

Role of spatial ability, motivation and anxiety in learning neuroanatomy

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Abstract

Introduction: In the last decade, medical student neuroanatomy knowledge has been below an acceptable level. Teaching interventions targeted towards factors relevant to learning neuroanatomy, such as spatial ability or motivation, may be developed to improve knowledge acquisition and long-term retention. This paper seeks to characterise the relationship between spatial ability, motivation and anxiety on learning neuroanatomy.

Methods: Students (n = 131) enrolled in a neuroanatomy course (males n = 53; females n = 78; age = 22±6 [mean ± SD] years) completed a mental rotations test (MRT), condensed Motivated Strategies for Learning Questionnaire (MSLQ) and Depression, Anxiety and Stress Scales (DASS-21) survey to assess spatial ability, motivation and anxiety, respectively. Spearman correlations were calculated between students' scores on these tools and examination/unit results.

Results: Final unit score and perceived task value were weakly positively correlated ($r_s = 0.22$, $p = 0.016$, n = 112), whereas final unit score and anxiety were weakly negatively correlated ($r_s = -0.22$, $p = 0.04$, n = 82). There was a weak positive correlation between spatial ability and spatial MCQ results ($r_s = 0.232$, $p = 0.016$, n = 108) but no other assessment modality.

Conclusions: Targeting interventions to increase students' perceptions of the value of learning neuroanatomy and to reduce anxiety will further improve student performance in this subject. Data from this report may guide the development of personalised educational techniques with the aim of improving knowledge acquisition. Future research into devising these interventions and characterising their effect on neuroanatomy learning would be beneficial.

Keywords: neuroanatomy; learning; motivation; spatial ability; anxiety; education

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Introduction

Learning neuroanatomy is challenging for students and junior doctors due to the complexity of the topic, difficult clinical aspects relating to the anatomy and interconnectedness of anatomical structures (Giles, 2010; Javaid et al., 2018; Jozefowicz, 1994). In practice, lower levels of neuroanatomy knowledge are associated with poorer confidence of junior doctors and general practitioners in managing neurological conditions (Loftus et al., 2016; McCarron et al., 2014; Schon et al., 2002; Zinchuk et al., 2010). Evidence has implicated lack of understanding of neuroanatomical variations to unsafe medical practice and complications in clinical work (AlHindi et al., 2016; Moeller et al., 2008; Waterston & Stewart, 2005). As medical education has changed, with integrated curricula and fewer hours dedicated to teaching neuroanatomy, students' performance in neuroanatomy may be below an acceptable level (Bradley et al., 2015; McBride & Drake, 2018; McKeown et al., 2003; Newman et al., 2021; Prince et al., 2005; Waterston & Stewart, 2005). Three factors have been identified in the literature as being relevant to a student's learning of anatomy: spatial ability, motivation and anxiety (Luffler et al., 2012; Pizzimenti & Axelson, 2015; Plumley et al., 2013).

Spatial ability

Spatial ability can be measured in many ways, with one of the simplest and most validated being the mental rotations test (MRT). Developed originally in 1971 (Shepard & Metzler, 1971), the MRT has been adapted (Vandenberg & Kuse, 1978) and redrawn (Peters et al., 1995) to stay relevant to educational research. In Roach et al.'s (2020) paper, across 15 studies and 1,245 participants, spatial ability was weakly associated with anatomy performance ($r_{\text{pooled}} = 0.240$; CI at 95% = 0.09, 0.38; $p = 0.002$). Performance on spatial and relationship-based assessments (i.e., practical assessments and drawing tasks) was correlated with spatial ability, while performance on assessments utilising non-spatial multiple-choice items was not correlated with spatial ability (Roach et al., 2020). A study of 13 undergraduate health science students showed a significant correlation between spatial ability and neuroanatomy test scores (Brewer et al., 2012). However, authors of this paper suggested larger studies be conducted to verify this finding (Brewer et al., 2012). Another study showed that spatial ability had a weak, positive correlation with performance on neuroanatomy tests when assessing the effectiveness of a 3D online learning module (Allen et al., 2016). A study is yet to fully characterise the relationship between spatial ability and neuroanatomy across a range of assessment modalities as well as content.

