Visuospatial Abilities in Surgical Training

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Abstract

Introduction: Visuospatial Abilities (VSA) are important for learning and performing technical tasks. These abilities appear to be malleable, suggesting that they can be improved through training. We therefore hypothesize that VSA are fundamental to surgical skill and can be learned. The field of VSA research seems to contain inconsistencies regarding the operationalization and testing of VSA, resulting in a poor understanding of which processes are relevant to a particular task. Chapter one of this thesis presents a scoping review that aims to identify the terminology, VSA processes, psychometric instruments, and training interventions found in studies exploring the role of VSA in surgical and non-surgical trainees. To improve consistency, a model for testing VSA in the surgical field is proposed. Chapter two aims to use the proposed model in a cross-sectional pilot study to gain a deeper understanding of the VSA processes that may be involved in basic surgical tasks as defined by the laparoscopic peg transfer and precision cutting tasks in medical students and residents.

Methods: In chapter one, a scoping review was designed to identify relevant records from EMBASE and Medline until January 13th, 2020. Data were extracted on VSA terminology, dimensions, instruments, and interventions with results stratified by specialty (surgical, non-surgical, or mixed). Conference abstracts, opinion pieces, and review studies were excluded. A model for testing VSA in surgical research was proposed. In chapter two, residents and medical students were recruited to participate in a cross-sectional pilot study. The proposed model for testing VSA in surgical research was used to guide the selection of psychometric instruments used. Three visuospatial tests were completed followed by the peg transfer and precision cutting task. Due to the small sample size, no statistical analyses were conducted. Mean differences were compared to provide a preliminary indication of differences in VSA performance and surgical performance between residents and medical students using Microsoft Excel.

Results: Out of 882 total records, 26 were identified in chapter one that met the criteria for inclusion. Surgical specialties were represented in >90% of the results. A total of 16 unique terms were used to describe VSA and were measured using 34 instruments, of which eight were used more than once. Eighteen different dimensions were identified. A single study explored the effects of a targeted VSA intervention. In chapter two, recruitment and data collection were severely impacted by the COVID-19 pandemic. A small sample size of four was therefore collected. Medical students had higher VSA scores, and lower surgical performance compared to residents. No conclusions on the predictive relationship between VSA and surgical performance were made.

Conclusion: This work has explored and identified gaps in the literature exploring VSA in surgical and non-surgical research. A model to guide future research has been proposed and applied in a pilot study, in hopes that a greater understanding of the underlining VSA mechanisms involved in technical performance will be realized. A pilot study was conducted and offered insight on the design and statistical analysis for a future study exploring the relationship between VSA and surgical performance. Although further research is needed, VSA training is promising and may have the potential to greatly improve residency curricula.

Résumé

Introduction: Les aptitudes visuospatiales (AVS) sont importantes pour l'apprentissage et l'exécution de tâches techniques. Ces capacités semblent être malléables, ce qui suggère qu'elles peuvent être améliorées par l'entraînement. Nous émettons donc l'hypothèse que les AVS sont fondamentales aux compétences chirurgicales et qu'elles peuvent être apprises. Le domaine de la recherche sur les ASV semble contenir des incohérences concernant l'opérationnalisation et le test des ASV, ce qui entraîne une mauvaise compréhension des processus qui sont pertinents pour une tâche particulière. Le premier chapitre de cette thèse présente une revue littéraire, qui vise à identifier la terminologie, les processus d'ASV, les instruments psychométriques et les interventions de formation trouvée dans les études explorant le rôle de l'ASV chez les stagiaires chirurgicaux et non chirurgicaux. Afin d'améliorer la cohérence, un modèle de test de l'ASV dans le domaine chirurgical est proposé. Le chapitre deux vise met en pratique le modèle proposé dans une étude pilote transversale. Cette étude cherche à mieux comprendre les processus d'ASV qui peuvent être utilisés dans les tâches chirurgicales de base telles que définies par le «peg transfer» et les tâches de coupe de précision chez les étudiants en médecine et les résidents.

Méthodes: Dans le premier chapitre, revue littéraire a été conçue pour identifier les enregistrements pertinents d'EMBASE et Medline jusqu'au 13 janvier 2020. Nous avons extrait les données concernant la terminologie, les dimensions, les instruments et les interventions de l'ASV avec des résultats stratifiés par spécialité (chirurgicale, non chirurgicale ou mixte). Les résumés de conférence, les articles d'opinion et les études de synthèse ont été exclus. À la fin du chapitre, un modèle pour tester l'ASV dans la recherche chirurgicale est proposé. Au chapitre deux, des résidents et des étudiants en médecine ont été recrutés pour participer à une étude pilote transversale. Le modèle proposé au chapitre un, pour tester l'ASV dans la recherche chirurgicale, a été utilisé pour guider la sélection des instruments psychométriques utilisés. Trois tests visuospatiaux ont été réalisés, suivis par le «peg transfer» et par la tâche de découpe de précision. En raison de la petite taille de l'échantillon, aucune analyse statistique n'a été réalisée. Les différences moyennes ont été comparées pour fournir une indication préliminaire des différences de performance VSA et de performance chirurgicale entre les résidents et les étudiants en médecine en utilisant Microsoft Excel.

Résultats: Sur un total de 882 enregistrements, 26 ont été identifiés dans le premier chapitre qui répondaient aux critères d'inclusion. Les spécialités chirurgicales étaient représentées dans >90% des résultats. 16 définitions, au total, ont été utilisés pour décrire l'ASV et ont été mesurés à l'aide de 34 instruments, dont huit ont été utilisés plus d'une fois. Dix-huit dimensions différentes ont été identifiées. Une seule étude a exploré les effets d'une intervention ciblée sur l'ASV. Dans le chapitre deux, le recrutement et la collecte des données ont été gravement affectés par la pandémie de COVID-19. Un petit échantillon de quatre personnes a donc été collecté. Les étudiants en médecine ont obtenu des notes ASV plus élevés et des performances chirurgicales plus faibles que les résidents. Aucune conclusion sur la relation prédictive entre l'ASV et la performance chirurgicale n'a été produite.

Conclusions: Cette thèse a exploré et identifié les lacunes dans la littérature explorant l'ASV dans la recherche chirurgicale et non chirurgicale. Dans l'espoir de parvenir à une meilleure compréhension des mécanismes sous-jacents de l'ASV impliqués dans la performance technique, un modèle pour guider les recherches futures a été proposé et

appliqué dans une étude pilote. Cette dernière a offert un aperçu de la conception et de l'analyse statistique pour une étude future explorant la relation entre l'ASV et la performance chirurgicale. Bien que d'autres recherches soient nécessaires, la formation à l'ASV est prometteuse et peut avoir le potentiel d'améliorer considérablement les programmes de résidence.

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Preface and Contributions of Authors

Dr. Kevin J. Lachapelle and Dr. Jason M. Harley supervised the entire project and were involved throughout the whole process. Dr. Hellmuth R. Muller Moran, Dr. Mohammed Alharbi, Dr. Elif Bilgoc, and Mr. Byunghoon Tony Ahn provided wonderful contributions as outlined below.

Chapter 1

Chapter 1 was written by M.M.V. K.J.L and J.M.H reviewed and edited the section.

Chapter 2

Chapter 2 was presented as a manuscript published in the Surgery Open Science Journal. M.M.V was involved in the conception and design, development of search strategy, article screening, data extraction, data analysis and interpretation, manuscript drafting, and submission. H.R.M.M was involved in the conception and design, article screening, data analysis and interpretation, manuscript edits, and approval for submission. M.A was involved in conception and design, data analysis and interpretation, manuscript edits, and approval for submission. B.T.A was involved in data analysis and interpretation, manuscript edits, approval for submission. J.M.H and K.J.L were involved in conception and design, development of search strategy, data interpretation, manuscript edits, and approval for submission.

Chapter 3

M.M.V was involved in the conception and design, recruitment and data collection, data analysis and interpretation and writing the chapter. K.J.L and J.M.H were involved in the conception and design, aided with recruitment and reviewed and edited the section. E.B and H.R.M.M provided feedback and suggestions on the research design and set-up.

Chapter 4

Chapter 4 was written by M.M.V. K.J.L and J.M.H reviewed and edited the section.

List of Abbreviations

VSA: Visuospatial Abilities

MRT: Mental Rotation Test

PTSOT: Perspective Taking Spatial Orientation Test

PFT: Paper Folding Test

FLS: Fundamentals of Laparoscopic Surgery

Chapter 1: Introduction to VSA

Visuospatial abilities (VSA) are a fundamental characteristic of intelligence. They are defined as "an individual's abilities in the visual field, apprehending the forms, shapes, and positions of objects as visually perceived, forming mental representations of those forms, shapes, and positions, and manipulating such representations 'mentally'".[1] This definition not only demonstrates the complexity of this psychological construct, but also the multiple processes VSA encompasses. Having said that, agreement regarding the individual processes that make up VSA appears to be lacking in the literature.

