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The Relationship between Spatial ability, Spatial Anxiety, and Gender

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Abstract

Spatial learning using innovative tools like the Microsoft HoloLens is becoming more popular in STEM fields and education. However, not every individual seems to benefit from this type of instruction the same way. This might be caused by individual differences in spatial ability, but also by the cognitive load that AR learning can generate that could vary between individuals. This study tries to investigate several factors that might influence spatial learning when using 3D AR tools like the Microsoft HoloLens. The impact of the factors embodiment, spatial ability, spatial anxiety, and gender on spatial learning are examined and whether there is an relationship between these factors.

Participants were 110 individuals between the age 18-35 that performed several online embodied and non-embodied spatial ability tests and had to fill in an spatial anxiety questionnaire to assess self-reported spatial anxiety. A three-way mixed ANOVA was performed on the different factors with two between subject variables – gender and spatial anxiety – and one within subject variable – embodiment in spatial ability, with two levels: embodied and non-embodied spatial ability score.

Results show comparable scores between embodied and non-embodied cognition, genders, and spatial anxiety types, hence no interaction effect was found, $F(1, 77) = .011$, $p = .915$, partial $\eta^2 < .001$. Furthermore, no significant main effects were found. The results from the current study are not line with previous research, making it debatable whether these factors are of main influence on spatial learning and suggesting that there are other factors at play. Reasons for the conflicting results as well as suggestions for future research are discussed.

Layman's abstract

New innovative tools can be used to teach medicine, and more specifically, anatomy. One example is the Microsoft HoloLens which can project anatomical structures of the body in the environment. However, research shows that not every individual benefits from this type of instruction. What could be the cause of such a difference?

Individuals differ on a lot of skills, including spatial skills and the ability to learn using 3D animations. Besides spatial ability, factors like gender, spatial anxiety, and whether spatial tasks can be solved using an embodied strategy can also influence spatial learning. This study looks at these possible factors and tries to investigate the effect on spatial learning.

Participants consisted of 110 individuals between the age of 18-35 who performed several spatial tasks, each measuring either an embodied or non-embodied spatial strategy, and they filled in an spatial anxiety questionnaire measuring the amount of anxiety they experience during spatial tasks.

Results of the study show comparable scores between both spatial ability strategies, gender, and spatial anxiety. This indicates that based on this study spatial learning is not influenced by either one of the investigated factors, which is not in line with previous research. It might be the case that other factors than the ones discussed in the current study are of more influence on spatial learning. For example working memory capacity or subtypes of spatial anxiety. Critical notes and suggestions for future research are discussed.

Introduction

There is a lot of variability in cognitive abilities among individuals. This variability especially exists within the concept of spatial ability (Huk, 2006; Lufler, Zumwalt, Romney, & Hoagland, 2011; Bogomolova, Hierck, van der Hage, & Hovius, 2019). Spatial ability can be defined as a cognitive skill that is important for the representation, transformation, generation and, recall of symbolic, visual images (Lohman, 1996). Spatial ability is important for a range of daily activities and in specific occupational and scientific areas like anatomy, dentistry, and chemistry (Wai, Lubinski & Benbow, 2009; Malanchini et al., 2017). Previous research has shown a positive relationship between spatial ability and anatomy learning (Guillot, Champely, Batier, Thiriet, Collet, 2006). Because of this importance of spatial ability it is interesting to investigate what factors influence spatial ability and why there are individual differences. The present study will look at spatial ability, embodiment, spatial anxiety, and gender as factors that possibly influence spatial learning and whether and to what extend there is a relationship between these factors. By further understanding these factors and relationship between them, plans can be construed to help improve or overcome these factors, hence improving spatial learning.

Technological innovations make it possible to study spatial learning in new ways. One example of these new developments are innovative tools like the Microsoft HoloLens, that use artificial reality (AR) learning. This technology can also be used as a solution to problems in traditional anatomy teaching like the limited availability of cadavers and the time pressure on the curriculum (Bogomolova et al., 2019). However, not every individual benefits the same way using this kind of instruction. In the study by Bogomolova and colleagues (2020), AR model type instruction was compared to traditional instruction formats and they found that individuals' spatial learning performance was not only related to initial spatial ability, but also to the visual spatial characteristics of information participants were presented with.

