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ARTICLE

The relation of spatial skills, spatial memory span, and two anxiety types with statistics anxiety in European and North American University students

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Abstract

Background & Aims: The present two studies investigated the role of spatial cognition in statistics anxiety. The hypothesis that spatial representations and/or visuospatial skills are related to the acquisition of statistics abilities which, when lacking or unused, generate statistics anxiety is examined.

Materials & Methods: To this end, a total of 680 students in Social Sciences from 14 different universities located in one of three countries enrolled in a statistics class at the time of the study were recruited. Study 1 examined a mediation model where visuospatial and verbal working memory (WM) spans as well as spatial anxiety are predictors of statistics anxiety with mathematics anxiety as the mediator.

Results: The results show a partial mediation and strong associations between all three types of anxiety (i.e., spatial anxiety, mathematics anxiety and statistics anxiety). The subscale statistics interpretation anxiety was best predicted by visuospatial WM span. Study 2 examined a path regression model where performance on a spatial and a verbal task along with spatial anxiety are predictors of statistics anxiety.

Discussion: The results indicate that the mental manipulation subscale of spatial skills is a strong predictor of mental manipulation anxiety which, in turn, predicts interpretation anxiety in statistics.

Conclusion: Both studies support the role of spatial cognition in statistics understanding. These results have implications for the teaching and learning of statistics.

KEYWORDS
mathematics anxiety, spatial anxiety, spatial skills, statistics anxiety, working memory

BACKGROUND

There is widespread agreement that statistics education needs to be improved (e.g., Carver et al., 2016; Moreira Da Silva & Pinto, 2014). Difficulties in learning and teaching statistics stem from a multitude of factors (Cousineau & Harding, 2017; Cui et al., 2019; Harth, 2018). On the learners' side, a major factor impeding the learning of statistics is students' fears, worries and apprehensions towards any form of statistical concepts or operations (Gibeau et al., 2023; Onwuegbuzie et al., 1997). This well-documented phenomenon is known as *statistics anxiety* (Esnard et al., 2021; Ruggeri et al., 2011; Williams, 2015; Zeidner, 1991). Statistics anxiety has three dimensions (Cantinotti et al., 2017; Gibeau et al., 2023; Vigil-Colet et al., 2008). The first dimension concerns the anxiety towards exams and tests in a statistics course (*evaluation anxiety*). The second dimension is about asking the instructor or the teaching assistants for help in understanding something or doing an exercise (*anxiety of asking for help*). Lastly, *interpretation anxiety* concerns the anxiety towards interpreting statistical results. This framework comes from the work of Vigil-Colet et al. (2008), in which they developed the *Statistical Anxiety Scale*. It is the framework used herein as it has good factorial structure compared with the factor structure of a recent psychometric evaluation of the other leading framework in statistics anxiety; the *Statistical Anxiety Rating Scale* (STARS; Nesbit & Bourne, 2018).

Statistics anxiety is widely observed in university students (Chiou et al., 2014). In particular, Zeidner (1991) reported a high level of statistics anxiety in 70% of Social Sciences students. Similarly, Onwuegbuzie and Wilson (2003) reported that a majority of graduate students felt ‘uncomfortable’ with statistics. A more recent study reported that half of a large sample of college students enrolled in a wide range of programmes have moderate to severe statistics anxiety (Huang et al., 2023). According to previous research, statistics anxiety strongly influences grades in statistics courses. Specifically, Cantinotti et al. (2017) reported a correlation of −.33 between these two variables (see also Fullerton & Umphrey, 2016, and Chiesi & Primi, 2010, for similar findings); making this variable one of the strongest predictors of the final grade and presumably, an important predictor of statistics *learning*. Identifying the determinants of statistics anxiety and better understanding how it relates to achievement in statistics could facilitate the development of learning activities to improve students' understanding of the underlying concepts of statistics. Indeed, as statistically literate citizens, people will be better qualified to contribute to societal discussions and debates in a world where policies need to be informed by relevant data (e.g., Cui et al., 2019; Lewin et al., 2012).

A few reliable relations between statistics anxiety and other constructs are now well established, such as gender (Edirisooriya & Lipscomb, 2021; Mandap, 2016, but see Gibeau et al., 2023, which question this relation), achievement goals (Lalande et al., 2019; Valle et al., 2021), attitudes towards the subject (Chiesi & Primi, 2010; Macher et al., 2013; McIntee et al., 2022), and mathematics anxiety (Baloglu, 2004; Jordan et al., 2014; Zeidner, 1991). In the present studies, three cognitive factors that might be *predictors* of statistics anxiety are examined. Those are working memory (WM), spatial anxiety, and mathematics anxiety.

Potential predictors of statistics anxiety

Research involving statistics anxiety and statistics ability is only now emerging. Indeed, there is not much research on the influence of WM on statistics. As such, this subsection considers research on mathematics anxiety or ability as they are strongly related but distinct constructs (Baloglu, 1999, 2004; Zeidner, 1991).

The influence of working memory in mathematics

Working memory is strongly related to mathematics (Raghubar et al., 2010; van de Weijer-Bergsma et al., 2022). Indeed, the understanding of a problem cannot be better than its internal representation in WM. Specifically, Raghubar et al. (2010) argue that WM, by definition, is related to mathematical skills since 'problem solving in these domains often involves the holding of partial information and the processing of new information to arrive at a solution' (p. 110). This association is evidenced in multiple studies reviewed in their article. For example, a previous study indicates that the Phonological Loop and the Visuospatial Sketchpad (two of three WM components according to Baddeley, 1992) influence performance on a multiplication task and a subtraction task, respectively, when measured simultaneously (Lee & Kang, 2002).

Similarly, in a recent study, Giofrè et al. (2018) observed a distinction between verbal WM span and spatial WM span with regards to mathematics and statistics. Specifically, the authors tested three models: one in which both memory spans were considered undistinguishable onto the memory tasks; a second model in which both memory spans were considered separately onto the memory tasks; and a third in which both memory spans were considered separately along with mathematics and reading ability onto their corresponding tasks. The second model had a better fit than the first one, suggesting that verbal WM and visuospatial WM are involved in distinct cognitive processes. The authors reported that visuospatial WM explained 10% of the variance in mathematics while verbal WM explained only 4%.

This supports the hypothesis that visuospatial WM, compared with verbal WM, should be more related to the present study's main variables (spatial, mathematics, and statistics anxieties). Furthermore, the literature on the relation between WM and anxiety is extensive, specifically with mathematics anxiety. For example, a recent study looked at verbal WM, numerical WM, mathematics anxiety, and calculation performance (Peng & Ma, 2025). The results suggest that only verbal WM is a significant mediator in the relation between mathematics anxiety and calculation performance. However, the authors only examined the phonological loop component of WM using two different stimuli. It is still unclear whether visuospatial WM (the other component of the WM system according to Baddeley, 2010). In another recent study, the authors included spatial WM (He et al., 2025). The results suggest that children with high spatial and verbal WM tend to be less mathematically anxious and that those with mathematics anxiety and low spatial WM have lower performance in an approximate number system task. It is consequently hypothesized that statistics anxiety will be more negatively associated with visuospatial WM span than with verbal WM span (which will serve as a control).

Only one study, that we know of, examined WM and mathematics alongside statistics, instead of only mathematics. Indeed, Bonnot and Croizet (2007), looking at the relations between statistics performance, mathematics performance, and WM related to gender differences, concluded that women who held the inferiority stereotype in mathematics also had lower grades in statistics and lower self-evaluation in mathematics. Additionally, there was a bigger difference in mathematics performance when WM was involved. In other words, women who held the inferiority stereotype had lower mathematics performance and lower self-evaluation only in difficult tasks (i.e., when WM is more solicited). These studies suggest that WM may be associated to statistics ability, mathematics ability and spatial skills (described below).

The spatial skills influence on statistics anxiety

Spatial skills are cognitive abilities that allow one to mentally manipulate, transform, and represent elements within their mind (Bennett-Pierre & Gunderson, 2023; Uttal et al., 2013). They are typically grouped into one of three dimensions: *mental manipulation*, *navigation*, and *imagery* (Lyons et al., 2018). The first dimension involves crude and dynamic elements, the second involves dynamic and vague or detailed elements, and the last one involves static elements with many details.

These skills are believed to be used to solve and accomplish a wide variety of problems and tasks (Davis et al., 2021; Jaeger et al., 2016; Miller et al., 2020). For example, spatial skills appear critical to mathematics learning, understanding, and performance (Geary et al., 2023; Kyttälä & Björn, 2014; Rittle-Johnson et al., 2018). Specifically, a recent study suggests that spatial skills and attention during class are the two best predictors of mathematics performance (Geary et al., 2021). Furthermore, spatial skills are related to problem-solving and reasoning activities required in many professions, notably those that are STEM-related (Science, Technology, Engineering, and Mathematics; Atit et al., 2022; Sorby et al., 2018). This relation between spatial skills and competence and interest in STEM fields has been amply described (Hinze et al., 2013; Sorby et al., 2018; Yang et al., 2020). However, studies examining the relations between spatial skills and statistics learning in non-STEM fields are only now emerging.