Multiple studies have attempted to operationalize subcomponents of VSA, resulting in a wide number of VSA processes found in the literature.[1–3] In 1985, Linn and Peterson identified three different VSA processes, including spatial perception, spatial visualization, and mental rotation.[2] They found spatial visualization to be the most complex of these factors, as it could encompass a mix of both spatial perception and mental rotation processes.[2] In 1993, Carroll characterized the following five VSA processes through a survey of factor analysis studies: visualization, spatial relations, closure speed, flexibility of closure, and perceptual speed. Another factor labeled spatial scanning was investigated but lacked evidential support.[1] Multiple psychometric instruments for measuring these different processes have been proposed, including *Paper Folding tasks* for visualization, *the Cards test* for spatial relations, *the Gestalt Completion test* for closure speed, *the Copying test* for flexibility of closure, and *the Posner Letter Matching task* for perceptual speed, among many others.[1] In addition to this work, researchers have also referred to the kit of factor-referenced cognitive tests developed by Ekstrom and colleagues to define and measure VSA processes. The authors of this kit determined 23 different factors—a portion being VSA related processes—and proposed psychometric instruments to measure each factor.[3] Common subcomponents of VSA from this kit included spatial orientation, spatial scanning, visualization, flexibility of closure, speed of closure, visual memory, and perceptual speed.[3] They could be measured using the Cards Rotation test, Maze Tracing Speed test, Paper Folding test, Hidden Figures test, Gestalt Completion test, Shape Memory test, and Finding A's test respectively.[3] In addition to the psychometric instruments outlined above, there are many more available in the literature. With such a wide array of identified processes and available instruments, confusion is bound to arise regarding which processes to study and instruments to select.

Although there appear to be inconsistencies regarding the underlining processes that make up VSA, there is consensus that VSA, in general, plays a fundamental role in many different domains, such as the STEM disciplines, aviation industry, and medical and surgical domains.[4–6] Research has shown that VSA is linked to performance in engineering courses as well as solving chemistry and physic problems.[7–9] VSA has also been linked to mathematics performance in children and has predicted flight training performance in pilots.[10,11] VSAs are further important for open surgery and closed technical interventions which use two-dimensional imaging modalities. Certain medical and surgical tasks require specialists to form an internal representation of the anatomy.[12] They may also depend on a two-dimensional image to represent such anatomy.[12] These tasks in turn require a degree of VSA. Studies have also found a predictive relationship between VSA levels and technical performance.[13–17] In novices performing simulated minimally invasive tasks, skills acquisition was significantly quicker for those with higher VSA.[13–17] These findings not only reinforce the relevance of VSA when performing certain surgical and medical tasks but also when learning them.

Performance in both surgical and non-surgical related fields is reliant on VSA. However, with such a variety of factors and instruments available, it is unclear whether consensus has been attained regarding the individual components of VSA and their respective psychometric instruments, particularly in the field of surgery. The fluidity of the field in general warrants a scoping review to help understand how VSA is used in surgery specifically.

Chapter 2: Innate versus Learned Ability

Individual differences in VSA processes exist.[5] It is debatable as to whether individual differences may be caused by innate factors, environmental factors, or a mix of both. Research has shown that the brain is highly plastic, signifying that abilities are generally not innate.[18] In fact, most abilities can be developed over time through deliberate practice.[18] It has also been suggested that individual differences in VSA—more specifically sex differences—may be influenced by a combination of environmental and innate factors.[4] These findings, as well as studies that found enhanced VSA levels after practice,[19–24] supports the notion that VSA processes are malleable and not fixed.

A study conducted on rats demonstrated the influence that environmental factors may have on VSA levels.[25] Rats reared in an enriched environment had higher performance on VSA tasks compared to rats reared in standard conditions.[25] Although this study was not conducted on humans, it does demonstrate that VSA are flexible in other species. Halpern and Collaer identified a multitude of different factors that may influence VSA levels in humans.[4] They included factors related to training, culture, stereotypes, neuroanatomy, hemispheric lateralization, and sex steroids, which were used to explain sex differences in VSA found in the literature.[4] The interaction between these factors and VSA levels supports the argument that VSA are dynamic and not entirely based on fixed determinants.

Many studies have demonstrated an increase in VSA through interventions and training. A meta-analysis exploring the flexibility of VSA found that it was susceptible to training.[19] Training programs included courses, videogames, and spatial task training.[19] A study in the engineering field found an increase in VSA following a weekly spatial intervention.[21] Transfer effects from the spatial intervention to performance in a calculus course were also observed.[21] Another study that also introduced a weekly spatial intervention on undergraduate students also found increases in VSA by the end of the training.[22] Finally, multiple studies in the healthcare field observed improvements in VSA following training.[20,23,24] The trainings consisted of an anatomy course, an abdominal sonography course, a hands-on radiology course, and a single-session spatial training.[20,23,24]

The effects of training on VSA performance do appear to be beneficial, which is of great relevance for the purpose of this thesis. Based on this evidence, we believe that VSA can be trained. What remains unclear is which processes of VSA to teach. Nonetheless, given the malleability of VSA processes and the importance of such processes when learning and performing specific surgical and medical tasks, VSA training may have positive implications for residency curricula.

Chapter 3: Potential Benefits of VSA Training for Resident Curriculums

Many skills must be learned during residency. The question arises as to whether it is more beneficial to focus on improving specific skills directly, such as a suturing technique, or underlying abilities, such as VSA. A study found that the performance on a robotic task was enhanced for participants who engaged in a 25-to-45-minute spatial training session, compared to those who did not.[24] The spatial training session time-efficient and did not require expensive equipment.[24] It also showed that the abilities gained from the spatial training were transferred to another surgical task. These results suggest that a single VSA training may in turn facilitate the acquisition of surgical skills on multiple surgical tasks by reducing resident's learning curves. Not only would a VSA training be time-efficient and inexpensive, but it would also potentially reduce the time residents spend learning surgical tasks directly. We believe that the briefness of the training coupled with the reduction in time spent improving surgical skills would serve as a motivator for residents and educators alike.

Chapter 4: Objectives and Hypothesis

The objectives of this thesis are as follows:

1. To determine the status of the field of VSA in surgery through a scoping review
2. To develop a framework for testing VSA to help establish consensus in future research
3. To determine which VSA processes are involved in simple surgical tasks using the proposed framework

We hypothesize that visuospatial abilities are fundamental to surgical skill and can be learned through training.

Chapter 5: Scoping Review

The study of visuospatial abilities in trainees: A scoping review and proposed model

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Abstract

Background: Visuospatial abilities are an important component of technical skill acquisition. Targeted visuospatial ability training may have positive implications for training programs. The development of such interventions requires an adequate understanding of the visuospatial ability processes necessary for surgical and nonsurgical tasks. This scoping review aims to identify the components of visuospatial ability that have been reported in surgical and nonsurgical trainees and determine if there is consensus regarding the language and psychometric measures used, clarifying the elements that may be required to develop interventions that enhance visuospatial ability.

Methods: A scoping review was designed to identify relevant records from EMBASE and Medline until January 13, 2020. Data were extracted on visuospatial ability terminology, dimensions, instruments, and interventions with results stratified by specialty (surgical, nonsurgical, or mixed). Conference abstracts, opinion pieces, and review studies were excluded.

Results: Out of 882 total records, 26 were identified that met criteria for inclusion. Surgical specialities were represented in > 90% of results. A total of 16 unique terms were used to describe visuospatial ability and were measured using 34 instruments, of which eight were used more than once. Eighteen different dimensions were identified. A single study explored the effects of a targeted visuospatial ability intervention.

Conclusions: A wide range of visuospatial ability terms, instruments, and dimensions were identified, suggesting an incomplete understanding of the components most relevant to surgical and nonsurgical tasks. This confusion may be hindering the development of visuospatial ability targeted interventions during residency training. A rigorous methodological model is proposed to help unify the field and guide future research.

Keywords

Visuospatial Abilities, Training, Trainee, Surgical Education, Scoping Review, Medical Education

Abbreviations

VSA, Visuospatial Ability; BVMT-R, Brief Visuospatial Memory Test-Revised; CRT, Card Rotation Test; CCT, Cube Comparison Test; MPT, Map Planning Test; MR, Mental Rotation; MRT, Mental Rotation Test; SO, Spatial Orientation; SP, Spatial Planning; SS, Spatial Scanning.