How an individual processes spatial information and whether an individual is successful in spatial learning can be considered from the cognitive load theory (Castro-Alonso, Ayres, & Sweller, 2019). This theory states that working memory resources are limited and that processing and maintaining information uses a certain proportion of these resources. According to this theory there are three types of cognitive load that influence learning (Paas, Renkl, & Sweller, 2003; Debue, & van de Leemput, 2014): Intrinsic load, extraneous load, and germane load. Intrinsic load relates to the learning material which is defined by the amount of interactivity between elements that need to be processed. This load is related to the amount of prior knowledge or skill an individual has; the more expertise an individual has, the lower the cognitive load he or she experiences. Initial spatial ability can be an example of this type of load. Extraneous load consist of elements that do not contribute to learning and should be kept as low as possible. An example of this can be the presentation or instructional format in which the learned material is presented. Germane load relates to the mental resources that are used to enhance learning. Elements of the instructional format can be an example of this type of cognitive load. Where extraneous load has to be reduced to avoid exceeding working memory resources, germane load must be promoted to enhance learning (Debue, & van de Leemput, 2014).

In the study by Huk (2006) the cognitive load theory is applied in 3D model spatial learning. It is proposed that individuals with lower spatial abilities can become cognitively overloaded when offered a 3D learning environment, and that these individuals preferred 2D computer animations instead. Conversely, individuals with higher spatial abilities more easily comprehended the information when offered in a 3D learning environment and benefitted from this type of learning, since their working memory capacity was not overloaded. This study shows that not every individual benefits from 3D model learning the same way and that spatial abilities are an important predictor for performance on AR learning tasks.

Next to initial spatial ability, another intrinsic load factor might possibly influence spatial learning, namely the amount of spatial anxiety experienced during spatial processing. Lawton (1994) first described spatial anxiety as the anxiety about environmental navigation and later Lyons and colleagues (2018) defined it as the nervousness and fear toward spatial processing. In a study by Ramirez, Gunderson, Levine, and Beilock (2012), they found that spatial anxiety was negatively related to performance on spatial tasks, and that spatial anxiety was significantly higher in girls than in boys. However, this would not be the case for all individuals, as working memory capacity might play an mediating role. The authors proposed that especially high working memory individuals experience these anxiety related decrements, as they experience more performance worry during working memory intensive tasks. Next to the consequence of spatial anxiety to performance in spatial learning, spatial anxiety might also cause individuals to be less prone to engage in experiences and opportunities that might otherwise improve their spatial abilities (Lyons et al., 2018). The ability to accurately identify individuals experiencing spatial anxiety can be important because then individuals that might struggle with certain spatial tasks in the workplace or learning environments can be offered additional training and help to overcome this.

The cognitive load theory also incorporates how the information is presented to an individual and how this can influence learning: extraneous and germane load. A factor that can possibly influence this is the amount of embodiment in spatial ability. Spatial ability can be divided into non-embodied and embodied spatial ability (Amorim, Isableu, & Jarraya, 2006; Tversky & Hard, 2009; Gardner, Brazier, Edmonds, & Gronholm, 2013). Non-embodied cognition is applicable when spatial cognition solely relies on processing in the brain. Embodied spatial ability is applicable in situations when spatial processing does not solely occur in the brain, rather it also employs the rest of the body and the environment (Castro-Alonso, Paas, & Ginns, 2019). These two forms of spatial ability might independently influence the amount of cognitive load experienced and thus the performance on spatial task.

Amorim and colleagues (2006) investigated this by applying bodily features to the Shepard and Metzler cubes matching task (Shepard & Metzler, 1971). They proposed that body-like stimuli can elicit embodiment, which in turn improved performance on this shape-matching task. Looking at the theory of embodiment, a new model of the cognitive load theory, that also takes into account bodily and environmental variables can possibly explain this effect (Choi, van Merriënboer, & Paas, 2014). This model states that the body and the environment can be an extension of the mind. By placing cognitive demands onto the body, new limits for working memory capacity can be set. The study by Amorim and colleagues (2006), shows that participants possibly project their own bodies onto the stimuli, extending the capacity of their cognitive load and making processing of the spatial stimuli easier. For the cognitive load theory embodiment can be seen as germane load, since it might positively influence the learning experience.

