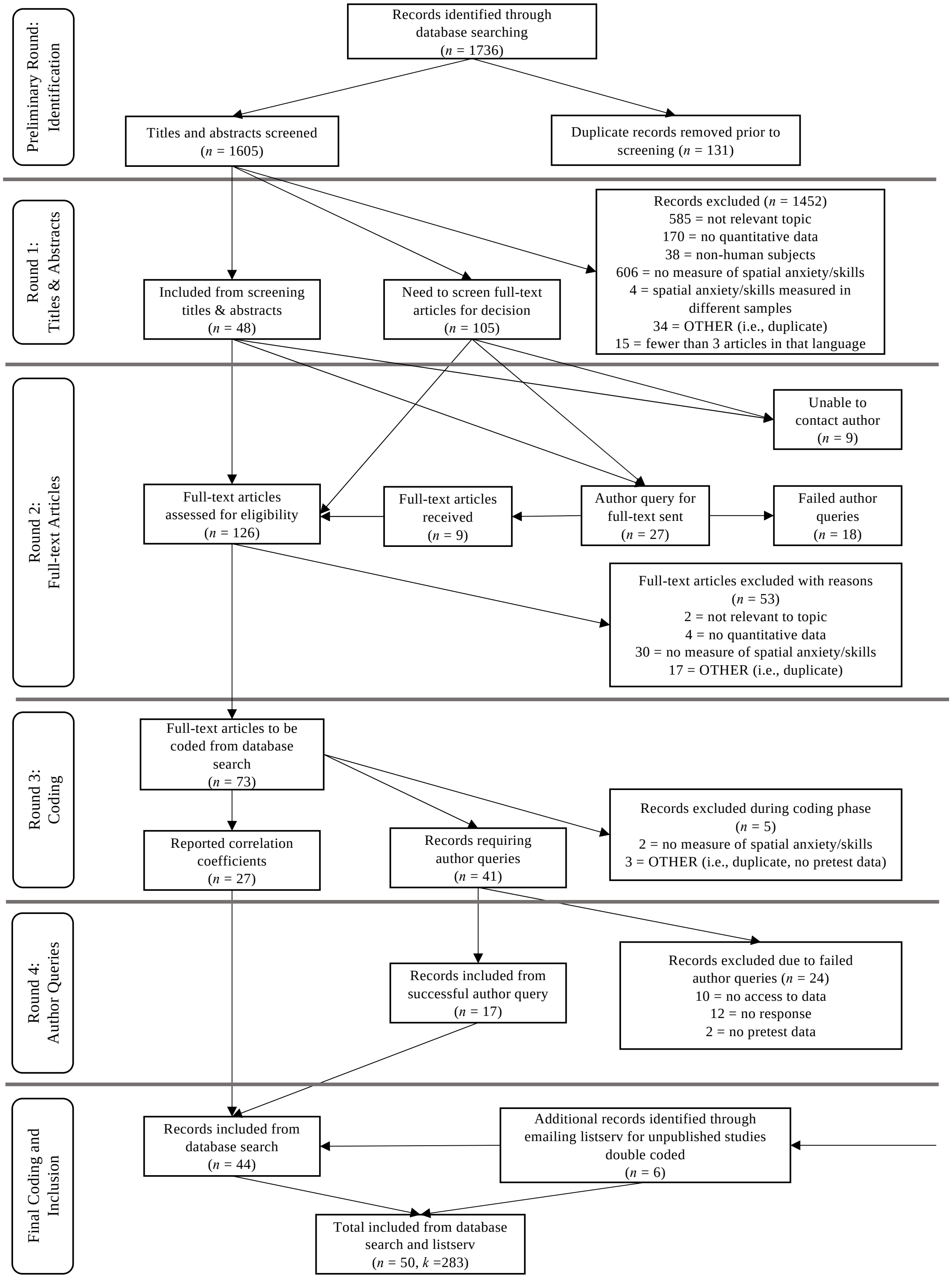
Table 5

Pairwise Comparisons of Matching Anxiety and Skill Subtype Moderator – Uttal et al., (2013)

		95% CI		
	b	LL	UL	*k*
Mental Manipulation (MM)				
MM Anxiety and MM Skill vs. MM Anxiety and Other Skill	0.09	0.00	0.18	18
MM Anxiety and MM Skill vs. Other Anxiety and MM Skill	0.14**	0.04	0.23	69
MM Anxiety and Other Skill vs. Other Anxiety and MM Skill	0.01	-0.07	0.08	75
Navigation (N)				
N Anxiety and N Skill vs. N Anxiety and Other Skill	-0.01	-0.06	0.05	157
N Anxiety and N Skill vs. Other Anxiety and N Skill	-0.06	-0.14	0.01	53
N Anxiety and Other Skill vs. Other Anxiety and N Skill	-0.14***	-0.20	-0.07	144