Introduction

Visuospatial abilities (VSAs) are important for both surgical- and non–surgical-related tasks, such as laparoscopic interventions and the interpretation of medical imagery.[12] A positive relationship between VSA and technical performance has been reported in the literature.[12,14–17] In addition, longer learning curves have been observed during laparoscopic suturing[15] and appendectomy[14] tasks in students with low VSA. The aggregate of these findings suggests that the learning curves of trainees performing tasks requiring a degree of VSA could be shortened when VSA is improved through training. VSA targeted training may therefore be promising for surgical and non-surgical specialties.

Although the literature has shown an overall positive relationship between VSA and technical performance, discrepancies in this relationship have also been reported.[26] A multitude of terms, conflicting definitions, and instruments have been used to describe and measure related visual and spatial processes in the literature.[1,10] It has been argued that the types of testing used to assess VSA could partially explain these discrepancies, as the selection of appropriate instruments appears to lack sufficient theoretical reasoning.[26] The tests may therefore not align with the task in question. This may result in a lack of consistent testing methods and make it challenging to establish the relevant VSA processes, impeding the development of potential VSA training interventions.

Given the broad scope and multiple dimensions of VSA, it is important to understand the components that are *fundamental* to surgical and non-surgical specialties. We have explored these components by conducting a scoping review. Scoping reviews, like systematic reviews, use structured guidelines to synthesize information.[27] Though, they are designed to illustrate the landscape of the literature towards a topic, as opposed to systematically narrow down specific studies to assess their quality and implications.[27] While conducting a systematic review aligns with our goals of improving our understanding of VSA and enhancing related training programs, a scoping review is first needed to map out the overall characteristics of the field and identify potential gaps in the literature.[27] As such, this scoping review seeks to gain insight on the studies exploring the role of VSA in surgical and non-surgical trainees and determine if there is consensus regarding the language and instruments used. We aim to report the VSA (1) terminology, (2) instruments, (3) dimensions, and (4) targeted training found in the literature as well as suggest a model for future research in hopes of forming a consensus in the literature.

Methods

Framework

The methodological framework used to guide this review was the Five-Stages for conducting a scoping review by Arksey & O'Malley, which involved (1) identifying the research question; (2) identifying relevant studies; (3) study selection; (4) charting the data; and (5) collating, summarizing, and reporting the results.[28] The Preferred Reporting Items for Systematic reviews and Meta-Analyses extension for Scoping Reviews (PRISMA-ScR) checklist was also consulted.[29]

Criteria for selection

Empirical journal articles written in English that used instruments to measure any dimension of VSA in trainees were considered for inclusion. There were no date limitations. The article was considered for inclusion if the population was composed of trainees, which we operationalized as residents, fellows, or any participant that completed a medical degree and was currently in training. Since we were interested in trainees specifically, articles were excluded if trainees were not isolated as their own group when studies included non-trainees. Our intent was to examine completed studies that measured VSA in trainees specifically, therefore conference abstracts, opinion pieces, and review articles were excluded (but were reviewed for relevant information). Articles unavailable online were also excluded. If an instrument was intended for children, it was excluded as it was not designed for the population in question. If the instrument had additional sections assessing factors that were not VSA (i.e., topic knowledge, motor skills, etc.), it was excluded as we believed these measures were designed for a distinct task and would not be beneficial for a researcher interested in specifically determining an individual's VSA levels. In other words, we sought to isolate instruments used to measure VSA alone.

Search strategy and selection procedure

A search strategy was developed in two stages. In the first stage, a preliminary literature review using basic keywords related to VSA and healthcare (i.e., visuospatial, visual spatial, spatial perception, resident*) was conducted in Embase and MEDLINE with the purpose of identifying additional keywords related to VSA. In the second stage, a comprehensive search strategy using keywords and MeSH terms was developed with the help of a health sciences librarian. The final search was performed January 13th, 2020 in MEDLINE (1946 – Jan 13, 2020) and Embase (1947 – Jan 13, 2020). The search strategy can be found in the appendix. Two authors (MMV and HRMM) independently screened titles and abstracts using the online web application Rayyan Qatar Computing Research Institute (Hamad Bin Khalifa University, Doha, Qatar).[30] Discrepancies were settled through discussion (MMV and HRMM) until consensus was met. Full-text articles were obtained and examined for possible inclusion by MMV using the selection criteria.

Data extraction

Data were compiled into a data-charting table. Extracted data from the full-text analysis included the author, year, publication type, location of study, field (surgical, non-surgical, or mixed) and specialty of the trainees, instruments used to measure VSA, dimensions of VSA examined, and terminology used for VSA. Data extraction was completed by one researcher (MMV).

Results

Study selection process

Figure 1 illustrates a flowchart of the selection process. The initial MEDLINE and Embase search yielded 882 titles. After deduplication, 626 titles underwent title-abstract screening based on the selection criteria and 62 articles remained for full-text review. A total of 26 articles met the inclusion criteria after full-text review and underwent data extraction and analysis.

Study characteristics

The study characteristics are presented in Table 1. The studies included in this review were published between 1992 and 2019. The percentage of studies published in the last 10 years (i.e., 2010) was 61.54% (n = 16). The study designs comprised of observational studies (n = 21) and experimental studies (n = 5). Only 1 study introduced a VSA training intervention.[24]

The field of the trainees investigated were surgical (n=21; 80.76%), non-surgical (n=2; 7.69%), or both (n=3; 11.54%). A total of 14 studies (53.85%) specified the specialties of the trainees (Table 1). One study considered all residents investigated as surgical residents, including anaesthesia.[24] Since the authors considered their population surgical and not mixed, they were marked accordingly for consistency. Since obstetrics and gynecology residents are classified as a surgical speciality by the Royal College of Physicians and Surgeons of Canada,[31] studies that included this specialty were deemed surgical, unless the authors explicitly specified otherwise.

VSA terminology

Sixteen different terms to describe VSA were found. The terms were Visual Spatial Ability (n=10), Visuospatial Ability (n=8), Spatial Ability (n=7), Visual Spatial Aptitude (n=4), Visual Spatial Skills (n=3), Perceptual Ability (n=1), 2D–3D Visual Spatial Ability (n=2), Spatial Skills (n=2), Visuospatial Aptitude (n=2), Visuospatial Skills (n=2), Spatial Aptitude (n=1), Spatial Perception (n=1), Visual Perception (n=1), Visual-Spatial Perception (n=1), Visual-Spatial Processing (n=1), and Visuospatial Perception (n=1).

Eleven studies (42.31%) used a consistent term for VSA, whereas14 studies (53.84%) used 2 or more terms interchangeably. One study did not specify a term for VSA, but instead focused on the specific dimensions of interest.[32] The term *perceptual ability* was used in an additional study, however, we did not count it in the analysis because the authors explicitly deemed it a separate construct from VSA.[33]

Dimensions of VSA

Out of the 26 studies included in this review, only 10 studies (38.46%) explicitly stated the dimension of VSA they were assessing. A total of 18 dimensions were investigated, including Spatial Orientation (n=4), Mental Rotation (n=3), Spatial Scanning (n=3), Edge and Surface Extraction (n=1), Mental Rotation of Visual Forms (n=1), Mental Visualization Involving 2D and 3D Spatial Rotations and Translation (n=1), Perspective Taking (n=1), Spatial Judgement (n=1), Spatial Planning (n=1), Spatial Visualization (n=1), Spatial Visualization and Manipulation (n=1), Visual Analysis (n=1), Visual Memory (n=1), Visual Problem Solving (n=1), Visual Spatial Learning and Memory (also referred to as Visual Learning and Memory) (n=1), Visuomotor Organization (n=1), Visuospatial Processing and Construction Ability (n=1), and Whole Object Recognition (n=1). One study investigated a subcategory of Spatial Judgment, known as Field Dependence.[34]

Instruments

Thirty-four different instruments were used to assess VSA across all 26 studies. No single instrument was used across all studies and only 8 instruments (23.53%) appeared in more than 1 study. They were the Card Rotation Test (n=7), Cube Comparison Test (n=5), Map Planning Test (n=5), PicSOr (n=3), Redrawn Vandenburg and Kuse Mental Rotation Test (n=4), Vandenburg and Kuse Mental Rotation Test (n=4), Gestalt Completion Test (n=2), and Surface Development Test (n=2). The remaining 26 instruments are presented in Table 1. One study used an additional instrument to measure VSA.[35] However, it was excluded from analysis as it measured additional aptitudes including general cognitive ability, verbal ability, and numeric ability.[35]

PicSOr

Three studies included in our analysis used the PicSOr instrument as a measure of VSA.[36–38] It was also used in a fourth study; however, we did not count it in our analysis as the authors used it to measure a construct they explicitly considered separate from VSA.[33]

Different versions of the Mental Rotation tests

We found 3 different versions of the Mental Rotation Test (MRT). They were the Mental Rotation Task derived from the Shepard and Metzler MRT (n=1), the Vandenburg and Kuse MRT (n=4), and the Redrawn Vandenburg and Kuse MRT (n=4). There were 2 subversions of the Redrawn Vandenburg and Kuse MRT, Version A and Version C. Three studies used Version A,[35,39,40] only, and one study used Versions A and C.[41] Two additional studies included a MRT instrument, but did not specify the version used.[34,42]

Discussion

The main objective of this scoping review was to gain insight on the studies exploring the role of VSA in surgical and nonsurgical trainees and determine if there was consensus in the literature regarding critical domains and testing. More specifically, we reported the terminology used to describe VSA, the instruments used to assess VSA, the dimensions of VSA explored, and the VSA training interventions found in the literature. Our review has demonstrated that there is a lack of commonality in both the language and instruments used in the study of VSA. There also appears to be a lack of understanding on the particular VSA domains underlying a particular skill, in addition to a lack of VSA training in general. This lack of consensus toward operationalizing VSA could be problematic in designing and evaluating educational programs and serves as a barrier toward generalizing and applying various study results to different contexts. Hence, the results of our study highlight the need for methodological guidelines to help bring a firm consensus toward operationalizing, studying, and training VSA in medical and surgical education.