In recent work, statistics anxiety has been linked to the anxiety towards activities or reasonings requiring spatial skills (*spatial anxiety*; e.g., anxiety towards needing to mentally manipulate an element; Gibeau et al., 2023). Specifically, it was observed that people higher in mental manipulation anxiety are also higher in statistics interpretation anxiety, or vice versa. Indeed, interpretation of statistics anxiety was most strongly positively associated to mental manipulation anxiety, weakly positively associated with imagery anxiety and not at all with navigation anxiety. Cousineau and Harding (2017) argued that the mental representations underlying statistical reasoning are visuospatial in nature. This hypothesis explains why statistics anxiety relates to spatial anxiety (Gibeau et al., 2023). Herein, this hypothesis is explored more fully by examining actual spatial *skills* in addition to spatial *anxiety*.

Even though there is an established relation between spatial anxiety and statistics anxiety, it does not necessarily follow that spatial performance will also relate to statistics anxiety. In the current studies, the goal is to deepen the understanding of the link between statistics anxiety and spatial processing by examining the relations between performance on measures of spatial skills and responses to measures of spatial anxiety. Specifically, the relations between performance on two separate measures of spatial skills are explored: visuospatial WM span (Rouet et al., 2012; Wang et al., 2021) and spatial problem-solving (Henn et al., 2018; Rodán et al., 2022). Study 1 examines spatial processing on statistics anxiety using visuospatial WM. Study 2 examines spatial processing on statistics anxiety using spatial problem-solving.

Hypotheses

The main goal of this study is to examine the role of spatial processing skills (through visuospatial WM and then through spatial problem-solving) in statistics anxiety, while considering spatial anxiety and mathematics anxiety. First, it is hypothesized that visuospatial WM, compared with verbal WM, influences the levels of spatial anxiety, which, in turn, will influence statistics anxiety through mathematics anxiety. It is also hypothesized that spatial skills, compared with verbal abilities, influence the levels of spatial anxiety, which, in turn, will influence statistics anxiety through mathematics anxiety. Below is the explanation of how these hypotheses came to be.

Mathematics anxiety will be used as a mediator between spatial anxiety and statistics anxiety. This decision is motivated by the possible presence of a cascade of influence between those three variables. Specifically, spatial anxiety appears quite early in children (between 6 and 8 years old; Lauer et al., 2018; Ramirez et al., 2012) and mathematics anxiety has been reported around 8–9 years of age (fourth grade; Harari et al., 2013). In their study, Harari et al. (2013) reported moderate mathematics anxiety in first graders (6–7 years old); however, it correlated weakly with performance in mathematics. Statistics anxiety is thought to appear later as it is taught quite late in students' academic curriculum as a separate subject (i.e., college or university). Though, developmental longitudinal studies are needed to formally test this cascade of influence. On the other hand, and more realistic within the present studies, because spatial skills predict mathematics anxiety and mathematics ability, as described above, they may also influence statistics anxiety and statistics ability. To summarize, it is hypothesized that spatial skills relates to spatial anxiety, which directly and indirectly (through mathematics anxiety) relates to statistics anxiety. This is explored in two studies.

In Study 1, visuospatial WM span is measured with verbal WM span as a control. The relation of visuospatial WM span and statistics anxiety should be different for all three subscales of statistics anxiety, and is expected to be stronger for statistics interpretation anxiety relative to the other two, as spatial anxiety was more positively associated with statistics interpretation anxiety in a previous study (Gibeau et al., 2023). In Study 2, spatial skills are measured through a spatial reasoning test. It is hypothesized that the same pattern of associations will occur when spatial skills are used and when verbal ability is used as a control in a path regression model, similarly to numerous previous studies involving mathematics anxiety (e.g., Delage et al., 2021; Ferguson et al., 2015). When looking at the items measuring the anxiety of asking for help in the *Statistical Anxiety Scale* (SAS), one can see that the statements have a social component as it involves another person (e.g., 'Asking the teacher how to use a probability table'). This is why the anxiety of asking for help alongside general anxiety are considered as controls in the present research.

STUDY 1

Models of WM propose two specialized short-term memory systems, one for manipulating phonological information (the *phonological loop*) and a second for manipulating visuospatial information (the *visuospatial sketchpad*; Baddeley, 1992). One measure for each of those specialized dimensions is used in the present study, the Corsi-Blocks task and the n-Back task. Baddeley (1992) also assumed a central executive common to both memory systems.

Method

Participants

Participants were students recruited from Canadian, French, and Belgian universities. All participants were asked to complete the survey in French. They were undergraduates in Social Sciences or Human Sciences programmes and were enrolled in an introductory statistics course at the time of the study. They were informed of the study by their statistics instructor. Data collection was planned to occur during the academic year 2020–2021 but it was extended for an additional academic year (2021–2022; see Results section). Data were collected during the fall and winter semesters of these two academic years. No exclusion criteria were applied during or prior to data collection. The instructors were invited to use a one-page slide promoting the study, a short video showing the first and last author explaining the study, and/or an email sent to their students (according to their preference). It was specified to students that their course grade would not be affected by their decision to participate or not and that their instructor would not be given information about their participation.

Materials

Questionnaires

Spatial anxiety. Spatial anxiety was measured with the validated French version of the *Spatial Anxiety Questionnaire* (SAQ-F; Gibeau et al., 2023; original version in Lyons et al., 2018). All the items are preceded by a context and a question, 'Are you anxious when…'. This instrument has three subscales: mental manipulation anxiety (SAQ-M; e.g., '… you are asked to determine how a series of pulleys will interact given only a 2-dimensional diagram'), navigation anxiety (SAQ-N; e.g., '… you are asked to do the navigational planning for a long car trip') and imagery anxiety (SAQ-I; e.g., '… you are asked to recall the shade and the pattern of a person's tie you met for the first time the previous evening'). Each subscale included eight items, for a total of 24 items. Participants indicated how much anxiety they would experience if facing the situation described on a 5-point scale (0: 'not at all', 1: 'a little', 2: 'a fair amount', 3: 'much', 4: 'very much'). The authors of the French validation study reported excellent internal reliability ($\omega = .93$ overall). External validity of the original version was assessed by the relations between its three subscales and their corresponding attitudes and skills while controlling for general anxiety (Lyons et al., 2018). The authors reported that each subscale was moderately-to-strongly related with its relevant self-reported and objective skill.

Statistical anxiety. This variable was measured with the validated 21-item French version of the *Statistical Anxiety Scale* (SAS-F; Cantinotti et al., 2017; original version in Vigil-Colet et al., 2008). The original version included 24 items divided into three subscales: evaluation anxiety (SAS-E; e.g., '… studying for a statistics exam'), anxiety of asking for help (SAS-A; e.g., '… asking the professor or their assistant(s) to explain a concept I did not understand') and interpretation anxiety (SAS-I; e.g., '… reading advertisement that includes tables and graphs'). As reported in Cantinotti et al. (2017), three items did not contribute enough to the confirmatory factor analysis on the French version and were removed. Again, participants indicated how much anxiety they would experience if facing the situation described in each item on a 5-point scale; 'no anxiety' (1), '…' (2), 'medium anxiety' (3), '…' (4) and 'a lot of anxiety' (5). The authors of the French version reported excellent reliability of scores ($\omega = .95$ overall). Validity was assessed by a clear 3-factor structure and by a strong correlation with students' final grade in statistics course (Cantinotti et al., 2017).

Mathematics anxiety. This variable was measured with the validated French version of the *Abbreviated Math Anxiety Scale* (AMAS; Gibeau et al., 2023; original version in Hopko et al., 2003). The questionnaire measures mathematics anxiety on two dimensions: learning mathematics anxiety (AMAS-L; e.g., '… listening to a lecture in math') and mathematics evaluation anxiety (AMAS-E; e.g., '… you receive a pop quiz in your math class'). The learning anxiety subscale has 5 items, and the evaluation anxiety subscale has 4 items, for a total of 9 items. Participants indicated how much anxiety they would experience if facing the situation described on a 5-point scale; 'low anxiety' (1), '…' (2), 'medium anxiety' (3), '…' (4) and 'high anxiety' (5). The authors of the French validation study reported excellent reliability of scores ($\alpha = .90$ overall). Validity is indicated by a strong correlation with the statistics anxiety scale ($r = .79$; Gibeau et al., 2023).

Tasks

Tasks were programmed in JavaScript and implemented into Qualtrics.

n-Back task. This task measures executive functions as well as phonological WM span (Baddeley, 1992). A previous study examined the task's validity (Kearney-Ramos et al., 2014). The authors concluded that this is a valid measure for WM. One trial featured a series of letters with alternating upper- and lower-case to avoid similarity-based recall (e.g., B, f, H, k, M, q, R, x; Vytal et al., 2013). They were presented in the centre of the screen, one letter at a time, with a font size of 30. They were all black over a white background. The first three letters never included targets. All letters were presented for 1000 ms with an inter-item delay of 500 ms. Each trial was composed of 30 items including 10 targets.

Participants were asked to press on the space bar when the letter displayed on the screen was the same as the letter presented just before (1-back condition), two letters before (2-back condition) or three letters before (3-back condition). The 1-back condition is trivially easy for the intended population. Each of the three conditions was repeated three times. Conditions were presented in ascending order of difficulty. The number of correct responses in each condition (a correct response being either a correct spacebar press or a correct no-response) were recorded for a score from 0 to 90 per n-back condition.

A participant who never presses the space bar obtains a score of 60 out of 90 (i.e., 30 errors). The score was rescaled on a range from 0 to 100. If the cumulative number of errors reached 24 or more at the end of a condition, the task was interrupted and the participant could not continue to the next condition (see the implementation given in Bradley-Garcia & Bolton, 2023).