Targeting spatial ability to improve knowledge acquisition is not a new concept. It was shown in a group of engineering students with poor spatial ability that participating in a dedicated course designed to enhance spatial ability through lectures and computer laboratories had a significant, positive effect on knowledge acquisition in their studies over the course of a year (Sorby & Baartmans, 2000). Research has already been conducted into developing teaching techniques that specifically aid student

conceptualisation of complex neuroanatomy, including development of interactive 3D learning tools (Pedersen et al., 2013). If spatial ability is well correlated with learning neuroanatomy, early identification of weak spatial ability, and targeted academic interventions, may increase the performance of these students (Langlois et al., 2019; Vorstenbosch et al., 2013).

Motivation

The theory of self-regulated learning (SRL) is a framework used by educators to measure level of engagement in the classroom (Zimmerman, 1989). Zimmerman (1989) defines learners as “self-regulating” based on the extent to which they are “metacognitively, motivationally and behaviourally active participants in their own learning process” (p. 329). There are well-designed instruments, such as the Motivated Strategies for Learning Questionnaire (MSLQ), for measuring SRL empirically (Pintrich et al., 1991, 1993). This tool assesses multiple factors of motivation, including intrinsic and extrinsic goal orientation, task value, control of learning belief, self-efficacy for learning and performance, and test anxiety (Pintrich et al., 1991, 1993). The early psychometric research conducted on this instrument is described in the MSLQ manual (Pintrich et al., 1991). Over the past decade, the MSLQ has been validated by many Australian health and science students, including nursing (Salamonson et al., 2009), midwifery (Carter et al., 2017), medical (Soemantri et al., 2018) and chiropractic science students (Meguid et al., 2019).

Motivation has been linked with anatomy examination performance in two recent studies. Intrinsic goal orientation, task value, control of learning beliefs and self-efficacy for learning were significantly positively correlated with American medical students’ final score in their gross anatomy course (Pizzimenti & Axelson, 2015). The subscale “self-efficacy for learning and performance” was significantly positively associated with Australian chiropractic science students’ final score in their gross anatomy course (Meguid et al., 2019). The relationship between motivation subscales and neuroanatomy performance is unknown.

Anxiety

The concept that test anxiety is negatively correlated with student performance has been established (Cassady & Johnson, 2002), and it is hypothesised that it contributes to poor performance in neuroanatomy education (Jozefowicz, 1994). Methods for reducing test anxiety can be divided into two categories: behavioural modifications and environmental adjustments. Behavioural modifications include social–psychological interventions that target students’ beliefs, thoughts and feelings about learning, and when applied in the correct context, these interventions have been shown to improve students’ performance (Yeager & Walton, 2011). Journaling, for example, has been shown to reduce test anxiety and increase elementary students’ examination scores in mathematics (Ramirez & Beilock, 2011). Self-administered interventions such as progressive muscle relaxation

increase the pass rate of medical students re-sitting licensure examinations (Powell, 2004). Behavioural adjustments rely on students implementing the modifications to reduce their anxiety.

A review of nine methods for reducing neuroanatomy anxiety was published in 2016 and included implementing team-based learning, use of digital teaching tools and integration of basic and clinical sciences (Abushouk & Duc, 2016; Anwar et al., 2015). A survey of medical students found more bedside tutorials and patient exposure would be helpful in reducing neurophobia (Zinchuk et al., 2010). Many other studies have investigated ways of mitigating neurophobia (Chhetri, 2017; Dewar et al., 2020; Kam et al., 2013; Moore, 2020; Sandrone et al., 2019; Shelley et al., 2018; Tarolli & Józefowicz, 2018; Youssef, 2009). Targeted teaching strategies such as interactive virtual reality tools are amongst those that may reduce anxiety and improve knowledge acquisition for students (Ekstrand et al., 2018). However, there is little data in the available literature for which specific interactive tools are empirically proven to do so, and this would be a useful area for future research (Sotgiu et al., 2019).