VSA in the surgical field

VSA appeared to be of particular significance for the surgical field, as > 90% of publications included a surgery specialty. It is therefore apparent that although surgical and nonsurgical specialties alike may perform visually demanding tasks, the interest in VSA seems focused toward surgery. A possible explanation for this may be the perceived relevance of VSA during routine day-to-day duties. Depending on the specialty and whether apparent VSA-oriented tasks make up a smaller component of daily duties, VSA research may be of less interest. As many of the tasks routinely performed by surgeons seem to directly involve different VSA processes, such as the mental formation of anatomical representations prior to surgical procedures,[12] VSA research may be more germane to surgical specialties.

Fragmented field

A wide array of VSA measures were discovered; however, no single instrument appeared in all of the included articles. We also found a broad base of VSA related terms, with up to 16 different terms being used. Inconsistencies between a term used to describe a VSA-related process and an instrument used for measurement were also discovered, making it difficult to compare results between studies. For example, the PicSOr instrument was used as a measure of VSA in 3 studies,[36–38] but was separated from the VSA measures in a fourth study according to the authors.[33] In addition to the numerous instruments available to assess VSA levels, we also found multiple versions of an instrument, such as the MRT. Moreover, the version used was not always clearly documented, which may negatively impact the rigor and validity of a study. Conflicting findings pertaining to VSA and technical performance have been documented in the literature[26] and they may be explained by this lack of unity in VSA research. Our scoping review suggests that unified guidelines for studying VSA in medicine do not exist.

Dimensions of VSA

Most studies did not specify the dimensions of VSA measured. Although the importance of VSA may be understood by surgical specialties in particular, there may be a lack of insight on the most relevant areas because they are either unspecified or unexplored. A systematic review exploring spatial cognition in minimally invasive surgeries found that the mental rotation test was used significantly,[13] suggesting that mental rotation was one of the most studied dimensions amid the areas explored. Consistent with their results, we found that the different versions of the MRT were among the most prominently used instruments, with mental rotation being among the most documented dimensions. However, less than half of the studies included in this review specified the dimensions measured. Many of the instruments seem to have been selected as a general measure of VSA without taking into consideration the specific dimension of interest. VSA seems to be treated as a singular process, and it therefore becomes difficult to identify the specific relevant processes,[13] which adds to the difficulty of interpreting and comparing results between studies.

VSA training

Although VSA specific training interventions could have promising positive implications for trainees, only 1 study was identified that explored the effects of a VSA training session on technical task performance. Participants in the training condition significantly improved performance on a robotic suturing task, demonstrating that the VSA intervention was easily accessible and time efficient.[24] These results support the notion that VSA-specific training sessions may be promising for surgical education specifically, yet there remains a large gap in the literature. As evidenced by the heterogeneity identified in this review, this may partially be explained by an inadequate understanding of task specific VSA processes.

Suggested model for future research

Our scoping review has demonstrated both the lack of—and necessity for—a unified framework for VSA testing in the surgical field. We have developed a model based on our interpretation of ideas and work found in the literature. We first suggest investigating the following broad mental processes (Fig. 2): (1) *egocentric transformations*, where the self is reoriented to view the environment from an alternate perspective, and (2) *object-based spatial transformations*, where an object is mentally manipulated and the position of the individual remains unchanged.[43] Egocentric transformations have been said to involve the spatial orientation process.[44,45] Consequently, we have categorized *spatial orientation* as a dimension of egocentric transformations in our model. In contrast, processes that describe object-based transformations typically range in their level of complexity.[44,45] We have therefore divided object-based spatial transformations into simple and complex transformations. Simple object-based transformations constitute of a very simple mental operation, while complex object-based transformations include multiple mental operations.[2,44,45] As the name describes, the mental rotation process involves rotating an object mentally and has been depicted as a simpler process.[2,44,45] On the other hand, spatial visualization is typically more complex and comprises of multiple operations.[2,44,45] We have therefore considered the dimensions of simple and complex object-based transformations in our model as mental rotation and spatial visualization, respectively. Both egocentric and object-based transformations should encompass a fair range of processes that may be involved in medical tasks, such as reorienting an organ along an axis (simple object-based; mental rotation), reorienting an organ in a series of mental manipulations (complex object-based; spatial visualization), or viewing it from an alternate perspective (egocentric; spatial orientation).

There are an overwhelming number of instruments said to measure VSA. To prevent further heterogeneity and confusion, we have recommended instruments that align with the above identified VSA dimensions. For spatial orientation, we recommend researchers use the Perspective Taking Spatial Orientation Test.[46] It is an updated version of the spatial orientation test that has demonstrated discrimination from mental rotation tests.[45] The test is available online or as a paper and pencil test. For the dimension of mental rotation, we recommend using the Redrawn Vandenburg and Kuse Mental Rotation test.[47] It is an updated version of the original Vandenburg and Kuse MRT test, providing complete and clear items that had faded over time.[47] We also suggest using version MRT(A) of the test, as the MRT(C) is composed of much more difficult items.[47] We believe the increase in difficulty is unnecessary for the purpose of measuring simple transformations. If researchers plan to measure mental rotation at two points in time, MRT(B) should be used at retest.[47] This version reduces practice effects by presenting identical items from MRT(A) in a different sequence.[47] Finally, we propose measuring spatial visualization using the Paper Folding Test as its purpose aligns with that of complex transformations.[3]

Surgical relevance of proposed model for testing VSA in the surgical field

In egocentric spatial transformations (Fig 3, A), more specifically spatial orientation, the visual field changes. Surgical procedures that appear to involve these processes include fluoroscopic image–guided interventions. In such tasks, the camera presents different views of the anatomy of interest while the patient is stable. For example, in a transcatheter aortic valve replacement, the patient is supine while the fluoroscopy rotates around the target, providing different perspectives of the heart valve. Thus, the perspective of the anatomy and its environment is changing.

In object-based spatial transformations (Fig 3, B), the observer remains static while the object itself is manipulated. These transformations include mental rotation and spatial visualization, which involve rotating an object along an axis and visualizing a series of transformations respectfully. Laparoscopic and open surgical tasks appear to involve these processes. For example, in a laparoscopic cholecystectomy, the camera remains fairly static for a large proportion of the procedure. The gallbladder is manipulated through a series of steps, which include being rotated while the surgeon searches for anatomical landmarks such as the gall duct and artery. Additional manipulations may then occur, such as detaching the gallbladder. In open surgery, the surgeon exposes a target structure. They must visualize the best way to retract the target and/or surrounding tissue to optimize their operative exposure. They must also be able to predict what other structures may be present underneath and around the landmark. Another example would be preoperative surgical planning using CT reconstruction of relevant anatomy. Here, the organ and associated tumor can be rotated to mentally visualize what will be seen and expected in the operating room.

It is very important to note that these processes may overlap in certain procedures. There may be a combination of both egocentric and object-based spatial transformations involved in a procedure, but one may be predominant over the other. For example, although laparoscopic tasks appear to be predominantly guided by mental rotation and spatial visualization, there are instances where the camera may also be moved. Spatial orientation may therefore also be relevant. In addition, the processes involved in a procedure may depend on how the procedure is performed. For example, when a venous or arterial central line placement is performed without an ultrasound, the surgeon must determine the correct angle to properly puncture the vein using landmarks and tactile sensation. This procedure would involve object-based transformations as they are directly observing the anatomy. When it is performed with an ultrasound, a probe is used to illustrate different viewpoints of the vein or artery. These viewpoints are changed until the correct position is reached. Descriptions of each test and examples of relevant surgical tasks are presented in Table 2.