Corsi-blocks task. To measure participants' ability to memorize visuospatial information, the forward Corsi-Blocks Task was used (Corsi, 1972; Milner, 1971). Validity evidence for measuring spatial WM is difficult to find as there are many different versions of the task (Gibeau, 2021). Note that there are many measures of visuospatial WM. It was considered convenient for the present study in terms of accessibility and programmability.

Nine black squares on a white background were presented on participants' screen at random locations. The size of each square was 10% of the screen's width and the minimal distance between the squares was 1% of the screen's width. A sequence of highlighted squares was presented. To highlight the squares, they turned from black to green for 400 ms. The sequences are of varying lengths; they can be composed of 3–7 squares with 4 trials of each for a total of 20 trials with an inter-trial delay of 2000 ms. During the presentation of the sequence, participants' mouse cursor was hidden to avoid motor recall. At the end of the sequence, to indicate that the recall period has begun, a 500 Hz audio signal was played for 400 ms with the volume set at 15% of the highest volume. To recall the sequence, participants needed to click on the correct squares in the correct order. When participants clicked on a square, it turned grey for 200 ms (see the implementation given in Gibeau, 2021). A trial was coded as successful (1 point) if the entire sequence was reported in the correct order. Sequences of length 3 are very easy to perform for healthy adults. Each condition of that task —sequences from 3 to 7 squares— received a score between 0 and 4 (as there were four trials per condition). Then, the score of each condition was weighted so that success in recalling 7 squares (multiplied by 5) was worth more than success in recalling 3 squares (multiplied by 1). The resulting score, ranging from 0 to 60, was rescaled on a range from 0 to 100 to ease interpretation.

Procedure

In the promotional material, a URL link to an online Qualtrics study was distributed. The study took approximately 30 min to complete. No compensation was provided, but Canadian participants could enter into a draw to win a $50 gift card. One gift card for every 50 participants was drawn at the end of the academic years.

First, participants provided informed consent and answered a short series of sociodemographic questions. Then, they completed three questionnaires followed by two tasks as described above. The questionnaires and their items were presented in a randomized order.

The items were divided into seven blocks. The first four blocks contained eight items from the *Spatial Anxiety Questionnaire* (SAQ) and 8 from the *Statistical Anxiety Scale* (SAS; two blocks for each questionnaire in a random order). The fifth and sixth blocks contained the last 8 items of the SAQ and the last 5 items of the SAS. Finally, the last block was composed of the 9 items of the *Abbreviated Math Anxiety Scale* (AMAS). Each questionnaire's total score as well as its subscale scores were rescaled on a range from 0 to 100 to ease the interpretation. As recommended by Cousineau (2020), descriptive statistics are reported with one decimal and standardized effect sizes are reported with two decimals in the present study.

Results

Data screening

In total, 1332 people clicked on the URL link and 420 completed the questionnaire (31.5%). This was unexpected as in a prior study (September 2019–April 2020) involving the same population and the same universities, 82.1% of the individuals who clicked on the URL completed the whole survey (Gibeau et al., 2023). One possible explanation may be that the COVID-19 pandemic influenced the students, making them too preoccupied and more prone to leave the study. Another explanation might be that the tasks were judged too demanding. Furthermore, many of the remaining participants (114) had a score of 0 in all three conditions of the Corsi-Blocks Task (presumably due to browser or device incompatibility with the programme) and were excluded from further analyses. Thus, a total of 306 participants were included in the final analyses. This is the reason why data collection was extended over a second academic year. Among the remaining data, there were 105 missing values (.6% of the items). The Little test was performed to make sure that the missing data were missing completely at random ($\chi^2=1689.55$, $df=1621$, $p=.12$).

All participants completed the 1-back task (90 without error), but 41 (13%) did not progress to the 2-back condition. Of the remaining 265 participants, almost all (262) reached the 3-back condition. Skews and kurtosis were extremely high in the 1-back condition (−2.02 and 3.45 respectively) and in the 2-back condition (−1.67 and 2.85 respectively). This might be due to a ceiling effect, where the first two conditions are too easy. For the last condition (3-back), skew and kurtosis were acceptable (−.41 and −.31 respectively). An arcsine transformation on the proportion correct for each condition was used (Laurencelle & Cousineau, 2022), which considerably reduced these deviations from normality (the skews are −1.39, −.79, and .12 respectively and the kurtosis are .99, .13, and −.40 respectively). The total score to the n-Back Task was the sum of the arcsine-transformed scores on the three conditions, rescaled on a range of 0–100.

The Corsi-Blocks Task was easy for sequences of 3 and 4 squares (mean number of successful trials of 3.8 and 3.5 out of 4 trials); then accuracy decreased abruptly for sequences of 5–7 (means of 2.8, 1.8, and .9). Asymmetry was initially negative (too easy with a ceiling effect); then became positive (too hard with a floor effect), ranging from −3.40 to .95. Kurtosis also varied significantly across conditions (ranging from 11.95 to −1.02). However, the weighted total score, used for further analyses, was nearly normally distributed (skew of −.09 and kurtosis of −.35).

Descriptive statistics

Table 1 presents the descriptive statistics of participants' tasks and questionnaires. Among 306 participants, 255 identified as women, 43 as men, and 8 answered ‘other’, ‘prefer not to say’ or did not answer the question. A total of 240 participants answered the question about their age. The majority of those 240 participants are from 18 to 24 years old, with a mean of 22 and a median of 20. Participants were recruited from two different continents: 213 from Europe (either France or Belgium) and 93 from North America (Canada). A prior study found no between-continent differences with respect to the questionnaires used herein (Gibeau et al., 2023), thus the present analyses are collapsed across continents. Finally, the questionnaires' reliability indices were very similar to those reported in the original studies (McDonald's omega ranging from .92 to .96).

TABLE 1 Descriptive statistics of all variables used in Study 1.

Variables	*N*	Mean [95% CI]	SD	Min.	Max.	Skewness	Cronbach's α	McDonald's ω
NBack	306	77.6 [76.0, 79.2]	14.1	38.8	94.7	−1.54	–	–
CBlocks	306	51.8 [49.6, 53.9]	19.5	2	100	−.09	–	–
SAQ	306	42.7 [40.4, 44.5]	18.0	0	91	.80	.92	.94
SAS	306	50.8 [48.3, 53.1]	20.1	0	96	−.09	.93	.96
AMAS	306	46.8 [44.1, 49.4]	22.6	0	100	.24	.90	.92

Note: All the questionnaires are the French-validated versions. The questionnaires and tasks were rescaled on a range from 0 to 100 points.
Abbreviations: AMAS, Abbreviated Math Anxiety Scale; CBlocks, Corsi-Blocks Task; NBack, n-Back Task; SAQ, Spatial Anxiety Questionnaire; SAS, Statistics Anxiety Scale.

Correlations between questionnaires' total scores and tasks

First, the relations between the three anxiety questionnaires were examined (see Table 2). Replicating the results of Gibeau et al. (2023), all three anxieties were moderately-to-strongly positively correlated ($r = .49$ to $.74$). As expected, mathematics anxiety and statistics anxiety show the largest correlation ($r = .74$). These correlations, as well as the following correlations in the present text, were compared using the Medcalc.org website. The comparisons of these correlations are significant. The result of the comparison between the spatial anxiety and mathematics anxiety correlation ($r = .49$) and the mathematics anxiety and statistics anxiety correlation ($r = .74$) is: $z = -5.10$, $p < .0001$. As for the comparison between spatial anxiety and statistics anxiety correlation ($r = .52$) and the mathematics anxiety and statistics anxiety ($r = .74$), the results are: $z = -4.61$, $p < .0001$. The two WM span tasks were weakly positively associated ($r = .15$), indicating that they do not measure the same components of WM.

Next, the hypothesis that performance on the Corsi-Blocks Task would be negatively related to each of the anxiety questionnaires was tested. As predicted, there were significant negative correlations between performance on the Corsi-Blocks Task and the anxiety questionnaires (spatial anxiety $r = -.13$, mathematics anxiety $r = -.24$, and statistics anxiety $r = -.13$). Performance on the n-Back Task was also negatively correlated with the questionnaires (spatial anxiety $r = -.10$, mathematics anxiety $r = -.14$, and statistics anxiety $r = -.13$). Even though the correlations are weak to moderate, they have the expected directionality. By contrast, the correlations between scales' totals are strong because they are all quite similarly framed, asking questions about self-reported anxiety.

Correlations between anxiety subscales

Relations between the components of the three anxieties were explored. Mathematics anxiety subscales (AMAS-L and AMAS-E; last two rows of Table 3) were strongly correlated with statistics anxiety subscales (SAS-E, SAS-A, and SAS-I). These high intercorrelations were expected and are frequently observed for these two related forms of anxiety (Paechter et al., 2017). Anxiety of asking for help in statistics had the weakest correlations with both subscales of mathematics anxiety (.37 and .38 respectively; comparison of AMAS-L – SAS-E and AMAS-L – SAS-A: $z = -8.95$, $p < .0001$; comparison of AMAS-L – SAS-I and AMAS-L – SAS-A: $z = -2.51$, $p = .01$; comparison of AMAS-E – SAS-E and AMAS-E – SAS-A: $z = -2.48$ $p = .01$; comparison of AMAS-E – SAS-I and AMAS-E – SAS-A: $z = -6.14$, $p < .0001$). This was unsurprising as the AMAS has no explicit social dimension. The fact that mathematics evaluation anxiety was less related to statistics evaluation anxiety than to statistics interpretation anxiety is an oddity observed in other studies (e.g., Gibeau et al., 2023).