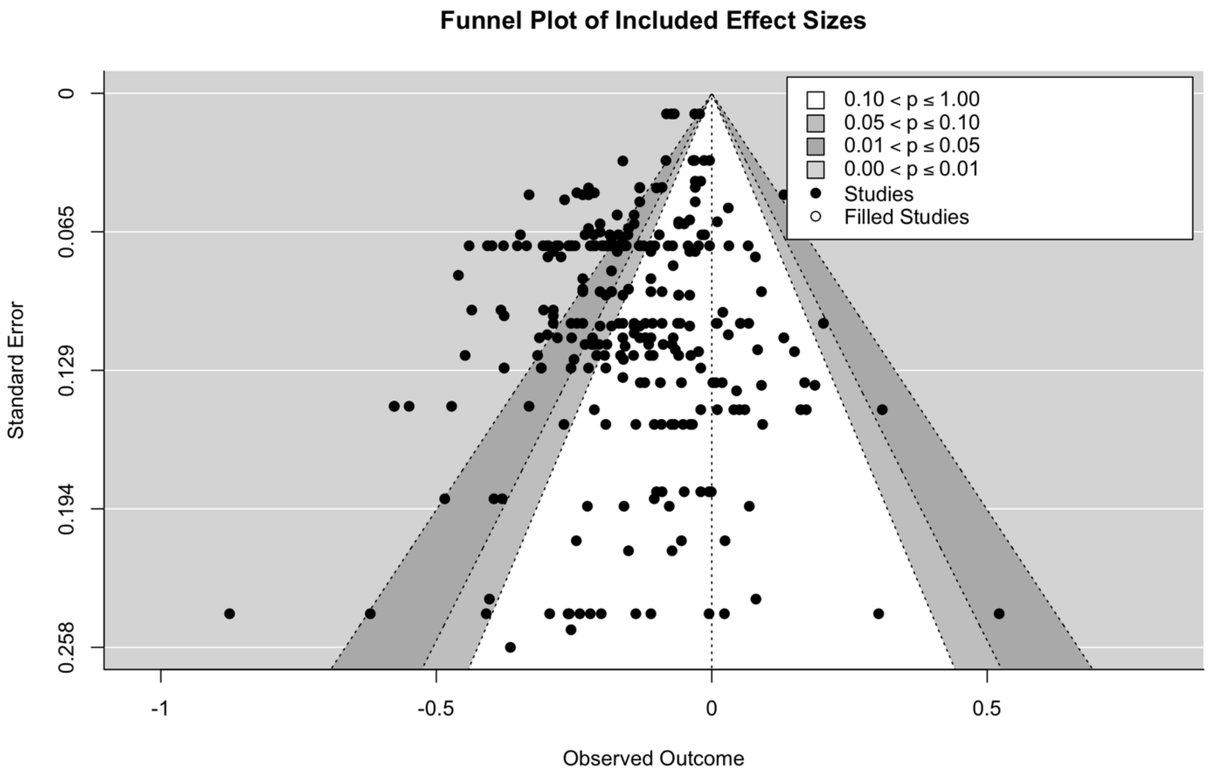
Note. $p < .05$*; $p < .01$**; $p < .001$***; CI = Confidence Interval; LL = Lower Level; UL = Upper Level. Each regression coefficient (b) is calculated by subtracting the second category effect size from the first category effect size. Thus, a positive b means that the first category has a stronger negative relation and a negative b means that the first category has a weaker negative relation.

Figure 1.
Flow Chart of Screening and Coding Process.



Note. Flow diagram of the included and excluded studies for this meta-analytic review. Within the figure and throughout the manuscript *n* refers to the number of studies and *k* refers to the number of effect sizes.