Future directions based on proposed model

Future directions should gather empirical evidence to strengthen the validity of this model and use it to improve commonality in the field. Should researchers want to use additional or alternate instruments, we advise that they provide a rationale outlining their reasoning and choices. We also recommend that they clearly report the dimensions measured and instruments used. By improving commonality in the field, a greater understanding of the processes involved in the procedure of interest can be achieved. This understanding would permit researchers to continue exploring the relationship between VSA training interventions and technical task performance. The efforts to date—although rudimentary—are promising and have demonstrated the potential to improve curricula in a time-efficient manner

Strengths and limitations

Strengths of this study included a comprehensive search strategy that was developed in stages with the help of a health sciences librarian and composed of both MeSH terms and keywords. Well-established guidelines were used to guide our study,[28,29] and all title-abstracts were screened by 2 independent researchers. Limitations included the lack of a quality assessment, which may have provided some measure of the relative merit particularly if many VSA training interventions had been identified. However, it is not common practice in scoping review studies, and like most, our primary goal was to illustrate the landscape of VSA conceptualization in medical and surgical education [28] Hence, quality assessment was excluded from our study. We also did not search the gray literature, and only 1 researcher was involved in full-text screening, where 2 would have been ideal.

Conclusion

In conclusion, this review has identified a growing interest in the field of VSA research. Although VSA appears to be particularly germane to surgical specialties, the relevance of VSA to routine duties may not be unique. A wide variety of VSA terms, dimensions, and instruments were identified, demonstrating fragmentation in the methods used to study VSA. As there have been no formal frameworks or unified guidelines to guide researchers in considering the dimensions of VSA to explore and the instruments to use, we have proposed a model for future VSA research in the medical field. A deeper understanding of the relevant VSA processes could help guide researchers investigating the benefits of VSA targeted training interventions in trainees, with the potential of improving current training paradigms.

Appendix

Search Strategies

Database Name: Ovid Embase+Embase Classic
Platform: Ovid
Database Coverage: 1947 – Present
Date Last Searched: January 13th, 2020

1. Spatial Orientation/
2. Mental* Rotat*.tw,kw.
3. Mental Manipulation.tw,kw.
4. Three-dimensional manipulation.tw,kw.
5. 3D manipulation.tw,kw.
6. 3-D manipulation.tw,kw.
7. Spatial Intelligence.tw,kw.
8. Space perception.tw,kw.
9. visuospatial*.tw,kw.
10. visual spatial*.tw,kw.
11. (visual* adj (skill or skills or ability or abilities or competenc* or knowledge or attribute* ortechnique* or trait* or capacit* or perception* or intelligence* or aptitude* or visuali#ation* or intelligence*)).tw,kw.
12. (spatial* adj (skill or skills or ability or abilities or competenc* or knowledge or attribute* ortechnique* or trait* or capacit* or perception* or intelligence* or aptitude* or visuali#ation* or intelligence* or orientation*)).tw,kw.
13. mental rotation test/
14. visual-spatial ability test/
15. embedded figures test/
16. PicSOr.tw,kw.
17. Pictorial Surface Orientation.tw,kw.
18. Card rotation test*.tw,kw.
19. card rotation task*.tw,kw.
20. Cube comparison test*.tw,kw.
21. Cube comparison task*.tw,kw.

22. mental rotation test*.tw,kw.

23. mental rotation task*.tw,kw.

24. Alice Heim group ability test*.tw,kw.

25. Visualization of Views Test.tw,kw.

26. embedded figures test*.tw,kw.

27. embedded figures task*.tw,kw.

28. space relations test*.tw,kw.

29. resident/

30. residenc*.tw,kw.

31. (Intern or interns*).tw,kw.

32. Resident*.tw,kw.

33. trainee*.tw,kw.

34. postgraduate medical student*.tw,kw.

35. post graduate medical student*.tw,kw.

36. 1 or 2 or 3 or 4 or 5 or 6 or 7 or 8 or 9 or 10 or 11 or 12 or 13 or 14 or 15 or 16 or 17 or 18 or19 or 20 or 21 or 22 or 23 or 24 or 25 or 26 or 27 or 28

37. 29 or 30 or 31 or 32 or 33 or 34 or 35

38. 36 and 37

Database Name: Ovid MEDLINE®ALL

Platform: Ovid

Database Coverage: 1946 – Present

Date Last Searched: January 13^{th}, 2020

1. Visual Perception/
2. Space Perception/
3. Spatial Navigation/
4. Mental* Rotat*.tw,kf.
5. Mental Manipulation.tw,kf.
6. Three-dimensional manipulation.tw,kf.
7. 3D manipulation.tw,kf.
8. 3-D manipulation.tw,kf.
9. Spatial Intelligence.tw,kf.
10. Space perception.tw,kf.
11. visuospatial*.tw,kf.
12. visual spatial*.tw,kf.
13. (visual* adj (skill or skills or ability or abilities or competenc* or knowledge or attribute* ortechnique* or trait* or capacit* or perception* or intelligence* or aptitude* or visuali#ation* or intelligence*)).tw,kf.
14. (spatial* adj (skill or skills or ability or abilities or competenc* or knowledge or attribute* ortechnique* or trait* or capacit* or perception* or intelligence* or aptitude* or visuali#ation* or intelligence*)).tw,kf.
15. PicSOr.tw,kf.
16. Pictorial Surface Orientation.tw,kf.
17. Card rotation test*.tw,kf.
18. card rotation task*.tw,kf.
19. Cube comparison test*.tw,kf.
20. Cube comparison task*.tw,kf.
21. mental rotation test*.tw,kf.
22. mental rotation task*.tw,kf.
23. Alice Heim group ability test*.tw,kf.
24. Visualization of Views Test.tw,kf.

25. embedded figures test*.tw,kf.

26. embedded figures task*.tw,kf.

27. space relations test*.tw,kf.

28. Education, Medical, Graduate/

29. residenc*.tw,kf.

30. (Intern or interns*).tw,kf.

31. Resident*.tw,kf.

32. Trainee*.tw,kf.

33. postgraduate medical student*.tw,kf.

34. post graduate medical student*.tw,kf.

35. 1 or 2 or 3 or 4 or 5 or 6 or 7 or 8 or 9 or 10 or 11 or 12 or 13 or 14 or 15 or 16 or 17 or 18 or19 or 20 or 21 or 22 or 23 or 24 or 25 or 26 or 27

36. 28 or 29 or 30 or 31 or 32 or 33 or 34

37. 35 and 36

Tables

Table 1. Synthesis of Data and Study Characteristics

Article	Study Design	Field	Specialty	VSA Terminology	Instruments	Dimension of VSA
Luko et al, 2019[24]	Experimental Study	Surgical	General Surgery, Gynecology, Urology, Anesthesia, Orthopedics, Otorhinolaryngology, Oral and Maxillofacial surgery	Spatial Skill, Spatial Ability	Vandenburg and Kuse MRT, The Object Perspective Taking Test, The Tower of London Test	MR, Perspective Taking, SP
Nayar et al, 2019[48]	Observational Study	Mixed	-	Visual Spatial Ability, Visual Spatial Aptitude	Spatial reasoning practice test 1 from online source	-
De Witte et al, 2018[49]	Experimental Study	Surgical	-	Spatial Ability	Vandenburg and Kuse MRT, Spatial OrientationTest	SO, MR
Henn et al, 2018[50]	Observational Study	Surgical	General Surgery, Orthopedic Surgery, Plastic Surgery, Pediatric Surgery, Urology, Cardiothoracic Surgery, Neurosurgery, Ophthalmology	Visual Spatial Aptitude, Visual Spatial Ability, Spatial Aptitude	CRT, CCT, MPT	SO, SS

Hinchcliff et al, 2018[51]	Observational Study	Surgical	Obstetrics and Gynecology, General Surgery, Urology	2D–3D Visual SpatialAbility, Visuospatial Perception, Visuospatial Aptitude, Visuospatial Ability, Spatial Perception	CCT, CRT, MPT, Surface Development Test	-
Milam et al, 2018[52]	Experimental Study	Surgical	Cardiothoracic, General Surgery, Neurosurgery, Otolaryngology Head and Neck Surgery, Ophthalmology, Orthopedics, Plastics, Urology, Vascular	Visual- Spatial Processing	Vandenburg and Kuse	MR
Henn et al, 2017[36]	Observational Study	Surgical	-	Perceptual Ability	PIcSOr	-
Louridas et al, 2015[37]	Observational Study	Surgical	General Surgery, Orthopedic Surgery, Urology, Plastic Surgery, Vascular Surgery, Neurosurgery, Cardiac Surgery, Ear Nose and Throat	Visual Spatial Ability, Visual SpatialSkill, 2D–3D Visual SpatialAbility	PicSOr, CCT, CRT	-