Regarding associations between the three spatial anxiety subscales and the five other questionnaires' subscales, all correlations were strong, and their distribution seemed bimodal. Eleven of them were around .30 (from .20 to .38 with a mean of .29) whereas four were above .42 (.42 to .55 with a mean of .48). All four of them were with respect to SAQ-M. This is interpreted as indicating that a correlation of about .30 is a baseline for associations between anxiety variables. Hence, any correlation above .30

TABLE 2 Correlation matrix of all questionnaires' total scores and tasks in Study 1.

Variables	NBack	CBlocks	SAQ	SAS
CBlocks	.15 [.05, .25]			
SAQ	−.10 [−.21, .02]	−.13 [−.21, −.02]		
SAS	−.13 [−.25, −.02]	−.13 [−.25, −.02]	.52 [.42, .61]	
AMAS	−.14 [−.26, −.03]	−.24 [−.35, −.11]	.49 [.39, .59]	.74 [.69, .79]

Note: The numbers between brackets are the 95% confidence intervals of the correlation coefficient.

Abbreviations: AMAS, Abbreviated Math Anxiety Scale; CBlocks, Corsi-Blocks Task; NBack, n-Back Task; SAQ, Spatial Anxiety Questionnaire; SAS, Statistics Anxiety Scale.

TABLE 3 Correlation matrix of subscales and tasks scores in Study 1.

Variables	NBack	CBlock	SAQ-M	SAQ-I	SAQ-N	SAS-E	SAS-A	SAS-I	AMAS-E
CBlock	.15 [.04, .26]								
SAQ-M	−.13 [−.24, −.02]	−.19 [−.30, −.07]							
SAQ-I	−.02 [−.14, .10]	.04 [−.07, .16]	.44 [.34, .54]						
SAQ-N	−.07 [−.18, .04]	−.14 [−.25, −.02]	.44 [.35, .54]	.44 [.33, .54]					
SAS-E	−.10 [−.23, .04]	−.20 [−.33, −.06]	.42 [.32, .52]	.23 [.11, .34]	.35 [.23, .45]				
SAS-A	−.10 [−.21, .01]	≈ .00 [−.11, .10]	.26 [.16, .36]	.29 [.17, .39]	.32 [.21, .42]	.40 [.30, .49]			
SAS-I	−.12 [−.23, −.01]	−.16 [−.27, −.04]	.55 [.47, .63]	.29 [.18, .39]	.28 [.18, .39]	.56 [.50, .62]	.40 [.30, .49]		
AMAS-E	−.14 [−.25, −.02]	−.24 [−.33, −.14]	.49 [.38, .58]	.24 [.11, .36]	.21 [.10, .32]	.53 [.46, .58]	.37 [.28, .47]	.71 [.63, .77]	
AMAS-L	−.12 [−.24, .01]	−.18 [−.30, −.06]	.45 [.35, .55]	.31 [.19, .42]	.38 [.28, .48]	.81 [.76, .85]	.38 [.27, .48]	.54 [.46, .62]	.62 [.56, .67]

Note: The numbers between brackets are the 95% confidence intervals of the correlation coefficient.

Abbreviations: AMAS-E, Evaluation Anxiety subscale of the Abbreviated Math Anxiety Scale; AMAS-L, Learning Anxiety subscale of the Abbreviated Math Anxiety Scale; CBlocks, Corsi-Blocks Task; NBack, n-Back Task; SAQ-I, Imagery subscale of the Spatial Anxiety Questionnaire; SAQ-M, Mental Manipulation subscale of the Spatial Anxiety Questionnaire; SAQ-N, Navigation subscale of the Spatial Anxiety Questionnaire; SAS-A, Fear of Asking for Help subscale of the Statistics Anxiety Scale; SAS-E, Evaluation Anxiety subscale of the Statistics Anxiety Scale; SAS-I, Interpretation Anxiety subscale of the Statistics Anxiety Scale.

denotes a substantive association based on the cognitive processes. The lack of a substantive correlation between SAQ-M and anxiety of asking for help ($r = .26$) supports this interpretation. The numerically, but not statistically, strongest correlation, $r = .55$, relates SAQ-M to SAS-I, in line with the main hypothesis.

Correlations between anxiety subscales and working memory tasks

Performance on the n-Back Task was weakly and negatively associated with all eight subscales of the anxiety scales (*rs* from −.14 to −.02). The correlations were all negative, suggesting that participants with good phonological span or good executive functions experience lower anxiety, and vice versa. The average r was −.10, with 4 of the 8 correlations involving anxiety subscales which did not differ significantly from zero. Notably, the correlation between the n-Back Task and anxiety of asking for help was −.10. This last variable was a control.

The Corsi-Blocks Task showed more varied correlations (ranging from −.24 to < .001). It was null with respect to anxiety of asking for help and very weak for imagery anxiety. The Corsi-Blocks Task involves schematized blocks (mere squares), which do not require any highly detailed imagery. As such, imagery anxiety was not involved in this task, or vice versa. The remaining six correlations (ranging from −.24 to −.14 with a mean of −.19) were all significant (all ps < .015). This critical result suggests that visuospatial WM span has some relation with anxiety towards spatial tasks, mathematics anxiety, and anxiety of statistics evaluation and statistics interpretation (but not towards anxiety of asking for help).

Although the correlations involving the Corsi-Blocks Task were not very strong, they were almost twice as large as the correlations involving the n-Back Task. Thus, even though the n-Back Task has an advantage (it measures two constructs: phonological span and executive functions), it failed to capture a significant part of the variance, and in addition, it did not distinguish social anxiety from interpretation anxiety. Consequently, it lacks specificity when considering statistics and mathematics.

The two critical correlations regarding the main hypothesis were the Corsi-Blocks Task and the n-Back Task on interpretation anxiety in statistics. The correlation is strongest for the Corsi-Blocks Task ($r = -.16$ vs. $r = -.12$) but the difference was small and not significant ($z = .50$, $p = .62$). One reason is that these variables may have variance that overlaps with other sources of variance.

To determine whether they are distinct correlations from a unique source of variance, semi-partial correlations were computed to find the specific portion of variance explained by the tasks over and above anxiety of asking for help (Abdi, 2007; Cohen & Cohen, 1975). Notably, each task had non-significant correlations with anxiety of asking for help. As this latter measure is a control, it was used to discount the contribution of anxiety items in general from the interpretation anxiety in statistics. Table 4 repeats the (regular) correlations and shows the semi-partial correlations for all three predictors with respect to interpretation anxiety in statistics.

As seen, the correlation between the n-Back Task and interpretation anxiety in statistics, when considering anxiety of asking for help and the Corsi-Blocks Task, decreased almost twofold whereas the

TABLE 4 Pairwise and semi-partial correlations for three predictors of interpretation anxiety in statistics (SAS-I) in Study 1.

	Correlations	
Variables	**Pairwise**	**Semi-partial**
NBack	−.12	−.06
CBlock	−.16	−.16
SAS-A	.40	.40

Note: The pairwise correlations are reproduced from Table 3 for easier comparison.

other two stayed nearly unchanged. This indicates that the n-Back Task shares variances with the other two variables whereas the Corsi-Blocks Task shares none with anxiety of asking for help (as seen in Table 3, this last correlation was undistinguishable from zero).

In the next section, two models are examined. These further suggest a stronger, distinct contribution of visuospatial WM span onto interpretation anxiety in statistics, compared with phonological WM span.

Path regression models

A post hoc power analysis was run in GPower to determine the statistical power for this analysis. With an effect size of .18 (the result of the first path regression from Figure 1), an alpha of .05, a sample size of 306, and three predictors, the power was estimated at .99.

When examining the correlations in the sections above, it was argued that there is a baseline association involving measures of anxiety. Hence, to get the distinct contribution of WM spans onto interpretation anxiety in statistics, it is necessary to control for that baseline. This is what covariance analysis does. Here, a linear regression predicting interpretation anxiety in statistics while controlling for anxiety of asking for help was performed using the mediation command in the MPlus software (version 7). Figure 1, left-hand panel, shows the results. As can be seen, the role of visuospatial WM span was stronger when the baseline is controlled for. As an exploratory analysis, the same regression was run with evaluation anxiety in statistics. The results show a similar pattern (Figure 1, right-hand panel).

In a second, more detailed, model, spatial anxiety is introduced. Visuospatial WM span is expected to first influence spatial anxiety, which, in turn, influences statistics anxiety. The results are shown in Figure 2. All variables were controlled for baseline anxiety using anxiety of asking for help. Mathematics anxiety was a mediator because it is believed that a fair amount of statistics anxiety is a carry-over of an anxiety towards mathematics, which is measurable years before statistics anxiety begins to manifest (Gibeau et al., 2023). Poor spatial skills (measured by a WM task) are expected to be the first predictor as previous research has shown that poor spatial skills predict higher mathematics anxiety and lower mathematics performance (Ashkenazi & Velner, 2023; Delage et al., 2022; Ferguson et al., 2015; Sokolowski et al., 2019). Also, mental manipulation in spatial anxiety, used in the model, is the most relevant predictor of interpretation anxiety in statistics (Gibeau et al., 2023).