The Depression Anxiety Stress Scales (DASS-21) is a quantitative measure of distress along three axes: depression, anxiety and stress (Henry & Crawford, 2005). It is a psychometrically validated, short form of Lovibond and Lovibond's (1995) 42-item self-reporting questionnaire (Henry & Crawford, 2005). Clark and Watson (1991) made the comment that while anxiety and depression are phenomenologically distinct, it is difficult to distinguish between these constructs by empirical means. It is expected that this is due to the common factor of negative affectivity predisposing an individual to perceived susceptibility for any one construct (Watson et al., 1988). The psychometric analysis demonstrated DASS-21 scales are a blend of variance common to stress, anxiety and depression. However, it is acceptable to use these scales with acknowledgement of this caveat in the design of its use (Henry & Crawford, 2005). A previous study demonstrated high internal consistency (Cronbach's $\alpha = 0.79$) of the DASS-21 survey in an Australian general population of 18–24 year olds (Crawford et al., 2011).

There is a lack of quantitative data that supports a correlation between spatial ability, motivation or anxiety and performance in learning neuroanatomy. The existence of this data would enable informed discussions by evidence-based educators about how to optimise student support. Trying to quantify the role of these factors in learning neuroanatomy is a difficult task. Differences in the role of spatial ability, motivation and anxiety in learning neuroanatomy may be revealed depending on the different teaching modalities applied. For example, it has been observed that in anatomy laboratories, cadaveric material is a well-known source of stress and anxiety not present in lectures, virtual learning environments or problem-based learning classes (Bernhardt et al., 2012). Conversely, motivation has been enhanced in dissection environments compared to traditional lectures (Abdel Meguid & Khalil, 2017). Similarly, the perceived roles of anxiety, motivation or spatial ability may change depending on the assessment modality

used (Guraya et al., 2018) and other factors, including cultural differences and language barriers. Therefore, any factor that is being addressed as relevant to a student's learning of neuroanatomy must be studied within the constraints of the teaching and assessment modalities applied.

To better inform further investigation into devising targeted teaching strategies, this cohort study aimed to assess relationships between these factors and students' final unit scores in an undergraduate neuroanatomy course. Based on studies of learning anatomy more broadly, it is hypothesised that all motivation subscales (except for test anxiety) will be positively correlated with final scores in a neuroanatomy unit.

Methods

The Human Research Ethics Committee of The University of Western Australia gave approval for this study to be conducted RA/4/20/5250.

Subject groups

Participants (n = 138) were science, biomedical science and neuroscience students enrolled in the neuroanatomy unit ANHB2217 in 2019. The unit consisted of 24 one-hour lectures and 12 two-hour laboratories over a 12-week semester taught by an experienced clinical anatomist. The mixed-method lectures are didactic, with elements of active learning strategies such as spot tests included. The lectures cover content outlined in Moxham et al.'s (2015) neuroanatomy curriculum. Laboratories are traditional in nature, consisting of prosections, plastinated specimens, models and clinical images arranged in five stations, with 20 minutes dedicated to each station. Laboratories cover content from the previous week's lectures. There is no dissection. Students repeating the unit, not providing consent or sitting the deferred examination were excluded from the study. Final unit score was derived from a practical manual completion mark (10%), mid-semester theoretical exam (20%), end-of-semester theoretical exam (40%) and end-of-semester practical exam (30%). No assessments were "must-pass" assessments; that is, none were required to be passed in order to pass the unit.

MRT

During an allocated 20-minute station of a compulsory laboratory midway through the semester, information and consent forms were explained and signed. A student's spatial ability was assessed using the 24-item, redrawn, validated MRT version A (MRT-A) (Peters et al., 1995; Vandenberg & Kuse, 1978), using the same procedure outlined by Peters et al. (1995). Each question shows one illustrated 3D shape composed of 10 cubes on the left, and four possible rotations of the target figure on the right. Two of the four stimulus figures are rotated versions of the target figure. Both correct choices had to be identified in order to score one point. Students had 6 minutes to complete the test, with a 2-minute break at 3 minutes (Peters et al., 1995). The 6-minute timeframe was chosen over 8 minutes, as it has previously been shown to heighten perceived differences in spatial ability within the study population (Peters et al., 1995).

A meta-analysis of MRT results and procedures showed that effect size varies according to how the test is administered or scored (Voyer et al., 1995). For face validity, results obtained in this study were compared to Guimarães et al. (2019). This was of a similar test design to the one outlined by Voyer et al. (1995) in scoring procedure, individual versus group testing and age/sex of the experimenter.