Sheikh et al, 2014[34]	Observational Study	Surgical	Cardiothoracic Surgery	Visual Spatial Skill, Spatial Ability	MRT (Unspecified Version), Adapted Purdue Visualization of Views Test, Judgment of Line Orientation Test, Adapted Rod and Frame Test	Spatial Visualization, Spatial Judgement (with a subcategory of field dependence)
Ahlborg et al, 2013[40]	Experimental Study	Surgical	Obstetrics and Gynecology	Visuospatial Ability	Redrawn Vandenburg and Kuse MRT, Subversion A	-
McDonald et al, 2013[32]	Observational Study	Non-Surgical	Internal Medicine	-	BVMT-R	Visual Spatial Learning and Memory
Ahlborg et al, 2012[39]	Observational Study	Surgical	Obstetrics and Gynecology	Visuospatial Ability	Redrawn Vandenbug and Kuse MRT, Subversion A	-
Nugent et al, 2012[53]	Observational Study	Surgical	-	Visual Spatial Aptitude, Visual Spatial Ability	CRT, MPT	-

Nugent et al, 2012[33]	Observational Study	Surgical	-	Visual- Spatial Aptitude, Visual Spatial Ability, Perceptual Ability	CRT, MPT	SO, SS
Smith et al, 2012[54]	Observational Study	Non-Surgical	Anesthesiology	Visuospatial Aptitude, Visuospatial Skill, Visuospatial Ability	Block Design Test, Digit Symbol Substitution Test, Trail Making Test, Pelli-Robson Contrast Acuity Testing	-
Rosenthal et al, 2010[55]	Observational Study	Surgical	-	Spatial Ability, Visual Spatial Ability, Spatial Skill	3-D-Cube Paper-and-Pencil Test of Mental Rotation	-
Langlois et al, 2009[41]	Observational Study	Mixed	Surgery, Anesthesiology, Emergency Medicine, Family Medicine, Internal Medicine	Spatial Ability	Vandenburg and Kuse MRT, Subversion A and C	-
Wanzel et al, 2007[56]	Observational Study	Surgical	-	Visual-Spatial Ability, Visual Spatial Skill	MR Task derived from Shepard and Metzler MRT	MR of Visual Forms

Enochsson et al, 2006[57]	Observational Study	Surgical	-	Visuospatial Ability	CRT	-
Stefanidis et al, 2006[38]	Observational Study	Surgical	-	Visuospatial Ability, Spatial Ability	MPT, Matrix Reasoning, Rey Figure, CRT, CCT, Minnesota, Paper Form Board, PicSOr	SS, Visual Analysis, Visual Problem Solving, Visuomotor, Organization, Visuospatial Processing and Construction Ability, Visual Memory, SO, Spatial Visualization and Manipulation

Information Not Specified (-). BVMT-R, Brief Visuospatial Memory Test-Revised; CRT, Card Rotation Test; CCT, Cube Comparison Test; MPT, Map PlanningTest; MR, Mental Rotation; MRT, Mental Rotation Test; SO, Spatial Orientation; SP, Spatial Planning; SS, Spatial Scanning

Table 2. Descriptions of psychometric instruments, targeted VSA processes, and surgical relevance.

Psychometric Instrument	Description of Task	Description of VSA Process	Surgical Relevance
Perspective Taking Spatial Orientation Test	Participants must draw a line indicating the imagined direction of an object relative to their position. Their position in the task is based on two other objects.	Mentally alter one's viewpoint of an environment.	May be relevant in fluoroscopic image guided interventions, in which the fluoroscopy rotates around the target structure, and venous or arterial central line placement with ultrasound. Example procedures include transcatheter aortic valve implantation, or similar.
Redrawn Vandenburg and Kuse MRT	Participants must select two out of four objects that are the same configuration as a target object. They must do so by mentally rotating the objects along an axis to determine which ones are the same.	Mentally rotate an object along an axis without changing one's position.	May be relevant in laparoscopic procedures, open surgical tasks, and preoperative surgical planning, more specifically when the target structure is rotated. Example procedures include laparoscopic cholecystectomy, laparoscopic colectomy, open heart surgery, tumor resection, or similar.
Paper Folding Test	Participants are presented a folded paper with a hole. They must visualize what it would look like once unfolded. They must do so through a series of mental operations, which include mentally unfolding the paper and imagining the correct location of the holes.	More complex than mental rotation. Includes performing a series of mental operations to determine what an object would look like after the operations are complete.	May be relevant in laparoscopic procedures, open surgical tasks, preoperative surgical planning, and venous or arterial central line placement without ultrasound, more specifically when the target structure is manipulated through a series of steps. Example procedures include laparoscopic cholecystectomy, laparoscopic colectomy, open heart surgery, tumor resection, or similar.

Figures

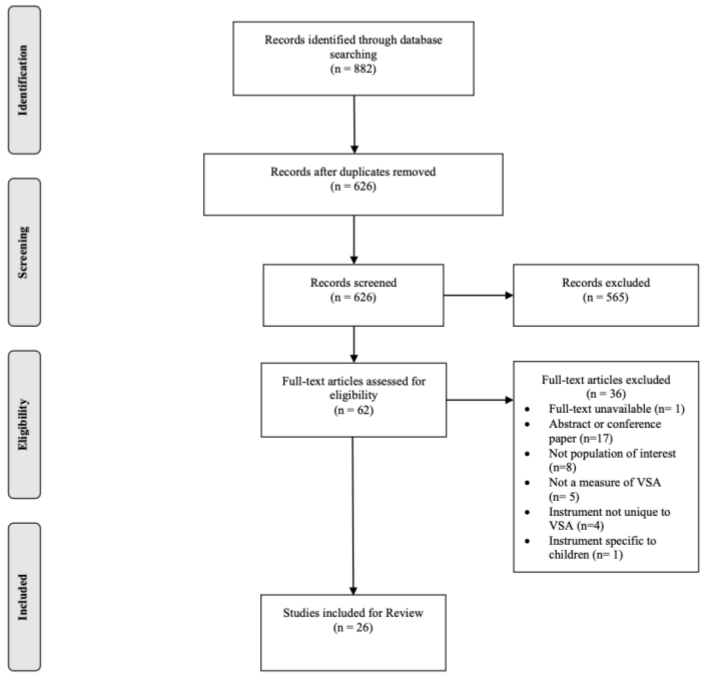

Fig 1. Preferred Reporting Items for Systematic Reviews and Meta-Analyses Study SelectionChart.

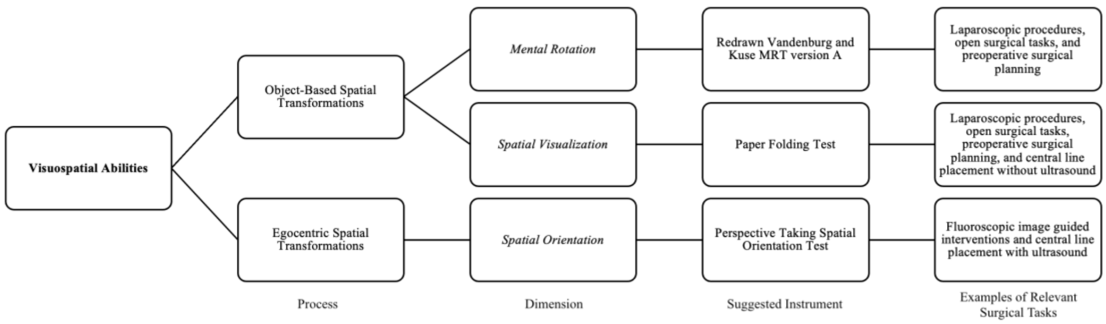

Fig 2. Proposed model for testing VSA in the surgical field.

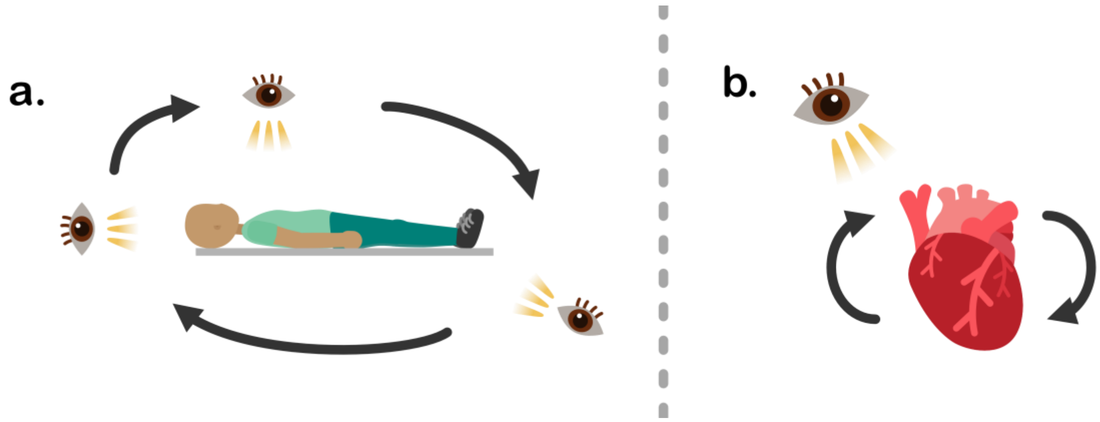

Fig 3. Illustration of (A) egocentric spatial transformations and (B) object-based spatial transformations.