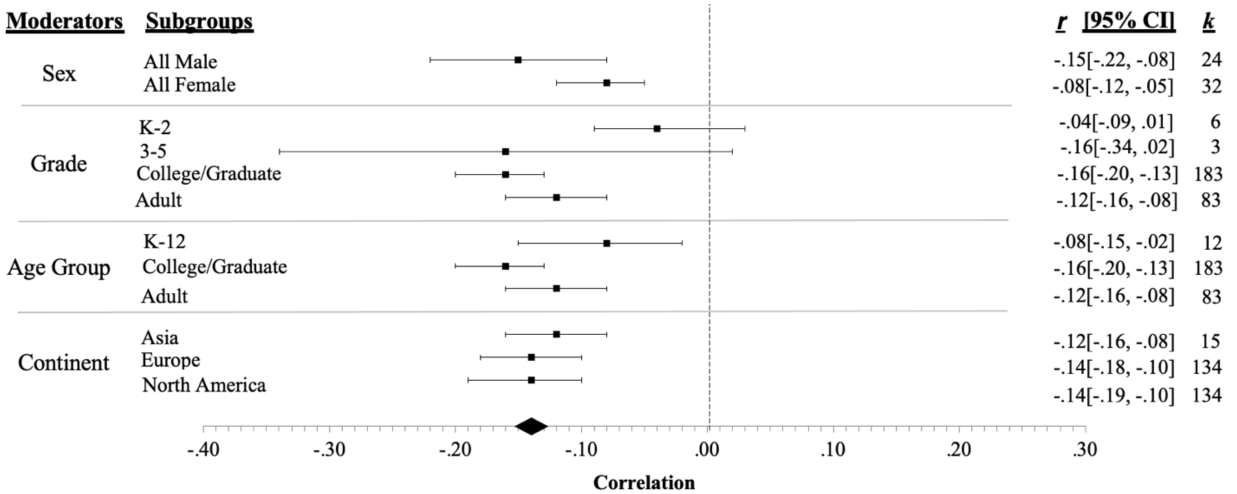
Figure 2.
Funnel Plot of Included Effect Sizes



Note. Funnel Plot of Fisher's *z*-transformed correlations for all included effect sizes (black dots) and trim-and-fill analysis (white dots).

Figure 3.

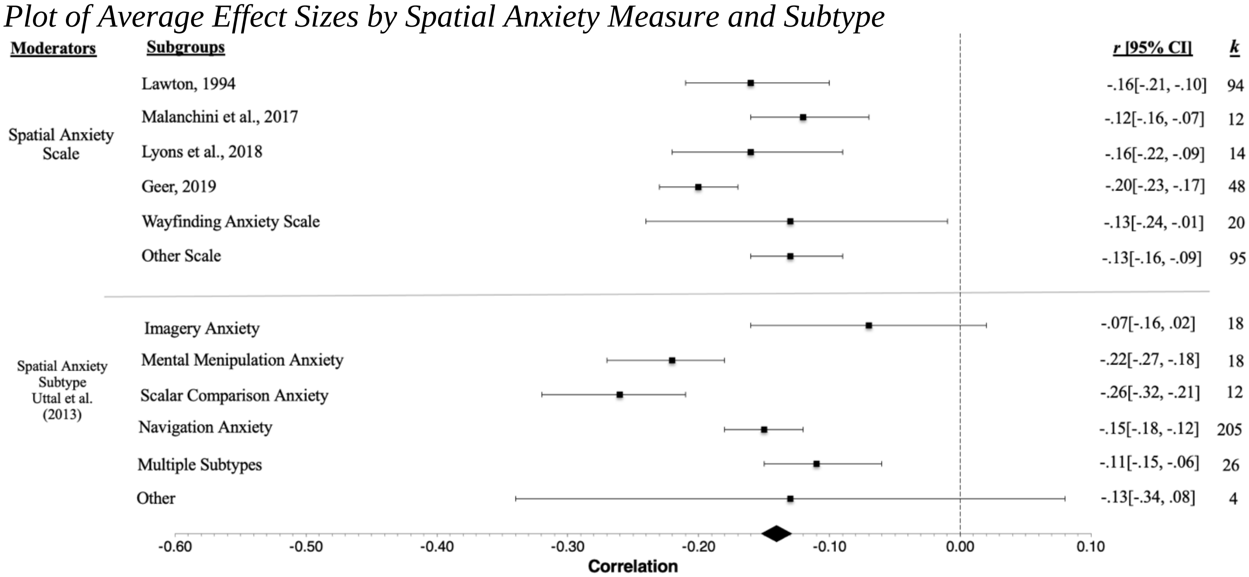
Plot of Average Effect Sizes by Demographic Subgroup



Note. The large diamond at the bottom of the graph is the overall average effect size for all effect sizes (*r* = -.14). The vertical dotted line denotes where zero is on the graph. K-2 refers to all effect sizes from samples of kindergarten through second graders. 3-5 refers to effect sizes from samples of third through fifth graders. K-12 refers to all effect sizes for school aged children and adolescents. The value 0 represents the null value of the effect size.