MSLQ and DASS-21

In three separate laboratories, a condensed 19-question version of the MSLQ and the DASS-21 were administered (Pintrich et al., 1991, 1993). The MSLQ subscale items assessing intrinsic motivation (IGO) (n = 4), extrinsic motivation (EGO) (n = 4), task value (TV) (n = 6) and test anxiety (TA) (n = 5) were included. These questions were completed on a Qualtrics electronic survey where demographic data was also collected.

Examination

The end-of-semester examination consisted of practical (1-hour) and theoretical (2-hour) components during the University examination period, approximately 5 and 8 weeks after gathering MSLQ and MRT data, respectively. The practical examination consisted of 22 stations with a stimulus (prosection, model, plastinated specimen, image) and question list, with 2 minutes per station. The question lists were drawn from a range of Bloom's taxonomy levels (Bloom, 1956; Thompson & O'Loughlin, 2015). Level one to three questions, including identification, featured at every station, with the occasional use of higher-order analysis level questions. The theory examination consisted of six short-answer (one- to five-word answers) and 39 multiple-choice questions. Two authors (HN and AM) independently reviewed the MCQs and extracted spatial (n = 5) and non-spatial (n = 34) questions. Spatial questions were those requiring students to form mental images built from visual perceptions of objects, for example: "What is the orientation of the medial lemniscus tract in a mid-level axial section of the pons?" The options might include: coronal plane, anterior; coronal plane, posterior; sagittal plane, anterior; sagittal plane, posterior. To increase the number of spatial questions, spatial MCQ data were extracted from two other intra-semester examinations from the same cohort using the same extraction process—first, from a pre-laboratory knowledge test (n = 9) 10 weeks prior to the final examination and, second, from a mid-semester examination 6 weeks prior to the final examination (n = 4). Full data sets of spatial MCQ questions were available for 108 students.

Students' demographic data, MRT, MSLQ, grade point average (GPA), final unit result, final spatial MCQ score, final non-spatial MCQ score, final SAQ score and final practical score were linked to a unique de-identified student code and analysed. GPA, as a marker of previous performance, was included to assess whether motivation, spatial ability and anxiety were correlated. Previous academic performance is a good predictor of future performance in medical education (Ferguson et al., 2002).

Statistical analysis

Where relevant, data is presented as mean \pm standard deviation (SD). A p -value of < 0.05 was considered significant. Statistical analyses were performed using R Commander software, version 3.2, Austria (Fox & Bouchet-Valat, 2017). Spearman's correlation coefficient between MRT results (ordinal values) and age, GPA, spatial MCQ, non-spatial MCQ, SAQ, practical examination result and total score were calculated. Independent t -tests were used to detect for relevant differences between males and females. A one-way ANOVA was used to detect interactions between the type of course studied by the student and results obtained in the unit.

Internal reliability of measurement scale responses (Cronbach alpha) for the MSLQ, DASS-21 and examination scores were assessed. Means for IGO, EGO, TV and TA were calculated. Spearman correlations with final unit score and GPA and their significance were reported.

Results

Demographic data is illustrated in Table 1. There were 131 (out of 185 enrolled, participation rate 70.8%) participants included in the study. There were seven students who did not consent to have their GPA accessed specifically and 19 students did not complete the MSLQ. These students were not included in relevant calculations and are indicated where appropriate. Three questions were excluded from the practical exam due to specimen orientation changing between students, and the final practical exam question number was reduced to 19. There were 108 complete data sets for spatial MCQ questions.

The mean final unit result was $69.7 \pm 15.3\%$. There was no significant difference between males and females (males = $71.1 \pm 13.8\%$; females = $68.8 \pm 16.2\%$, $p = 0.41$). There was no significant difference in students' results based on their enrolled course (1-way ANOVA, $F = 0.67$, $p = 0.65$).

MRT

The mean MRT result was 10.6 ± 4.7 . Male students achieved mean MRT scores 37% higher compared to female students (males = 12.6 ± 4.8 ; females = 9.2 ± 4.1 ; Cohen's $d = 0.77$; $p < 0.001$). MRT score was not correlated with age ($p = 0.06$).