Figure 2 shows the model parameters. It fits the data well (RMSEA = .08, CFI = .97, TLI = .92, SRMR = .05). The results suggest that mental manipulation anxiety contributes to interpretation anxiety in statistics. Both WM span tasks contribute to mental manipulation anxiety. However, the n-Back Task coefficient was not significant, whereas the Corsi-Blocks Task coefficient was significant. The present model also indicates a partial mediation. The indirect path shows that mental manipulation anxiety

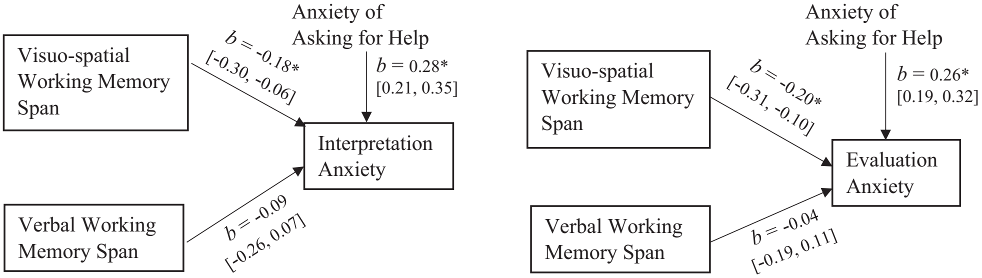

FIGURE 1 Regression of Corsi Blocks and n-Back tasks when anxiety of asking for help is used as a covariate on interpretation anxiety in statistics (left panel) and on evaluation anxiety in statistics (right panel). The numbers are the raw regression coefficients with their 95% confidence intervals. * The symbol signifies that the coeficient is significant as 0 is not included in its 95% confidence interval.

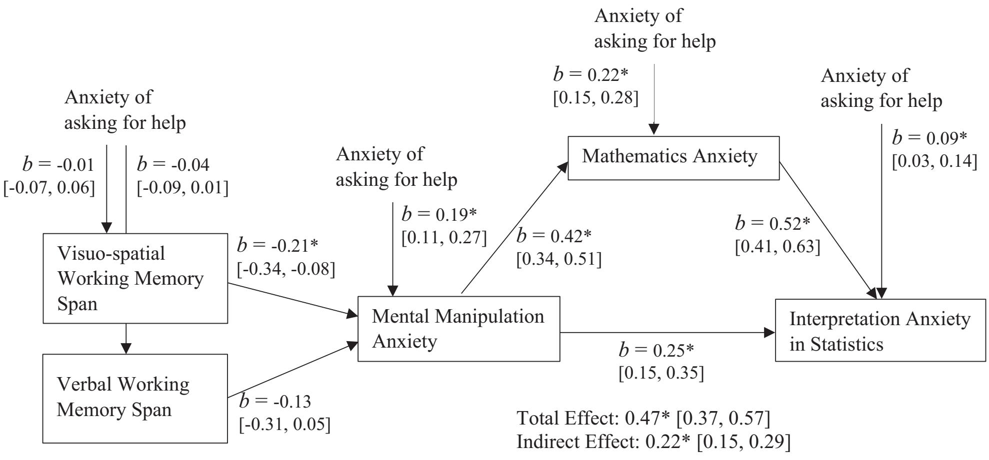

FIGURE 2 Model involving Working Memory Spans, Mental Manipulation Anxiety, Mathematics Anxiety predicting Interpretation Anxiety in Statistics from Study 1; the three anxiety measures and the tasks have anxiety of asking for help as covariate. The numbers are the raw regression coefficients with their 95% confidence intervals. * The symbol signifies that the coeficient is significant as 0 is not included in its 95% confidence interval.

contributes to mathematics anxiety, which contributes to interpretation anxiety in statistics, and the direct path shows that mental manipulation anxiety contributes to interpretation anxiety in statistics. Both were of similar magnitude, where the former explained 47% of the variance of interpretation anxiety in statistics. This supports the carry-over effect mentioned in the previous paragraph (also observed in Gibeau et al., 2023). However, the present study does not have a longitudinal design; consequently, no developmental conclusions can be made.

Discussion

The associations between tasks and anxiety types are not as strong as the correlations between different types of anxiety. This can be explained by the difference in data collection methodology of WM and anxiety (i.e., tasks vs. self-reported questionnaires; Clark & Maguire, 2020, report a similar pattern). Nonetheless, the analyses support the main hypotheses. Indeed, the consistently significant associations between visuospatial WM span, spatial anxiety, and statistics anxiety suggest that spatial cognition plays a role in statistics learning. This is in line with previous research in numerical cognition, in which spatial skills play a role in mathematics learning through a *cognitive-emotional framework* (e.g., Ashkenazi & Velner, 2023; Ferguson et al., 2015; Sokolowski et al., 2019). Furthermore, the mediation model also supports the influence of cognitive abilities on spatial anxiety with subsequent effect on both mathematics anxiety and statistics anxiety. This chain of associations passes through mental manipulation anxiety (with a correlation of −.19 with SAQ-M seen in Table 3) compared with navigation ($r = -.14$) and imagery anxiety ($r = .04$). This last result is also in line with previous research, in which mental manipulation anxiety is the strongest mediator in the relationship between gender and mathematics anxiety (Delage et al., 2022).

As such, visuospatial WM span can be considered as a *resource* available to perform cognitive tasks such as learning statistics. Having this resource, however, does not mean that the person is well trained to use it. Consequently, it would be interesting to examine visuospatial *skills* (i.e., the manifested skill to visuospatially manipulate organized information). To that end, the two WM span tasks can be replaced with ability tasks; one measuring spatial skills and one measuring verbal abilities. This is done in Study 2.

STUDY 2

It was observed in Study 1 that imagery anxiety had different correlations with WM spans and mental manipulation spatial anxiety. To examine this distinction further, a measure of mental imagery vividness was added in Study 2. The reason for this exploratory analysis is the conjecture that people with more vivid images might have better spatial skills and less spatial anxiety (but note that Blajenkova et al., 2006, argued that these two constructs may be unrelated).

Method

Participants

Study 2 was advertised to the same population as in Study 1. The only difference is that these students were enrolled in a statistics course during the 2022–2023 academic year.

Materials

First, participants provided informed consent and answered a short series of sociodemographic questions. Then, they completed three questionnaires and two tests as described below. The questionnaires, their items and the tests were presented in a randomized order. As in Study 1, all scores were rescaled on a range from 0 to 100 to ease interpretation.

Preserved measures

The mental manipulation and the imagery subscales of the *Spatial Anxiety Questionnaire* (SAQ) were included in this study because mental manipulation and imagery should be closely related concepts and a subsidiary goal is to deepen the understanding of their relation. Similarly, the anxiety of asking for help and interpretation anxiety subscales of the *Statistical Anxiety Scale* (SAS) were used because the second is the most important aspect of statistics anxiety, and the first is a good covariate to control for items bearing on anxiety.

Discarded measures

The *Abbreviated Math Anxiety Scale* (AMAS) was not included in Study 2 as its mediation effect is now well established. Also, navigation in spatial anxiety (SAQ-N) and evaluation anxiety in statistics (SAS-E) were removed because Study 1 showed no significant correlations between each of these two variables and statistics interpretation anxiety, which is the main concern of Study 2.

New measures

To measure spatial skills, a French translation of the *Spatial Reasoning Instrument* (SRI; original version in Ramful et al., 2017) was used. The questionnaire comprises 30 items divided into three subscales: one depicting mental manipulation (SRI-M; e.g., 'Here's a picture of two dogs. Which one of the following shows the picture after a 90 degrees turn to the right?'), another depicting navigation (SRI-N; e.g., 'Briana placed a hamster at the start of a maze as shown below. The hamster ran through the maze. It turned to its right, then turned left, then turned right. Where did the hamster finish?') and a third depicting imagery (SRI-I; e.g., 'Jane makes a pattern by first folding a square paper into 4 parts as shown below. She then cuts the folded piece of paper into the shape shown below. Which one of the following represents the pattern obtained by unfolding the paper?'). The original authors reported good reliability (α of .85 overall) and good construct validity (correlations between .33 and .62 with similar measures).

Three items were removed for the present study because one was a repetition and the other two had an ambiguous wording or response.[1]

To measure verbal abilities, 15 items measuring French writing skills and vocabulary were assembled. First, five questions on verb conjugation from the QCM-Concours website (VA; https://micromagie.com/quizfaber/francais/conj2/Conjugaison2) were used. To get 1 point for each question, participants had to find the correct answer. A loosely translated example is: 'We had (harm) each other without knowing', with 'harmt', 'harmed', 'harm', 'harms', and 'harming', Second, 10 items measuring verbal logic were added (https://micromagie.com/quizfaber/francais/logiqueverbale/Aptitude%20verbale), which implement a general level of cognitive functioning. A loosely translated example is: 'Find the word that best completes the following analogy: *For* is to *against*, what *always* is to…' with 'sometimes', 'only', 'again', 'never', and 'maybe' as response options. The items were scored as correct or incorrect and the total was computed, ranging from 0 to 15, and rescaled on a range from 0 to 100 for easier interpretation.

To explore the level of detail of mental images, the French version of the *Vividness of Visual Imagery Questionnaire* (VVIQ-F; Campos et al., 2000; original version in Marks, 1973) was used. This is a 16-item questionnaire divided into four scenarios of four questions each (imagine a family member; imagine a sunrise; imagine a store you often go to and imagine a country scene). Participants answered on a 5-point scale: (1) 'Perfectly clear and as vivid as normal vision', (2) 'Clear and reasonably vivid', (3) 'Moderately clear and vivid', (4) 'Vague and dim' and (5) 'No image at all, you only "know" that you are thinking of the object'. Note that the scale is actually reversed as a high score reflects a *lack of* vividness; scores ranged from 16 (perfectly clear)–80 (no image at all) which were then rescaled on a range from 0 to 100 for easier interpretation. Previous research has reported high validity and reliability of the VVIQ (Campos, 2011).