Chapter 6: The status of the field

Our scoping review has revealed inconsistency in the terminology, testing methods, and VSA processes found in VSA research in medical trainees. It also revealed that VSA are much more studied in surgical specialties in comparison to non-surgical medical training specialties. Sixteen different terms were found, 34 instruments were used, and VSA processes were acknowledged in only 10 out of the 26 studies. With such a lack of consistency, it becomes extremely difficult to compare results between studies. It is also difficult for future researchers to be in accord when selecting the appropriate instruments and dimensions to explore. We therefore developed a model for testing VSA—based on our interpretations of work in the field—to help address gaps in guidance.

The model described three VSA processes that are believed to align with a surgeon's daily tasks and proposed an instrument to measure each respective process. The processes included 1. *spatial orientation*, which involves changing one's frame of reference to view an object from an alternative view, 2. *mental rotation*, which involves mentally rotating an object on an axis, and 3. *spatial visualization*, which involves manipulating an object mentally though a series of mental operations. The proposed instruments included 1. the *Perspective Taking Spatial Orientation* test, 2. the *Redrawn* Vandenburg and Kuse Mental Rotation test, and 3. the *Paper Folding test.*

The next step in our hypothesis testing was to determine which VSA processes predict surgical skill. We plan to use the instruments proposed in our model to test VSA and analyze performance on the peg transfer and precision cutting tasks traditionally used in the Fundamentals of Laparoscopic Surgery curriculum in both medical students and residents. Future research will be able to design appropriate training interventions based on the pertinent VSA processes identified with the aid of our model.

Chapter 7: Experimental Study

Introduction

Surgical and medical trainees must learn an array of tasks that require a level of visuospatial ability (VSA). Although there is a positive relationship between the acquisition of technical skill and VSA documented in the literature, there also appears to be inconsistencies reported in this relationship.[14–17,26] In addition, there is little understanding of the exact VSA processes relevant to a particular task.[26] A deeper understanding of this relationship could be beneficial for surgical and medical curricula.

A recent scoping review has revealed a lack of consensus regarding language, instruments, and processes found in the literature exploring VSA in trainees.[58] Multiple instruments, terms, and processes were found in the 26 included articles.[58] The authors concluded that the inconsistent results between studies could potentially be attributed to a lack of consistent operationalization and testing methods.[58] It may also explain the absence of knowledge regarding which VSA processes are relevant for a particular task.[58] The authors proposed a model for testing VSA in the medical and surgical fields. The model suggests testing the spatial orientation, mental rotation, and spatial visualization processes using *the Perspective Taking Spatial Orientation test, the Redrawn Vandenburg and Kuse Mental Rotation test*, and *the Card Rotation test* respectively.[58] The use of this model would permit the field to form a consensus and identify the processes relevant for a particular technical task.[58]

The purpose of the current pilot study was to use the proposed model to examine the relationship between VSA levels and surgical performance in both medical students and residents. An understanding of this relationship would permit us to determine which

VSA processes may be relevant for performing the peg transfer and precision cutting tasks traditionally used in the Fundamentals of Laparoscopic Surgery (FLS) curriculum.

Due to the current COVID-19 pandemic, barriers in recruitment resulted in a very small sample size which did not make it possible to run statistical analyses. We have therefore proposed the following research questions and hypotheses to inform thinking for a full study in the future assuming a fuller sample size. We have examined RQ 1 and 2 with the data collected, but only descriptively. In other words, the questions are the same, but comparisons are made informally rather than with the use of statistical analyses.

Research question 1: Are spatial orientation, mental rotation, and spatial visualization levels statistically significantly different between medical students and residents?

Prior research has suggested that the environment could potentially influence VSA levels.[4] Seeing that residents are exposed to further training than medical students, we have hypothesized that residents would have higher spatial orientation, mental rotation, and spatial visualization levels in comparison to medical students.

Research question 2: Are surgical performance scores on the laparoscopic peg transfer and precision cutting tasks statistically significantly different between medical students and residents?

Although all participants may be a novice to a particular surgical task, we wanted to determine whether residents may have learned transferable skills throughout their training. As such, we have hypothesized that residents would have higher surgical performance scores on the laparoscopic peg transfer and precision cutting tasks in comparison to medical students.

Research question 3: Do (A) medical students and (B) residents' spatial orientation, mental rotation, and spatial visualization processes statistically significantly and positively predict surgical performance on the laparoscopic peg transfer and precision cutting tasks?

Research supports the notion that VSA are involved when performing simulated surgical tasks.[13] We therefore hypothesized that the spatial orientation, mental rotation, and spatial visualization dimensions would each statistically significantly and positively predict surgical performance on the laparoscopic peg transfer and precision cutting tasks for both medical students and residents.

Material and Methods

Participants

This study was approved by the McGill University Intuitional Review Board of the Faculty of Medicine (IRB: A07-E49-20B (20-07-011)). A cross-sectional pilot study was conducted between November 2020 and December 2020 at the McGill University Health Centre Glen Site. All medical students and residents from McGill University were eligible to participate. Participants were recruited via a convenience sampling technique, in which emails were sent out to student groups describing the study and inviting them to participate. Participation was completely voluntary. Challenges in recruitment were faced due to the COVID-19 pandemic, resulting in a small sample size, which included: (1) being unable to recruit in-person as originally planned, (2) being unable to test participants at the originally planned location due to their respective COVID-19 protocols

(3) being unable to schedule a participant if they had no other reason to be at the location of study, and (4) reduced availabilities of the population in question due to the COVID-19 pandemic. All safety measures in place were described to participants and were strictly observed in the study.

VSA instruments

The VSA instruments were selected based on the model for testing VSA in the surgical field.[58] The model proposed three psychometric instruments to obtain a holistic view of one's VSA levels while also forming consensus in the field.

The Perspective Taking Spatial Orientation test was used to measure spatial orientation, which involved changing one's perspective to visualize an object from an alternate perspective.[45,46] The paper-and-pencil version was used. Participants had to draw a line indicating the imagined direction of an object relative to their position.[46] They had a total of five minutes to attempt 12 items. Items were scored based on the instructions provided in the psychometric resources.[59] Since a smaller score meant a more accurate performance, the final score was reversed by subtracting it from 100 so that a higher value meant greater performance. This permitted us to average all VSA scores.

The Redrawn Vandenburg and Kuse Mental Rotation test was used to measure mental rotation, which involved mentally rotating a three-dimensional object along an axis.[47] The test was administered per the testing kit instructions. The items involved selecting two out of four objects that matched a specific object by mentally rotating it along an axis.[47] There were two sections with 12 items each and participants had three minutes to complete each section. Items were scored using the one-point-per-item scoring system described in the instruction manual.

The Paper Folding test was used to measure spatial visualization, in which each item required a series of object-based mental transformations.[3] It was administered according to the instructions in the testing manual. Participants had to visualize what a folded paper with a punched hole would look like unfolded.[3] There were two sections with ten items each. Participants had three minutes to complete each section. Scoring followed the instructions provided in the testing manual, in which a portion of the number of incorrect answers was subtracted from the number of correct answers. Since the exact proportion was not found in the instruction manual, an arbitrary proportion of 0.25 was used for simplicity.

Simulated surgical tasks

The simulated surgical tasks selected for this study included the peg transfer task and precision cutting task traditionally used in the FLS Curriculum. Tasks were selected on the basis that they were challenging enough to show discrimination between different levels of expertise yet could still be performed by all participants including those who were surgically naïve.[60] Additionally, the surgical tasks were not selected for teaching or certifying FLS. They were selected with the interest of obtaining scores on simulated surgical tasks using FLS related tasks, as seen in the literature.[61–64] In accordance with these studies, not all tasks found in the FLS curriculum were performed, and tasks were used as a measure of surgical performance. However, our study compared surgical performance to the VSA processes described by the model for testing VSA in the surgical field.[58] Performance on the FLS related tasks was graded using a derivative of the FLS scoring system proposed by Dr. Gerald Fried. Scoring for both tasks therefore followed the guidelines presented in the official FLS instructions manual, with a generic score of

25s applied for penalties (as the actual time assigned for penalties in the FLS exam is confidential information).