A student's spatial ability was not correlated with final unit result ($r_s = 0.122$, $p = 0.16$). However, there was a significant, weak positive correlation between MRT and spatial MCQ score ($r_s = 0.232$, $p = 0.016$, $n = 108$). Correlation coefficient between MRT and final unit result, spatial MCQ, non-spatial MCQ, SAQ and practical examination are shown in Table 2. MRT scores were not correlated with a student's GPA ($p = 0.59$, $n = 124$).

Table 1*Respondent Demographic Data*

Measure	Response
Age	Mean 22.0 (\pm 5.6), range 18–57 years
Gender	Male: 53 (41%) Female: 78 (59%)
Course	BBioMedSci: 56 (42%) BSc: 63 (48%) DipSci: 1 (< 1%) MBioMedSci: 3 (2%) MBioMedSci: 6 (4%) PhD: 6 (4%) BPhil (Hons): 1 (< 1%) Other: 1 (< 1%)

Table 2*Descriptive Statistics, Including Standard Deviation (SD) and Spearman Correlations (R_s) of Mental Rotations Test and Examination Results in a Neuroanatomy Course (n = 131)*

Question Type	Mean %	\pm SD %	Cronbach Alpha	Number of Questions	Correlation With Question Type (R_s)	p-value
Spatial MCQ	59.1	\pm 28.5	0.629	18 ^a	0.23	0.016
Non-spatial MCQ	74.1	\pm 16.9	0.852	34	0.12	0.18
Short answer	72.7	\pm 18.9	0.832	6	0.13	0.13
Practical	58.6	\pm 17.8	0.889	19	0.16	0.06
Final result	69.7	\pm 15.3	-	-	0.122	0.16

^a Sum number of MCQ questions taken from three points during semester, n = 108

MSLQ

The MSLQ means, Cronbach alpha scores and correlation with final unit scores for IGO, EGO, TV and TA are shown in Table 3 (n = 112). Final unit scores were weakly correlated positively with perceived task value ($r_s = 0.22$, $p = 0.016$) and negatively with test anxiety ($r_s = -0.29$, $p = 0.001$).

Table 3

Descriptive Statistics Including Standard Deviation (SD), Internal Reliability (Cronbach Alpha) and Spearman Correlations (R_s) of Motivated Strategies for Learning Questionnaire Subsets TA, TV, EGO and IGO and Final Unit Score in Neuroanatomy Course (n = 112)

Scale	Mean	± SD	Cronbach Alpha	Number of Items	Correlation With Final Score (R_s)	p-value
TA	4.50	± 1.30	0.809	5	-0.29	0.001
TV	5.86	± 0.76	0.811	6	0.22	0.016
EGO	5.32	± 1.12	0.714	4	0.16	0.08
IGO	4.88	± 0.99	0.703	4	0.07	0.45

DASS-21

There was a significant, negative correlation between the DASS-21 anxiety score and final unit scores ($r_s = -0.22$, $n = 82$, $p < 0.05$). Cronbach's alpha for neuroanatomy-specific anxiety was 0.82. There was no correlation between depression- or stress-related subscales and final unit score ($r_s = -0.18$, $p = 0.1$; $r_s = -0.05$, $p = 0.7$; $n = 82$).

Discussion

Learning neuroanatomy is positively correlated with perceived task value and negatively correlated with neuroanatomy-specific anxiety. Students of high spatial ability performed better in spatial MCQs. There was no correlation between spatial ability and other assessment types, although students of a superior spatial ability had a tendency to perform better in practical exams. Our knowledge of factors important for neuroanatomy teaching have been advanced and are discussed separately here.

It was encouraging to see MRT results were similar to previous studies of Guimarães et al. (2019) and Pizzimenti and Axelson (2015), respectively, with similar populations (undergraduate students) and test administration methods (method of scoring MRT, small groups, age/sex of the examiner). The overall MRT was low (10.6 ± 4.7). This was expected given the smaller timeframe provided to participants to complete the task (6 minutes rather than 8). This is not to be confused with students misunderstanding the task or improper administration of the test, highlighted by the consistency of these findings with larger samples (Peters et al., 1995). Previous studies have found spatial ability is negatively correlated with age (Voyer et al., 1995). It was not the objective of this study to examine age-related changes in spatial ability; and while in this study a negative trend was observed, it was not statistically significant. This may have been due to the negative skew in distribution of age of the population assessed.