Finally, one more item was added to the questionnaire. The item asked participants to rate their general anxiety level from 1 to 10. The item was added to provide a baseline anxiety level which will be used as a control alongside anxiety of asking for help in statistics (see Allen et al., 2022, for the use of single-item measurements). This measure was inspired by the Single-Item Math Anxiety questionnaire (Núñez-Peña et al., 2014).

Procedure

The procedure is the same as in Study 1.

Results

Data screening

A total of 679 students clicked on the link to the questionnaire provided by their instructor and 374 completed it. This represents a completion rate of 55.1%; better than Study 1 during the COVID-19 pandemic (31.5%) but lower than past studies conducted before the first lockdown.

There were 100 missing responses (about .3% of the items) and no outlier; all the scales and subscales had responses. The missing items' responses were imputed with the mean of the other responses. The distributions appear relatively normal, except for the SRI which has a small asymmetry in the scores (−.67). It is possible that some of the items were too easy, resulting in a ceiling effect. The distribution of VA and of the VVIQ were also skewed (−1.44 and 1.15, respectively).

[1]The items are Item 17 (which is identical to item 8): "Briana placed a hamster at the start of a maze as shown below. The hamster ran through the maze. It turned to its right, then turned left, then turned right. Where did the hamster finish?"; Item 24: "A pedestrian crossing sign is shown below. How many lines of symmetry do the sign have?"; Item 28: "Two plans of Victoria hospital are shown below. Which building is on the corner of Aranda Street and Macquarie Street?"

Descriptive statistics

The descriptive statistics are reported in Table 5. The majority of participants selected the age range 18–24 years old (86.4%) which is also the lower age range selected. The higher age range selected by one participant is 55–64 years old. Likewise, women composed 86.4% of the sample; men composed 11.2% and 2.4% self-identified as other genders. Participants were from North America (10.2%) and Europe (89.8%).

All the Cronbach's alphas and McDonald's omegas were good for SAS (α for SAS-A: .97, SAS-I: .88 and over all: .93; ω for SAS-A: .97, SAS-I: .88 and over all: .96), replicating the ones reported in the original publications. The Cronbach's alpha and McDonald's omega regarding the Verbal ability items is weak (a = .44; ω = .46). Of those, two conjugation items were poorly succeeded (14% and 19% correct respectively for the 11th and 14th items); when removed, α rose to .47 and ω rose to .50. It was decided to keep these two items. Despite the low reliability of this measure, it is kept herein for transparency.

Correlations between questionnaires' total scores and tests

Table 6 presents the correlation matrix. Spatial anxiety and statistics anxiety were strongly correlated (r = .48), which replicates the results of Study 1 and the results of a previous study (Gibeau et al., 2023). The spatial skills test (SRI) was negatively and weakly associated with both anxiety types (SAQ: r = −.18; SAS: r = −.16). Despite the weak correlations, this is congruent with the main hypotheses. Indeed, people with higher spatial skills would tend to be less spatially anxious and less anxious with respect to statistics, which supports the claim that spatial skills play a role in understanding statistics.

Verbal abilities are weakly and negatively correlated to spatial anxiety and statistics anxiety (SAQ: r = −.12; SAS: r = −.13). The relations are similar to the one between SRI and these forms of anxiety but are weaker. Finally, SRI and VA are moderately correlated (r = .44), suggesting some shared variance between the two measures.

Maybe surprisingly at first, lack of imagery vividness was weakly related to spatial skills; the correlation between VVIQ and SRI is not different from zero (r = −.08). However, according to Delem et al. (2025), it is not surprising. The results of their study suggest that aphantasics have intact spatial representations. The VVIQ is weakly and negatively correlated with verbal abilities (also r = −.08). As mentioned above, this latter measure had a weak Cronbach's alpha; consequently, no strong claims can be made, but this absence of relation with verbal abilities would be congruent with expectations.

TABLE 5 Descriptive statistics of all variables in Study 2.

Variables	*N*	Mean [95% CI]	SD	Min.	Max.	Skewness	Cronbach's α	McDonald's ω
VA	374	73.1 [65.6, 80.6]	11.4	20	100	−1.09	.44	.46
GenAnx	374	63.6 [61.2, 66.1]	23.8	10	100	−.53	NA	NA
SRI	374	74.0 [72.2, 75.3]	17.2	22	100	−.67	M: .70; N: .55; I: .63; all: .81	M: .70; N: .57; I: .63; all: .83
SAQ	374	39.7 [37.8, 41.6]	18.7	0	100	.06	M: .89; I: .85; all: 89	M: .89; I: .85; all: .91
SAS	374	46.5 [44.1, 48.8]	23.1	0	100	−.04	A: .97, I: .88; all: .93	A: .97; I: .88; all: .96
VVIQ	374	42.7 [41.2, 44.3]	15.3	19	100	1.15	.92	.94

Note: All the questionnaires and tasks are reported on a scale of 0–100 points.

Abbreviations: GenAnx, question about participants' general anxiety level; SAQ, Spatial Anxiety Questionnaire; SAS, Statistics Anxiety Scale; SRI, Spatial Reasoning Instrument; VA, verbal abilities; VVIQ, Vividness of Visual Imagery Questionnaire (where high scores mean a lack of vividness).

TABLE 6 Correlation matrix of all questionnaires' total score in Study 2 ($N=374$).

Variables	GenAnx	VA	SRI	SAQ	SAS
VA	−.08 [−.18, .02]				
SRI	−.13 [−.23, −.03]	.38 [.29, .47]			
SAQ	.26 [.17, .35]	−.12 [−.22, −.02]	−.18 [−.28, −.08]		
SAS	.44 [.35, .51]	−.14 [−.24, −.04]	−.16 [−.26, −.06]	.48 [.40, .55]	
VVIQ	−.04 [−.14, .06]	−.05 [−.16, .05]	−.08 [−.18, .02]	.13 [.03, .23]	.05 [−.05, .15]

Note: The numbers between brackets are the 95% confidence intervals of the correlation coefficient.

Abbreviations: GenAnx, question about participants' general anxiety level; SAQ, Spatial Anxiety Questionnaire (mental manipulation and imagery only); SAS, Statistics Anxiety Scale (interpretation and asking for help only); SRI, Spatial Reasoning Instrument; VA, verbal abilities; VVIQ, Vividness of Visual Imagery Questionnaire (where high scores mean a lack of vividness).

Finally, general anxiety moderately and positively correlates with spatial and statistics anxiety ($r=.26$ and .44, respectively; both CIs do not include 0). This variable also significantly correlates with spatial skills but negatively instead of positively ($r=-.13$). The other correlations involving general anxiety were not significant as evidenced by the confidence intervals that include 0. These moderate correlations support the conjecture from Study 1 that anxiety questionnaires have a common component. In the previous study, general anxiety was controlled for by using Anxiety of asking for help; here it will be more directly controlled by the general anxiety variable.

Correlations between subscales and tests

Table 7 presents the complete correlation matrix. The results replicate again previous research where Mental Manipulation Anxiety of the SAQ correlates more strongly with Interpretation Anxiety of the SAS ($r=.52$) than with the anxiety of asking for help of the SAS ($r=.30$; when comparing these rs, $z=-3.63$ and $p=.0003$). The SAQ-M subscale correlated well with Mental Manipulation skills –compared with Navigation skills– of the SRI ($r=-.33$ compared with $r=-.19$; $z=-2.05$ and $p=.04$). This was expected as both SAQ-M and SRI-M measure a similar construct, that is, manipulation of elements. Statistics interpretation anxiety was negatively related to SRI-M and to SRI-I ($r=-.25$ and $-.22$, respectively) but less with SRI-N ($r=.09$). However, all three scales of the SRI were strongly intercorrelated (all $rs>.47$), which indicates that they measure very closely related concepts.

Verbal abilities are positively related to all three subscales of spatial skills (with rs between .35 and .40). Moderate correlations could be expected as (a) the SRI has a language dimension since, to have the correct answer, one must understand the written question; (b) vocabulary is an indirect measure of IQ and therefore, high-performing participants on verbal abilities may likewise tend to be high functioning in other areas as well (e.g., Laasonen et al., 2020).

The correlations between Imagery Anxiety and Manipulation anxiety in the SAQ and Anxiety of Asking for Help in the SAS were fairly high (both $r=.30$, as in Study 1 where they were .26 and .29, respectively), which suggests that the imagery and manipulation subscales of the SRI would also be related to SAS-A. Surprisingly, they were not ($r=-.05$ and $r=-.04$, respectively). This strengthens the suggestion that the association between anxiety of asking for help (which is more social in nature), and imagery anxiety is solely a general anxiety relation and not a manifestation of a lack of abilities. This is also indicated by the correlations involving general anxiety. Indeed, general anxiety was positively correlated with all anxiety subscales with a mean r of .29. On the other hand, general anxiety was negatively correlated with navigation skills and imagery skills with an r of $-.12$ and $-.13$ respectively. This is why, in Study 1, anxiety of asking for help was used in the computation of partial correlations and as a covariate in the models. This is done again hereafter with the addition of general anxiety.

TABLE 7 Correlation matrix of subscales in Study 2.