In addition to cognitive factors, gender might also play a role in spatial learning performance. Studies show that, on average, females report higher amounts of spatial anxiety and perform worse on certain measures of spatial ability than males (Vandenberg & Kuse, 1978; Lawton, 1994; Ramirez, et al., 2012; Malanchini et al., 2017). Lawton (1994) investigated the relation between gender, spatial ability, and spatial anxiety and found that the use of certain wayfinding strategy, a route strategy, was more common in women than in men, who use another strategy, an orientation strategy. The orientation strategy that women applied was found to be negatively related to spatial anxiety. Previous research shows some evidence for a gender effect in spatial ability, however there is still a lot of discussion about the cause of this effect, for example the influence of sociocultural factors, biological factors and visuospatial experience (Castro-Alonso & Jansen, 2019).

The factors discussed above all possibly influence spatial learning, however it is unclear to what extend there is an influence and whether there is a relationship between these factors. The aim of this study is to examine this relationship between the factors: embodiment, spatial ability, spatial anxiety, and gender. This will give an overview of what influences the spatial learning performance of an individual and how measurements are related to each other. By knowing what influences performance, plans can be construed to help an individual to increase performance. For example, spatial ability can be a predictive factor for entry into STEM fields, including medicine and anatomy. Subsequently, spatial anxiety might have a negative effect on the individuals spatial performance. By measuring these factors individuals can be identified that might have problems doing complex spatial tasks. With this knowledge, plans can be construed to help these individuals overcome this ‘deficit’ in the form of spatial ability/anxiety training or by changing to mode of instruction. By reducing the burden of spatial anxiety, individuals might be more motivated to practice their spatial ability skills and by doing so obtain higher scores on spatial ability measures. By improving their spatial ability skills, scores on complex spatial tasks can also improve, possibly making new innovative technological learning tools, like AR learning, more fruitful (Huk, 2006; Bogomolova, et al., 2020). In this study it is therefore hypothesized that individuals that score higher on the spatial anxiety questionnaire show lower performance on the spatial ability tasks. Subsequently, it is expected that individuals with higher spatial anxiety will perform better on embodied spatial tasks than they will on non-embodied spatial tasks. The study also looked at the effects of gender on spatial ability performance and spatial anxiety. It was hypothesized that, female participants will report higher levels of spatial anxiety and will show lower spatial ability performance than male participants. From literature, this gender difference does not seem particularly strong. There is still a lot of debate about gender difference in spatial ability. The difference between males and females does not seem to be black and white, as there is still a lot of research being done at all the factors that possibly influence individual difference in spatial ability.

Method

Design

This study used a cross-sectional design. Participation was voluntary and informed consent was obtained from all participants. The study protocol was approved by the Psychology department of the Leiden University.

Participants

The group of participants composed of people between the age range of 18 to 35 years old. Individuals that suffer from a neurological or psychological condition where excluded from participation. Participants that took longer than two hours to finish the experiment will be excluded from further analyses, since this might indicate a participant not being engaged enough. To be able to do adequate analyses the study aims for collecting responses from 80 to 100 participants.

Measures

Measures of spatial ability were obtained with several tasks. Spatial ability is divided into measures of embodied spatial ability and non-embodied spatial ability. To measure embodied spatial ability the following tests were used: Bergen Left–Right Discrimination Test (Ofte, 2002). Here participants were presented with stickman figures either facing them (white head) or looking the other way (black head). One hand of the stickman is either a white circle or a red circle. The task for the participant is to indicate whether the red hand is a right or a left hand. The test consists of 32 items. Participants have 1 minute and 30 seconds to complete as many items as possible. The score is based on the total of correct answers the participants give within the timeframe.

Kessler Table Test (Kessler & Rutherford, 2010). The participants were presented with pictures of a person sitting at a round table at varying degrees. The middle of the table is equipped with lamps. The participant had to indicate whether the left or the right light is turned on from the perspective of the figure sitting at the table. The test consists of 11 items and the participant has 20 seconds to complete as many items as possible. Participants' performance is reflected in the total of correct answers given within the timeframe.

Hands Test (Egan, 1979). Participants were presented with pictures of a hand. This can either be the top or palm of a right hand, or the top or palm of a left hand. Participant see each pictures one-by-one and they have to indicate as fast as possible if they see a right or a left hand. Participants have to mentally rotate the hands to obtain the right answer. The test consists of 24 items and participant get 2 minutes to answer as many items as possible. The score is the total of correct answers the participants give within the given timeframe.