Spatial ability

Spatial ability was correlated only with a student's performance on spatial MCQs and not with other assessment modalities. A systematic review of spatial abilities tests and anatomy knowledge demonstrated a positive correlation when examination is of a pictorial or spatial nature, such as in practical examination (Langlois et al., 2019). While students of high spatial ability had a tendency to perform better in the practical exam, this conclusion was not statistically significant and is contrary to previous findings. Some students had commented to the unit coordinator that they had not dedicated much time to reviewing spatial relationships between structures, believing this to be a low-yield task that required significant cognitive load. Further, Allen et al. (2016) summarised that different studies may yield neutral findings if questions did not require complex enough spatial consideration, which may have been the case in this report.

It remains unclear if courses requiring practical neuroanatomy assessment, such as in medical or allied health schools or for students with surgical career intentions, would benefit from targeted interventions that improve spatial ability. From Gonzales et al. (2020), we know that greater than 2 hours of training with targeted interventions would be required to see an improvement in performance. However, neuroanatomy courses utilising predominantly non-spatial multiple-choice or short-answer examination formats, such as those in science or allied health, are unlikely to benefit from targeting teaching interventions towards spatial ability, where the link is not statistically significant.

A limitation of this study was the use of a compiled list of spatial questions to increase sample size. By selecting from multiple time-points, the mean value obtained may have been artificially high, as students learn to expect the style of question and prepare accordingly. This bias may have been negated by writing an exam with a greater proportion of spatial questions or writing a bespoke assessment specifically designed to assess spatial learning.

There was a significant difference between male and female MRT results, consistent with previous findings (Peters et al., 1995; Voyer et al., 1995). It should be noted that scoring out of 24 is known to increase the magnitude of the effect size (Voyer et al., 1995). Despite being well-documented, the reasons for this difference are poorly understood.

Motivation

The perceived value of content plays an important role in how effectively students learn neuroanatomical content; that is, the more interesting, important, or useful the student sees neuroanatomy, the better they will learn. Utilising digital technologies can make the process of learning more enjoyable (Abulaban et al., 2015). Most recently, a study on undergraduate students using the GreyMapp augmented reality tool versus cross sections of brains found students considered it a valuable addition to curricula and experienced less cognitive load when using the tool (Henssen et al., 2019). However, it remains largely unknown whether this is correlated with improved learning, and future studies may better

characterise this (Arantes et al., 2018). Further, enjoyment is a subjective experience, and some students may find the GreyMapp tool less enjoyable, particularly if they experience side effects such as dizziness, nausea and disorientation (Moro et al., 2017).

While not a complete list, modifiable factors that influence perceived value are degree of clinical relevance, curriculum autonomy and patient/clinical contact (Kusurkar et al., 2011). These factors, along with others not described here, should form the basis for selecting pedagogical approaches. Contrary to previous studies, intrinsic and extrinsic motivational subtypes were not as important in learning neuroanatomy compared to anatomy more broadly (Meguid et al., 2019; Pizzimenti & Axelson, 2015). Larger studies may be required to verify this finding.

Anxiety

As expected, there was a weak negative correlation between anxiety and neuroanatomy performance, providing quantitative evidence for the effect of neurophobia (Jozefowicz, 1994). Modifiable risk factors for neuroanatomy anxiety include poor teaching, complex terminology, separation of basic science teaching and clinical application (Abushouk & Duc, 2016). This evidence suggests interventions that decrease test anxiety, such as those described in the introduction, may have a positive effect on learning neuroanatomy.

Conclusion

Students' performance in neuroanatomy is positively correlated with the value they place on the subject and negatively correlated with the amount of anxiety they experience. Spatial ability and intrinsic/extrinsic motivation did not correlate with students' overall performance in neuroanatomy. However, spatial ability was correlated with scores on spatial MCQs. Larger data sets with cross-institutional sampling may be used to validate this study's conclusions. Targeting interventions to increase students' perceptions of the value of learning neuroanatomy and reduce anxiety will further improve performance in this subject.

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