Figure 4.

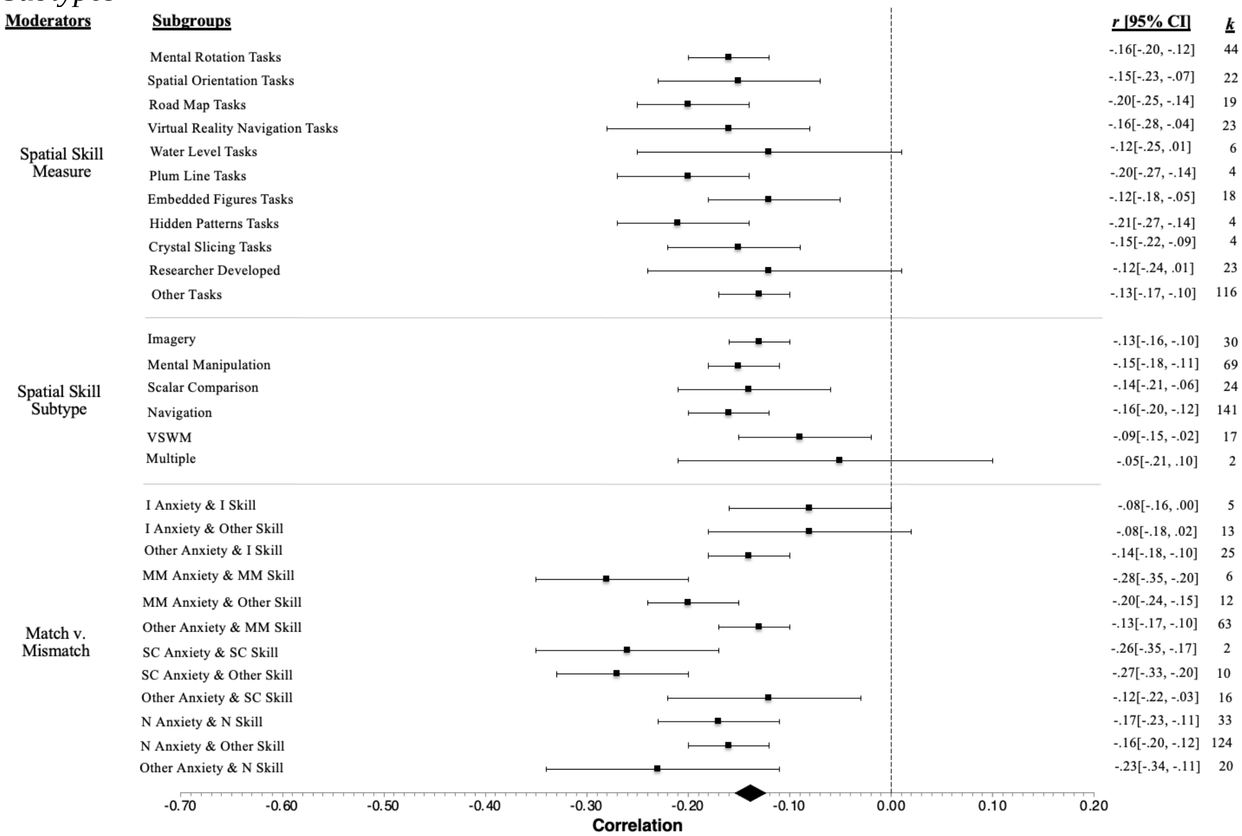
Plot of Average Effect Sizes by Spatial Anxiety Measure and Subtype



Note. The large diamond at the bottom of the graph is the overall average effect size for all effect sizes (*r* = -.14). The vertical dotted line denotes where zero is on the graph. The value 0 represents the null value of the effect size.

Figure 5.

Plot of Average Effect Sizes by Spatial Skill Measures, Subtypes, and Matching Anxiety/Skill Subtypes



Note. The large diamond at the bottom of the graph is the overall average effect size for all effect sizes (*r* = -.14). The vertical dotted line denotes where zero is on the graph. VSWM refers to tasks that measure the visuospatial working memory subtype of spatial skill. I = imagery, MM = mental manipulation, SC = scalar comparison, N = navigation. The value 0 represents the null value of the effect size.

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