Variables	GenAnx	VA	SRI-M	SRI-N	SRI-I	SAQ-M	SAQ-I	SAS-A	SAS-I
VA	−.08 [−.18, .02]								
SRI-M	−.08 [−.18, .02]	.32 [.23, .41]							
SRI-N	−.12 [−.22, −.02]	.35 [.26, .44]	.50 [.42, .57]						
SRI-I	−.13 [−.23, −.03]	.31 [.21, .40]	.62 [.55, .67]	.47 [.39, .54]					
SAQ-M	.25 [.15, .34]	−.11 [−.21, −.01]	−.33 [−.41, −.23]	−.19 [−.29, −.09]	−.27 [−.36, −.17]				
SAQ-I	.19 [.09, .29]	−.09 [−.19, .01]	.05 [−.05, .15]	−.04 [−.14, .06]	.04 [−.06, .14]	.43 [.35, .51]			
SAS-A	.41 [.32, .49]	−.08 [−.18, .02]	−.05 [−.15, .05]	−.04 [−.14, .06]	−.04 [−.14, .06]	.30 [.20, .39]	.30 [.20, .39]		
SAS-I	.30 [.21, .39]	−.16 [−.26, −.06]	−.25 [−.34, −.15]	−.09 [−.19, .01]	−.22 [−.31, −.12]	.52 [.44, .59]	.26 [.17, .36]	.39 [.30, .47]	
VVIQ	−.04 [−.14, .06]	−.05 [−.16, .05]	−.03 [−.13, .07]	−.13 [−.23, −.03]	−.07 [−.17, .03]	.08 [−.03, .18]	.15 [.05, .25]	.08 [−.02, .18]	−.02 [−.12, .08]

Note: The numbers between brackets are the 95% confidence intervals of the correlation coefficient.

Abbreviations: GenAnx, question about participants' general anxiety level; SAQ-I, Imagery subscale of the Spatial Anxiety Questionnaire; SAQ-M, is the Mental Manipulation subscale of the Spatial Anxiety Questionnaire; SAS-A, Anxiety of Asking for Help subscale of the Statistics Anxiety Scale; SAS-I, Interpretation subscale of the Statistics Anxiety Scale; SRI-I, Imagery subscale of the Spatial Reasoning Instrument; SRI-M, Mental Manipulation of the Spatial Reasoning Instrument; SRI-N, Spatial Navigation subscale of the Spatial Reasoning Instrument; VA, Verbal Ability Quiz; VVIQ, Vividness of Visual Imagery Questionnaire, where a high score means a lack of imagery vividness.

TABLE 8 Pairwise and semi-partial correlations for five predictors of statistics interpretation anxiety (SAS-I) in Study 2.

Variables	Correlations	
	Pairwise	Semi-partial
GenAnx	.30	.28
VA	−.16	−.08
SRI-M	−.25	−.15
SRI-N	−.09	.09
SRI-I	−.22	−.06

Note: The pairwise correlations are reproduced from Table 7 for easier comparison.

Concerning the VVIQ, it can be observed that it is weakly and positively related to the imagery subscale of the SAQ ($r = .15$). This suggests that people with higher imagery anxiety lack vivid images, and vice versa. Considering these results, one would expect to observe correlations between the VVIQ and the imagery subscale of the SRI. This is not what was observed. Indeed, imagery vividness is not related to the imagery subscale of the SRI (and neither it is to SRI-M). However, the second-highest correlation involving VVIQ is with the navigation subscale of the SRI. This is surprising at first but when looking at the items of the VVIQ, one can understand why that is; three out of four scenarios concern a physical place (e.g., a store one often *goes* to).

Table 8 presents the regular correlations and the semi-partial correlations of general anxiety, VA, all subscales of the SRI with regards to interpretation anxiety in statistics. As seen, the only skills having moderate unique variances that predict interpretation anxiety in statistics are mental manipulation skills (partial correlations of −.15). Both Imagery and Navigation skills (SRI-I and SRI-N) dropped to partial correlations of .09 and −.06 respectively. In addition, general anxiety (GenAnx) remained a good predictor when the other variables were partialled out, reinforcing the idea that interpretation of statistics anxiety has an anxiety component instead of only being a lack of skills.

Path regression models

A model was estimated using the mediation command in the MPlus software (version 7) to test the hypothesis that mental manipulation skills, compared with verbal abilities, predict mental manipulation anxiety, which in turn, predicts statistics interpretation anxiety. This model is analogous to the model of Study 1 (seen in Figure 2) and has the same rationale, but with skills replacing spans, removing Mathematics Anxiety as it is not part of the current study, and adding general anxiety as the second covariable.

Figure 3 presents the resulting model. As can be seen, the model fits the data well (RMSEA = .09, CFI = .96, TLI = .89, and SRMR = .05). The RMSEA is higher than the .05 recommendation. However, this fit index tends to be inaccurate in models with a large number of observed variables (Shi et al., 2020). The relation between SAQ-M and SAS-I (unstandardized regression coefficient of .44) has a similar magnitude as the total effect in the previous study, which indicates that this finding is replicated. The coefficient from the mental manipulation skills to manipulation anxiety is moderate and negative: those with better skills in this spatial dimension experience lower spatial anxiety. Verbal abilities, on the other hand, have no noticeable effect. In this model, the covariates *anxiety of asking for help* and *general anxiety* were used to control the various predictors and dependent variable prior to fit the whole model.

The model was replicated once with navigation skills and a second time with imagery skills, instead of mental manipulation skills. These changes barely had any effect on the goodness of fit and predicted mental manipulation anxiety with a little smaller but quite similar coefficients. Considering the small differences, these two models are not presented herein.

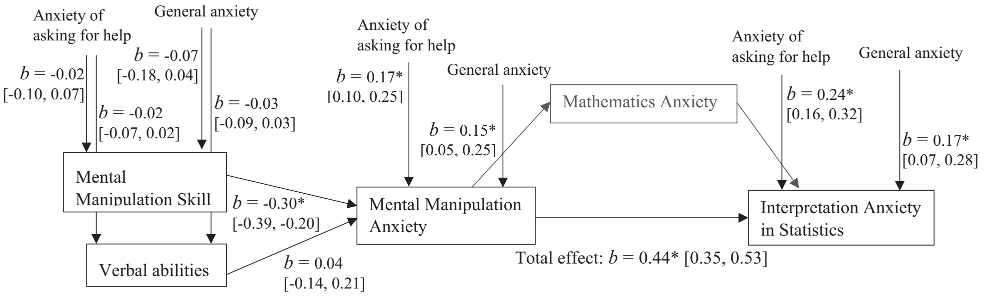

FIGURE 3 Mediation Model Between Spatial Skills, Mental Manipulation Anxiety, and Interpretation Anxiety in Statistics from Study 2. The numbers are the raw regression coefficients with their 95% confidence intervals. Mathematics anxiety is greyed as it was not measured in Study 2. * The symbol signifies that the coeficient is significant as 0 is not included in its 95% confidence interval.

Discussion

The primary objective of Study 2 was to further investigate the findings from Study 1 by replacing memory span tasks with skills tests to assess their association with spatial skills, statistics anxiety, and spatial anxiety, compared with verbal abilities. The results of Study 2 strongly support the hypothesis that better visuospatial skills are inversely related to mental manipulation anxiety and statistics interpretation anxiety.

The negative correlation between mental manipulation skills and spatial anxiety, as well as statistics interpretation anxiety, suggests that individuals with enhanced visuospatial abilities are less likely to experience anxiety in these areas. This finding aligns with previous research indicating the importance of spatial skills in reducing academic anxieties (Cantinotti et al., 2017; Vigil-Colet et al., 2008). In contrast, verbal abilities showed a negligible association with mental manipulation anxiety, which emphasizes the domain-specific nature of the anxiety experienced in statistics interpretation. Interestingly, the measure of mental imagery vividness, introduced as an exploratory variable, did not correlate significantly with statistics interpretation anxiety. This result can be understood by considering the nature of interpretation anxiety, which is more about manipulating data mentally rather than visualizing it in detail (Cantinotti et al., 2017). Thus, being able to conjure up detailed imagery might not be as critical as the ability to mentally manipulate abstract statistical concepts (see Delem et al., 2025, for results supporting this hypothesis). Considering that the VVIQ is solely visual, the results might have been different – or the distinction between imagery and manipulation could have been seen – if the *Object-Spatial Imagery and Verbal Questionnaire* (OSIVQ; Blazhenkova & Kozhevnikov, 2009) were used instead. This measure may be an interesting addition in future research.

The path regression model supported the hypothesis that mental manipulation skills predict mental manipulation anxiety, which in turn predicts statistics interpretation anxiety. This chain of associations underscores the critical role of spatial skills in academic contexts involving statistical interpretation. Moreover, these findings suggest that interventions aimed at improving spatial skills could potentially reduce statistics anxiety, thereby facilitating better learning outcomes in statistics courses. The results also reinforce the idea that while general anxiety contributes to various forms of academic anxiety, specific skills, and domain-specific anxieties play crucial roles in the learning process. The consistency of these findings with prior research (Gibeau et al., 2023) strengthens the validity of the proposed model and highlights the importance of considering both cognitive abilities and anxiety management in educational strategies.

Overall, Study 2 provides robust evidence for the significant impact of spatial skills on reducing anxiety in statistical interpretation, suggesting practical applications for educational practices and interventions aimed at improving student performance and reducing anxiety in statistics learning contexts.

GENERAL DISCUSSION

Today's society navigates within a Big Data era. From private to public sectors, from healthcare to social media companies, massive amounts of data are being collected and stored within the digital space (McMahon et al., 2020; Villarejo-Ramos et al., 2021). Despite the necessity for statistical literacy, many individuals struggle with interpreting statistical information due to inherent difficulties in understanding probabilistic, quantitative data and graphical representations (Béland et al., 2017; Husereau et al., 2024; Zang & Cousineau, 2025).