Same-Different Paradigm (Zacks, Mires, Tversky, & Hazeltine, 2000). Participants were presented with two human figures either extending their right arm to the right or left, or extending their left arm to the right or left. In each picture the human figures are rotated in various degrees. Participants have to indicate whether the two human figures are extending the same arm or that both extend a different arm. The test consist of 30 items and participants get 1 minutes to complete as many trials as possible. Participants' performance is reflected in the total of correct answers given within the timeframe.

Which hand test (Zacks, Rypma, Gabrieli, Tversky, & Glover, 1999). Participants were presented with a human figure either extending its right arm to the right or left, or extending his left arm to the right or left. In each picture the human figure is rotated in various degrees. Participants have to indicate whether the human figure is extending its right or left arm. The test consist of 47 items and participants get 2 minutes to complete as many trials as possible. The score is based on the total of correct answers the participants give within the given timeframe.

To measure non-embodied spatial ability the following tests were used: The mental rotation test was validated by Vandenberg and Kuse (1978) and in this experiment a redrawn version by Peters and colleagues (1995) is used. The test consists of 24 items. Each item consists of five cube figures represented in different angles. The first cube figure is the target figure and the participant are asked to identify the two cube figures matching this target figure. Participants have to mentally rotate the cube figures to fit the target figure. Participants have three minutes to complete as many trails as possible. Participants' performance is reflected in the total of correct answers given within the timeframe.

In the paper folding test (Ekstrom, French, Harman, & Dermen, 1976) participants had to imagine the folding and unfolding of a piece of paper. The test consist of 11 items. In each item the participant views a piece of paper being folded and then a hole is punched through it. The task of the participant is to identify the correct spatial arrangement of the punches after unfolding. Participants get 1 minute and 15 seconds to answer as many items as possible. Score is based on the total of correct answers given within the timeframe.

Cube Comparison Test (Ekstrom et al., 1976). Participants were presented with pictures of pairs of cubes with letters and digits drawn on them. The pairs can consist of two cubes that are the same or two cubes that are not. Based on the letters and digits on the cubes, participants have to mentally rotate the cubes to determine whether the cubes are the same or not. The test consists of 21 items and participants get 3 minutes to complete as many trials as possible. Participants' performance is reflected in the total of correct answers given within the timeframe.

Object Perspective Taking Test (Kozhevnikov & Hegarty, 2001). Participants were presented with an array of seven objects. Participants have to imagine standing at one of these objects, facing another object. Subsequently, participants had to indicate where from their prescribed perspective they can find a third object. Underneath the sheet there is a circle with 36 sections. Each section corresponds to a direction in which the third object can be found. Participants have to select the right section. The test consists of 11 questions and participants get 2 minutes and 30 seconds to complete as many trials as possible. The score is based on the total of correct answers the participants give within the timeframe.

In the Money Road Map Test (Money, Alexander, & Walker, 1965) participants were shown a route through a map. They have to imagine walking this route on the map and at each turn they have to indicate if they make a right of a left turn. Originally, this test is made paper and pencil, but for this study a computerized version is used. Participants see the map on the screen and next to each turn a number is displayed. Under the map the number 1 through 32 are shown, and the participant can answer at each number (corresponding to a turn on the map) if they make a left or a right turn. Participants have 1 minute to complete the path and scores will be based on total of correct responses.

The amount of spatial anxiety was measured using the Spatial Anxiety Scale as used in the study by Lyons and his colleagues (2018). The questionnaire consists of 24 questions that can be answered on a 5-point Likert scale. The scale consists of questions asking participants how much spatial anxiety they might experience in the described situations. The response options are: 'not at all', 'a little', 'a fair amount', 'much', 'very much'. Answered will be scored the following way: 0 (not at all) to 4 (very much). A maximum score of 120 can be obtained. A higher scores will indicate a higher measure of spatial anxiety and a lower score will indicate lower levels of spatial anxiety.

Participant were recruited using the SONA-system at the Leiden University. Participants were rewarded 2 credits for their participation in the study. This thesis project was part of a larger study investigating the influence of spatial ability and learning performance using dynamic visualizations of three-dimensional (3D) models. Not all the materials of the larger study were used in this article. In this larger study participants are asked to do a total of twelve tasks/questionnaires measuring spatial ability, spatial anxiety, navigation skills and mental imagery style. The tasks were administered on the participant own computer using software called Qualtrics (Qualtrics, Provo, UT, USA) which is accessible using an internet browser.