When learning about statistics, most students have high levels of anxiety, making it difficult to understand the subject (Cousineau & Harding, 2017; Garfield & Ben-Zvi, 2008; Gibeau et al., 2023; Onwuegbuzie, 2004; Onwuegbuzie & Wilson, 2003). The goal of the two studies presented herein was to identify potential predictors of statistics anxiety to eventually be able to decrease its negative effects on students and promote an increased understanding of the subject.

The results of the two studies presented in this text reveal patterns of correlations involving students' anxiety towards interpreting statistical information. In Study 1, visuospatial WM span influences the level of mental manipulation anxiety, which in turn influences the level of statistics interpretation anxiety (directly and indirectly through mathematics anxiety). This suggests that students with a lower capacity to retain visuospatial information also have higher anxiety towards mentally manipulating elements, higher anxiety towards mathematics, and higher anxiety towards interpreting statistical information, or vice versa. In Study 2, a similar pathway was identified when memory spans were replaced by abilities. Taken together, these studies highlight the influence of spatial processing in statistics anxiety. The experimental design does not allow inferring a precursory role to spatial processing nor a causal role. Both mathematics anxiety and spatial anxiety are observed in children as young as 6–8 years of age (Gunderson et al., 2013; Ramirez et al., 2012). Given that children at this age have not yet been exposed to formal statistics in school, it seems unlikely that exposure to statistics can have caused their math and spatial-related anxieties. Rather, it seems more likely that math and spatial anxiety, in general, comes online before statistics anxiety. However, this is only a hypothesis.

One difference between the two studies, presented herein, lies in the magnitude of the effects. In Study 1, the lag between the strength of association between memory spans and mental manipulation anxiety (−.21 for the Corsi vs. −.13 for the n-Back) is nearly three times smaller than the corresponding lag in Study 2 (−.30 for the SRI-M vs. .03 for the VA). One possible reason is that the n-Back Task also measures central executive functions, which are necessarily present in the Corsi-Blocks Task. Hence, the n-Back Task might lack specificity, leading to a conservative estimate of the lag. Another reason is that the verbal ability test that was assembled had poor psychometric properties (a Cronbach α of .44 over 15 items is quite low), leading to a liberal estimate of the lag. Better-controlled measures are recommended for future research.

Further, the pattern of results of the VVIQ was intriguing. It correlated moderately with navigation skills, perhaps because the items were biased toward depicting travelling to an area (and navigation is sometimes performed by retrieving a sequence of landmarks; Epstein et al., 2017). It also correlates moderately with imagery anxiety. Yet, both imagery anxiety and navigation abilities were uncorrelated. Finally, VVIQ was not correlated to interpretation of statistics anxiety. Such results could be reconciled by the hypothesis that visual skills and spatial skills may be distinct sets of skills.

Implications for statistics education

It is known that anxiety negatively impacts WM, reducing the quantity of relevant information stored and the quality of its processing (Dutke & Stöber, 2001; Eysenck & Calvo, 1992). When performing a task, it is necessary to focus on relevant information and to disregard distractors. People experiencing anxiety may pay less attention to relevant information, have intrusive thoughts, and show impaired spatial processes and reduced WM spans, all of which reduces the amount of cognitive resources one has available. Consequently, they are less likely to complete the task successfully and therefore impeding the quality of learning (Berggren & Derakshan, 2013; Lisica et al., 2022).

As observed in many studies, performance in statistics courses is predicted by anxiety towards the subject (Cantinotti et al., 2017; Hoegler & Nelson, 2018; Macher et al., 2015; McIntee et al., 2022). To improve students' performance in statistics, it is crucial to address a predictor: statistics anxiety. The findings from this research suggest a potential new set of predictors that could help in reducing statistics anxiety. The first step involves mental manipulation anxiety that could be reduced by improving mental manipulation skills through spatial training. The second step focuses on statistics interpretation anxiety that could be decreased by addressing mental manipulation anxiety, as this type of anxiety predicts levels of anxiety related to interpreting statistical information. Reducing mental manipulation anxiety could influence the levels of statistics interpretation anxiety.

While the ability to retain visuospatial information may not be easily enhanced, there is evidence supporting the efficacy of cognitive training in improving mental manipulation skills (Diamond & Ling, 2020). It is acknowledged that the present study's correlational design does not clarify whether improving visuospatial WM directly helps reduce mental manipulation anxiety. However, mental manipulation skills can be more readily improved with practice through targeted activities and interventions, as commonly done with children (e.g., Burte et al., 2017). These studies suggest that incorporating spatial activities into the curriculum could help improve students' spatial skills, which predict widespread apprehension towards statistics. Implementing spatial training exercises and dynamic visualization techniques within statistics education could provide a dual benefit: enhancing cognitive skills relevant to statistical tasks and reducing anxiety. Educators could integrate these activities into their teaching strategies, creating a more supportive learning environment that addresses both cognitive and emotional challenges faced by students in statistics courses. This pedagogical approach to improve performance in statistics needs formal testing as it is based on the present correlational studies.

Limitations

The results presented herein are positive and congruent with a contributing relation of spatial cognition and statistics understanding. There are a few caveats that are acknowledged here. First, this is a correlational study. It is hypothesized that there may be a cascade of influences from reduced spatial skills and lower visuospatial WM to higher statistics anxiety. However, it is impossible to infer the causality of this conclusion with the present data. Also, statistics anxiety probably has a historical aspect: learners who experienced difficulties understanding preliminary concepts useful to statistics in their past possibly developed heightened levels of statistics anxiety. To examine this developmental hypothesis, a longitudinal study, where measurement begins in early High School (or even earlier), is required. The results of the present study indicate that statistics anxiety has a few spatial predictors, but this does not mean that these predictors cause a heightened anxiety towards statistics.

Also, the sample is composed only of students in social sciences. These programmes are not mathematically oriented. Presumably, many students likely enrolled in these programmes because they do not perceive themselves as math- or science-oriented (Esnard et al., 2021; Paechter et al., 2017). Many possibly assumed that there would be no mathematics or statistics courses when enrolling in such programmes. The element of surprise and the fact that they do not perceive themselves as number-oriented people may exacerbate the amount of anxiety in such university students, in a form of stereotype effect. The fact that women are also typically more anxious towards statistics may also be explained in part by stereotype effects. However, some studies have shown that STEM students may also have a high level of anxiety towards statistics or mathematics (e.g., Daker et al., 2021). This suggests a widespread discomfort towards these two subjects whether or not people are number- or science-oriented.

Finally, some measures used herein have limitations. Some argue that the *Corsi-Blocks Task* does not fully capture visuospatial WM but short-term memory instead. The *Spatial Reasoning Instrument* seems to have a few items with a ceiling effect. The distribution of this measure is somewhat skewed where there are more participants at the high end of the distribution. Similarly, participants seem to be very good in the n-Back Task used in Study 1. Most participants finished all conditions without reaching the maximum number of errors allowed. Consequently, the 3-back condition may be too easy for the studied population. Another measure that is skewed, but expected to be, is the *Vividness of Visual Imagery Questionnaire*. More participants reported high levels of vividness, as reported in previous studies (e.g., Dance et al., 2022). On a side note, because memory is impacted by age, and that there are a few participants in their 40s and 50s, this variable should have been controlled for in the path regression analyses. Their age could have influenced the results.

Future research should examine which spatial activities help students develop their spatial skills. In doing so, these activities could be implemented in statistics courses to facilitate students' learning, understanding, and performance through learning how to use their spatial skills in statistics. This could further extend the literature on statistics education by proposing applicable solutions to instructors.

Take-class message

The message to keep in mind is that incorporating spatial activities and spatial visualizations into the teaching of statistics may be beneficial for students as it is in spatial intervention studies (e.g., Lowrie & Logan, 2023). By asking students to practice their spatial skills and to teach abstract concepts through visual stimuli instead of formulas and definitions, it may improve their spatial skills, reduce their anxiety and facilitate their understanding by providing concrete elements. A formal test of this hypothesis is yet to be performed.

As many statistics courses have two components (lectures and laboratories), it should be relatively easy to incorporate spatial training within the class. For example, the first few laboratories can ask students to participate in spatial tasks, like Tetris or origami folding (Burte et al., 2017). Then, the data collected with these tasks can be further used in demonstrating how to perform analyses, as it is often recommended to use real data when teaching statistics (e.g., Carver et al., 2016).

AUTHOR CONTRIBUTIONS

Rose-Marie Gibeau: Conceptualization; investigation; writing – original draft; methodology; validation; visualization; writing – review and editing; formal analysis; project administration; data curation. **Sébastien Béland:** Writing – review and editing. **Erin A. Maloney:** Writing – review and editing. **Michael Cantinotti:** Writing – review and editing. **Lucile Chanquoy:** Writing – review and editing. **Daniel Lalande:** Writing – review and editing. **Jessica Simon:** Writing – review and editing. **Charlotte Paulis:** Writing – review and editing. **Gaën Plancher:** Writing – review and editing. **Marie-Aude Boislard:** Writing – review and editing; data curation. **Denis Cousineau:** Writing – review and editing; supervision; project administration; conceptualization; methodology; resources; software; data curation; investigation; validation.

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CONFLICT OF INTEREST STATEMENT

The authors have no conflict of interest to declare.

DATA AVAILABILITY STATEMENT

The data that support the findings of this study are openly available in Open Science Framework at https://osf.io/j4trv/?view_only=1f50a5c3d7ac476f95d4c45b31d42b48.

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