After a short introduction about the study and providing informed consent, participants started doing the tasks. They were asked to pay close attention to the instructions of the tasks, informing them about the goal of the task and what the they had to do. After that, participant completed a few practice rounds. Subsequently, the test would begin. After completion of a test, the next test automatically followed, again first providing instruction and practice rounds. Participants completed the tasks in the following sequence: Mental Rotation Test (Vandenberg & Kuse, 1978), Object Perspective Taking Test (Kozhevnikov & Hegarty, 2001), Paper Folding Test (Ekstrom et al., 1976), Road Map Test (Money et al., 1965), OSIQ Questionnaire (Blajenkova, O., Kozhevnikov, M., & Motes, M.A. 2006), Hands Test (Egan, 1979), Bergen Left–Right Discrimination Test (Ofte, 2002), Spatial Anxiety Scale (Lyons et al., 2018), Cube Comparison Test (Ekstrom et al., 1976), Which hands test (Zacks et al., 1999), Wayfinding questionnaire (De Rooij, Claessen, van der Ham, Post, Visser-Meily, 2019), Kessler Table Test (Kessler & Rutherford, 2010), Same-Different Paradigm (Zacks et al., 2000).

After all the tests were done the participant was debriefed, providing further explanation about the aim of the study.

Statistical analyses

Baseline characteristics of participants and distribution of test scores were summarized using descriptive statistics. A three-way mixed ANOVA was performed on the data with two between subject variables – gender (male or female) and spatial anxiety (high or low) – and one within subject variable – embodiment in spatial ability, with two levels: embodied and non-embodied spatial ability score. Using this analysis, the relationship between embodiment, spatial ability, gender, and spatial anxiety was investigated. Participants' raw scores on the spatial ability tasks were transformed to Z-scores for comparison. The individual Z-scores a participant scores on the spatial ability measurements was summed and averaged for the embodied and non-embodied spatial ability tasks separate. This way a higher average Z-score indicated better spatial ability performance and a lower averaged Z-score indicated lower spatial ability performance. Individuals were grouped in low or high spatial anxiety groups based on the score obtained on the spatial anxiety questionnaire. To create two equally sized groups, 50% of the individuals that score the highest (high anxiety group) and 50% of individuals that score the lowest (low anxiety group) were separated from each other.

A one-way ANOVA way performed to investigate the difference in spatial anxiety scores between males and females. The grouping variable consisted of gender (male/female) and the dependent variable was the total score on the spatial anxiety questionnaire.

To check for the assumptions for three-way mixed ANOVA and one-way ANOVA the following steps were taken: to check for univariate outliers a boxplot was created of the data, and Mahalanobis distance was used to assess multivariate outliers, to assess normality the Shapiro-Wilk Test of Normality was used and to check for homogeneity of variances Levene's test for homogeneity of variances was used. All the analyses are performed in SPSS Statistical software package version 26 for IOS.

Results

A total of 110 participants took part in this study. Of these participants 29 were excluded from further analyses; twenty-two participants did not finish the experiment to completion, six participants were excluded because they took longer than the maximum allowed duration of two hours to finish the experiment, and one participant did not fall within the age range of 18-35 years old. A total of 81 participants remained for further analysis.

The gender distribution and the distribution among spatial anxiety groups is displayed in table 1. The mean age of participants was *M* = 21, 31, *SD* = 3.754. Mean spatial anxiety score was *M* = 32.59, *SD* = 12.47. To create two equal spatial anxiety groups, the data was split at the 50th percentile, which was a score of 33. All participants that with a score below 33 composed the low anxiety group, and all participants with a score above 33 composed the high anxiety group. Mean and standard deviations for both males and females, across both spatial ability types and spatial anxiety groups, are displayed in table 2. In table 3, mean and standard deviations are depicted across both spatial ability types and spatial anxiety groups for males and females combined.

Table 1

Distribution of participants among spatial anxiety groups

	Gender	
Spatial anxiety level	Male	Female
Low	12	27
High	18	24
Total	30	51

A three-way mixed ANOVA was run with two between subject variables – gender and spatial anxiety – and one within subject variable – embodiment in spatial ability, with two levels: embodied and non-embodied spatial ability score. The embodied and non-embodied scores were used to represent spatial ability. There was a linear relationship between the dependent variables, as assessed by scatterplot, and no evidence of multicollinearity, as assessed by Pearson correlation ($|r| < 0.9$). There were two univariate outliers in the data, as assessed by inspection of a boxplot, and no multivariate outliers in the data, as assessed by Mahalanobis distance ($p > .001$)[1]. Embodied spatial ability score was not normally distributed, as assessed by Shapiro-Wilk's test ($p > .05$), only for males in the low anxiety group. Based on calculations of skewness and kurtosis this group did not violated normality with a skewness of -.911 (*SE* = .536) and kurtosis of -.318 (*SE* = 1.038). Skewness and kurtosis also did not indicate departure from normality for the other combinations of gender and spatial anxiety. Results on Box's M test ($p = .615$) indicate that there was homogeneity of covariance matrices. Homogeneity of variances was assumed, as assessed by Levene's Test of Homogeneity of Variance ($p > .05$). The tests of within-subjects effects indicated that the three-way interaction between gender, spatial anxiety, and embodiment in spatial ability was not statistically significant, $F(1, 77) = .011$, $p = .915$, $\eta^2 < .001$. There was no statistically significant two-way interaction between spatial anxiety and gender, $F(1, 77) = .465$, $p = .497$, $\eta^2 = .006$. Statistical significance of a simple two-way interaction was accepted at a Bonferroni adjusted alpha level of .025. There were no significant simple two-way interactions of gender and spatial anxiety at the embodied spatial ability level, $F(1, 77) = .396$, $p = .531$, $\eta^2 =.005$ or at the non-embodied spatial ability level, $F(1, 77) = .339$, $p = 562$, $\eta^2 =.004$. Statistical significance of a simple simple main effect was accepted at a Bonferroni-adjusted alpha level of .025. There was a trend towards a statistically significant simple simple main effect of gender for low-anxiety individuals at the non-embodied level, $F(1, 77) = 3.834$, $p = .054$, $\eta^2 = .047$, but not for the high anxiety individuals, $F(1, 77) = .995$, $p = .322$, $\eta^2 = .013$. Further looking at this finding, pairwise comparisons were performed for statistically significant simple simple main effects. Bonferroni corrections were made with comparisons within each simple simple main effect considered a family of comparisons. Non-embodied spatial ability score was higher for males in the low anxiety group (*M* = .261, *SD* = 0.840) than females in the low anxiety group (*M* = -.168, *SD* = 0.693), a mean difference of 0.429, 95% *CI* [-0.007, 0.865], $p = .54$.

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[1] Analyses was repeated without the outliers. This did not lead to significantly different results.

Table 2

Mean scores of embodied and non-embodied spatial ability score for male and female

Embodied	Male	Female
	M(SD)	M(SD)
Low anxiety	.119 (.827)	-.120 (.864)
High anxiety	.017 (.769)	-.001(.596)
Total	.0784 (.792)	-.055 (.724)

Non-Embodied	Male	Female
	M(SD)	M(SD)
Low anxiety	.261 (.840)	-.168 (.693)
High anxiety	.147 (.648)	-.093 (.613)
Total	.215 (.759)	-.127 (.645)

A one-way ANOVA was conducted to test the hypothesis that gender has an influence on the reported levels of spatial anxiety. Participants were grouped according to gender: male (*n* = 30) and female (*n* = 51). There were two outliers detected using a boxplot[2]. The data was normally distributed for each group, as assessed by Shapiro-Wilk test ($p > .05$); and there was homogeneity of variance, as assessed by Levene's test of homogeneity of variances ($p = .252$). Spatial anxiety score was lower for the males ($M = 30.43$, $SD = 11.25$) than for females ($M = 33.86$, $SD = 13.08$), but this differences in spatial anxiety scores was not statistically significant, $F(1, 79) = 1.436$, $p = .234$, $\eta^2 = .02$

Table 3.

Mean total score on embodied and non-embodied spatial ability

	Embodied		Non-embodied	
	Mean	SD	Mean	SD
Low anxiety	-.0149	.846	.0203	.786
High anxiety	.0046	.643	-.0208	.625
Total	-.0053	.748	.0000	.704

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[2] Analyses was repeated without the outliers. This did not lead to significantly different results.

Discussion

Previous research has shown that an individuals ability for spatial learning in an 3D learning environment, for example using innovative tools like the Microsoft HoloLens, can be influenced by different factors. Factors can consist of initial spatial ability (Huk, 2006; Bogomolova et al., 2020), whether there is a possibility for embodiment in spatial tasks (Amorim et al., 2006; Gardner et al., 2013), spatial anxiety (Lawton, 1994; Ramirez et al., 2012; Lyons et al., 2018), and gender (Malanchini et al., 2017, Castro-Alonso & Jansen, 2019). This study investigated the relationship between these factors creating an overview whether and to what extend these factors are of influence on spatial learning and to what extend they influence each other. Using an overview of these factors, an individual's strengths and weaknesses in spatial learning can be objectified and plans can be construed to improve spatial learning. By improving spatial learning, usage of innovative tools like the Microsoft HoloLens can become more interesting in STEM fields like anatomy and chemistry teaching. It was expected that individuals that report higher levels of spatial anxiety show lower spatial ability performance. Furthermore, it was expected that these higher spatial anxiety participants would perform better on the embodied spatial anxiety test than on the non-embodied spatial anxiety tests. To further objectify possible differences in spatial ability, the study also looked at the effect of gender on spatial anxiety scores. Since previous research showed a gender effect in spatial ability, the current study also looked at this factors to investigate whether and to what extend there is a difference between males and females in the data. It was expected that female participant would report higher levels of spatial anxiety compared to males.

Looking at the first hypothesis, there were comparable scores on the spatial ability tests between high and low spatial anxiety participants. Thus, from this study it cannot be concluded that the amount of spatial anxiety has an influence on the performance on spatial ability tasks. This is not in line with previous research (Lawton, 1994; Lyons et al., 2018), that states that higher amount of spatial anxiety causes lower spatial ability performance. The study by Ramirez and colleagues (2012) also did not find a consistent relationship between spatial anxiety and spatial ability and discussed that working memory capacity might be a factor that influences this relationship. It might be that individuals with higher WM capacity in combination with low or high levels of spatial anxiety perform different on spatial ability tasks compared to low WM capacity individuals with low or high levels of spatial anxiety. This in turn might also influence the way embodied and non-embodied stimuli is processed. This study did not take into account participants' working memory capacity, but future research about spatial anxiety and spatial ability could focus on this possible factor. It is also important to reflect on how spatial anxiety is measured. In previous research (Lawton, 1994; Ramirez et al., 2012) different scales are used to assess spatial anxiety, each measuring different qualities of spatial anxiety as this is not a single facetted concept. In the current study the spatial anxiety questionnaire as applied by Lyons and colleagues (2018) was used, as this created a more extensive spatial anxiety measure compared to previous research. This might have caused the difference in results compared to other studies.

Furthermore, spatial ability performance did not seem to differ depending on whether a tasks could be completed using embodied or non-embodied strategies, since there were comparable results on both embodied and non-embodied spatial tasks. These results are not in line with previous research claiming that embodied strategies might place less of a burden on the working memory, making it easier to process spatial stimuli. Therefore, it is debatable whether the implementation of more embodied visual spatial characteristic of information can promote spatial learning for participants independently of initial spatial skills. There is a possibility that individuals whom already have strong spatial ability, do not necessarily benefit from embodied types of stimuli, and vice versa for low spatial ability participants that might already show lower spatial performance. However, in this study there was no control over what type of processing participants used on the stimuli, making it impossible to know which type of processing participants used. Possibly some participants still struggled with the stimuli although it could be processed in an embodied way. Future research might inform participants about the different ways spatial stimuli can be processed and ask the participants how they completed certain spatial tasks. However, the current study did not find evidence for the effect of embodied and non-embodied spatial processing, meaning that this dissociation possibly does not influence the working memory capacity of individuals during spatial processing in a substantial way.

Looking at the effect of gender, no clear difference in score was found between spatial anxiety scores and spatial ability between male and female participants. Although it is worth mentioning that there was a trend towards a significant difference between males and females with low levels of spatial anxiety. It was found that males performed better on the non-embodied spatial ability tests compared to the females in this group. So when spatial stimuli cannot be processed by placing cognitive demands on the body or environment, males might perform better than females. This small effect might be explained by a gender effect but still a lot of research is being done about gender differences and spatial ability, and there is no consensus about what the sizes and the underlying cause of this difference is. Research shows that the influence of gender might differ depending on the type of test being used (David Reilly, Neumann, Andrews, 2016; Castro-Alonso & Jansen, 2019). A lot of research investigating gender differences employed mental rotation tasks, in which males generally have the upper hand and moderate to large effect sizes are found. The present study looked at a variety of spatial ability tasks, providing an overall measure of spatial ability, and did not find a clear difference in gender. This proves that gender differences are not black and white, and a lot of factors might be of influence like sociocultural factors, biological factors and visuospatial experience (Castro-Alonso & Jansen, 2019). It would be interesting to see if gender differences are emerging when participants are tested using an 3D AR type of tasks, that tap into a lot of different spatial skills. Also, it might be important to look at the influence of visuospatial experience.

The present study had some strengths and limitations. A strengths of this study is that it uses variety of different spatial ability tasks creating a spatial ability score based on different types of spatial skills. Another strength was that the study was offered in an online format, making it easy for participants to take part in the experiment from home, especially considering the covid-19 pandemic. A possible limitation of the study is that the use of a variety of test can illicit malingering in participants. The experiment was quite long which can increase the possibility for participant to lose focus and motivation to do their best. While analysing the data, it was found that some participants took very long to finish the experiment and did the tests over several days. Because the study was offered online there was no way to check for malingering. Furthermore, the limited statistical power in this study may have played a role in the analysis generating a significant effect. A post hoc power analysis was performed using the G power tool (Faul, Erdfelder, Lang, & Buchner, 2007), which revealed a low observed power of $d = .05$ for the interaction effect. This means that there is a 5% chance of correctly rejecting the null hypothesis of no significant effect of the interaction of embodiment, spatial ability, gender, and spatial anxiety. An a priori analysis of the number of participants using the G power tool, indicates that with a power $d = .80$ a total of 108 participants are needed to find a significant effect. In addition, the data shows a lot of spread in the participants scores. Because of this the mean serves as a less reliable measure. Since the analyses make use of the mean scores of the spatial ability tests, there is a smaller chance that a significant result is found.

This study might be improved by using fewer spatial ability test so malingering might be reduced and more reliable scores can be produced. The present study did not take into account the types of spatial ability like object manipulation and spatial orientation (Kozhevnikov & Hegarty, 2001). Future research can distinguish these types of spatial ability as they may have a different influence on spatial learning. Furthermore, the used spatial anxiety questionnaire from the study by Lyons and his colleagues (2018), can be divided in specific types of spatial anxiety, namely navigation anxiety, mental manipulation anxiety, and imagery anxiety. This study did not look at these different types of spatial anxiety since it wanted to measure an overall spatial anxiety level. Investigating the effect of these different types of spatial anxiety might produce interesting insights in the influence they have on specific spatial ability tasks. The present study was bound to tasks being performed on a desktop computer. Perhaps future research might investigate the embodiment, spatial ability, gender and, spatial anxiety relationships using AR modes of testing, for example using the Microsoft HoloLens. This way more hand-on data can be collected creating a more direct measure of spatial learning while using these innovative modes of instruction and testing.

To conclude, the findings of the present study did not indicate a relationship between embodiment, spatial ability, gender, and spatial anxiety, which is not in line with the expectations and previous research. It is possible that other factors not directly investigated in this study are of more importance to spatial learning and individual differences in spatial ability, for example working memory capacity and specific subtypes of spatial anxiety. When designing new research these factors should be taken into account. Moreover, future research should look into the possibilities of using new innovative tools to investigate different variables that are of influence on spatial learning. This might provide more accurate hands-on data, which can be used to improve spatial learning.

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[2] -- Friday, September 10, 2021 -- 15:56:03
F tests - ANOVA: Repeated measures, within-between interaction

Analysis:   Post hoc: Compute achieved power
Input:      Effect size f                    =   0
            α err prob                       =   0,05
            Total sample size                =   81
            Number of groups                 =   4
            Number of measurements           =   2
            Corr among rep measures          =   0,587
            Nonsphericity correction ε       =   1
Output:     Noncentrality parameter λ        =   0
            Critical F                       =   2,7233426
            Numerator df                     =   3,0000000
            Denominator df                   =   77,0000000
            Power (1-β err prob)             =   0,0500000
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[5] -- Monday, October 11, 2021 -- 09:58:27
F tests - ANOVA: Repeated measures, within-between interaction

Analysis:   A priori: Compute required sample size
Input:      Effect size f                    =   0,15
            α err prob                       =   0,05
            Power (1-β err prob)             =   0,80
            Number of groups                 =   4
            Number of measurements           =   2
            Corr among rep measures          =   0,587
            Nonsphericity correction ε       =   1
Output:     Noncentrality parameter λ        =   11,7675545
            Critical F                       =   2,6919786
            Numerator df                     =   3,0000000
            Denominator df                   =   104
            Total sample size                =   108
            Actual power                     =   0,8166655
```