Both tasks were performed using a box trainer. The *peg transfer task* involved using two Maryland dissectors to transfer a total of six pegs from one side of the board to the other, and back.[65] The *precision cutting task* involved using a Maryland dissector and a pair of endoscopic scissors to cut a marked circle from the gauze. In lieu of the traditional one-circle gauze used in the FLS curriculum, the training version was used to ensure all participants would be able to perform the task. Participants had a total of 300 seconds to complete each task, or else they would automatically fail. Performance was recorded using a video capture device and scored using a video-based assessment approach. All files were named using the participant's ID only and had no other identifiers. Time to completion in seconds, considering any penalties as outlined in the official FLS instructions manual, was used as a measure of performance.

Safety measures followed during the COVID-19 pandemic

Participants were recruited at the McGill University Health Centre Glen Site during the COVID-19 pandemic. University and hospital regulations and policies were followed, which included informing participants of all safety measures in place, ensuring all parties involved wore a mask, disinfecting all instruments and surfaces prior to and after each experiment, and always maintaining a 2-m distance between the researcher and participant. Hand sanitizer was also readily available and had to be used upon entry into the room.

Data collection

All surfaces and instruments were disinfected prior to the participant's arrival. After all safety measures outlined above were implemented and consent was obtained, participants filled out a demographics form which included questions regarding their gender, educational background, handedness, past experiences with FLS tasks, and past experiences with surgical procedures. Once completed, they performed the Perspective Taking Spatial Orientation Test, the Redrawn Vandenburg and Kuse Mental Rotation Test, and the Paper Folding Test respectively to assess levels of VSA. The following phase was the peg transfer and precision cutting tasks. A standardized video was then shown prior to each task, which explained the procedure. Participants were asked if they had any questions and were able to familiarize themselves with the instruments at their own pace. Once ready, the timing commenced, and they had five minutes to complete the task. After the two simulated surgical tasks were completed, they were asked if they had any questions and were thanked for participating. All surfaces and instruments were then disinfected.

Data analysis

Microsoft Excel was the software used for data analysis. Due to the extremely small sample size, only descriptive statistics (i.e., means and standard deviations) were computed.

Preliminary results

Population

A total of four participants volunteered for this study (see Table 1 for demographics). Two were medical students (mean age = 23.5, SD = 0.71) and two were residents (mean age = 29, SD = 4.24). There was a total of two females and two males.

All residents were enrolled in a surgical specialty, which included Plastic and Reconstructive Surgery and Obstetrics and Gynecology. Residents reported prior surgical experience which may have included laparoscopic surgery experience, but not prior FLS experience. One medical student was in their first year of study and the other was in their fourth year of study. Medical students reported no prior surgical or FLS experience. Due to insufficient sample size, we could not run any statistical tests. We instead presented descriptive statistics including means and standard deviations. Although calculating means with a sample size of two was not ideal, we felt it was the best approach given the circumstances and our research objectives. A planned analysis outlining the appropriate statistical analysis given a fuller sample size follows in the discussion section of this chapter.

RQ1: Are spatial orientation, mental rotation, and spatial visualization levels statistically significantly different between medical students and residents?

Mean scores on the spatial orientation, mental rotation, and spatial visualization tasks are presented in Table 2. Although an independent samples t-test would have been the appropriate statistical test, a comparison of means was instead conducted. Medical students (Redrawn MRT mean = 53.69, SD = 11.11; PFT mean = 63.13, SD = 6.19; PTSOT mean= 89.27, SD = 1.91; Overall Score mean = 68.69, SD = 7.42) appeared to outperform residents (Redrawn MRT mean = 43.75, SD = 20.62; PFT mean = 56.88, SD = 9.72; PTSOT mean= 79.58, SD = 12.67; Overall Score mean = 60.07, SD = 15.06) in every VSA test. Data is illustrated in Figure 1. Statistical significance testing of these mean comparisons could not be made due to the small sample size.

RQ2: Are surgical performance scores on the laparoscopic peg transfer and precision cutting tasks statistically significantly different between medical students and residents?

Mean surgical performance scores on the peg transfer and precision cutting tasks are shown in Table 3. Although an independent samples t-test would have been the appropriate statistical test, a comparison of means was instead conducted. A higher score indicates a faster time to completion and fewer potential errors. Regarding the peg transfer task, residents had an overall higher average score (mean = 116.5, SD = 86.97) in comparison to the medical students (mean = 56.5, SD = 41.72). All participants in this study failed the precision cutting task. Data for the peg transfer task is represented in Figure 2. Statistical significance testing of these mean comparisons could not be made due to the small sample size.

RQ3: Do (A) medical students and (B) residents' spatial orientation, mental rotation, and spatial visualization processes statistically significantly and positively predict surgical performance on the laparoscopic peg transfer and precision cutting tasks?

The appropriate statistical tests to answer the research question would have been multiple regression analyses where spatial orientation, mental rotation, and spatial visualization were entered as predictor variables and laparoscopic peg transfer or precision cutting tasks were entered as the dependent variable. These two multiple regressions would have been run for medical students and residents, separately. Since this was not possible, a comparison of means between the spatial orientation, mental rotation, and spatial visualization scores and surgical performance on the peg transfer task was conducted for both medical students and residents. The precision cutting task was not included in the analysis since all participants received a score of zero.

Medical Students

Descriptive statistics (means) revealed that higher MRT and PFT scores were associated with lower peg transfer scores for medical students (Table 4 and Table 5; Fig. 3 and 4). Medical students that scored higher on the PTSOT appeared to also score higher peg transfer task (Fig. 5). Finally, medical students that had a higher overall VSA score had a lower peg transfer score (Fig.6). Statistical significance testing of these mean comparisons could not be made due to the small sample size.

Residents

Amongst residents, higher scores on the MRT and PFT tests were associated with higher surgical task scores (Table 6 and Table 7; Fig. 3 and 4). Residents that scored higher on the PTSOT appeared to score lower on the peg transfer task (Fig. 5). Residents that had a higher overall VSA score seemed to have a higher peg transfer score (Fig.6). Statistical significance testing of these mean comparisons could not be made due to the small sample size.

Discussion

The purpose of this pilot study with currently available data was to conduct a preliminary investigation of the dimensions of VSA that may be involved when performing the peg transfer and precision cutting tasks in medical students and residents using the model for testing VSA in surgical research.[58] Due to the small sample size resulting from the current COVID-19 global pandemic, significance testing using either parametric or non-parametric statistics could not be conducted. Only descriptive statistics were computed in order to examine preliminary mean differences. Therefore, conclusions could not be made on the statistical significance of the results but were instead used to provide insight for future studies.

VSA scores

The mean score on all VSA tests was higher for medical students in comparison to residents. Should the direction of these results be supported with a larger sample size and statistically significant differences in future research, our hypothesis that experience such as residency training improves VSA levels would be rejected. A possible explanation for this potential finding could be that the traditional training experienced by residents does not play a significant role in improving VSA levels. A recent systematic review from 2020 found that VSA scores were improved by specific courses, such as abdominal sonography, but not from the general surgery curriculum.[23] This suggests that only certain specialties may be exposed to tasks that may improve their VSA levels. These results would further reinforce the importance of designing and integrating VSA training into surgical curriculums, especially in early training.

Surgical performance

Residents had an overall higher mean score in comparison to medical students on the peg transfer task. All participants failed the precision cutting task. Our hypothesis that residents would have higher surgical performance scores in comparison to medical students would be accepted if the direction of these results would be supported with a larger sample size and statistically significant differences in future research. A possible explanation for this potential finding could be explained by experience. Although all participants reported no past FLS related performance, residents did report past surgical performance which may have included laparoscopic tasks. They may have learned skills from their prior experiences (i.e., familiarity with the instruments and previously learned strategies) and transferred them to the peg transfer task. However, seeing that all participants failed the precision cutting task, perhaps a better indication of their performance would be obtained through a learning or retention curve instead of a single trial.

Relationship between VSA scores and surgical performance

Statistical predictions (e.g., using multiple regression analyses) on the relationship between VSA scores and surgical performance could not be made due to the low sample size and lack of statistical analysis. However, when comparing mean differences, it appeared that medical students that scored higher on the MRT and PFT tests scored lower on the surgical task. The opposite was observed for the PTSOT. This was also apparent in residents. However, an inverse comparison was observed, in which higher MRT and PFT scores resulted in higher surgical task scores, and higher PTSOT scores observed lower surgical performance. A consideration that can be drawn from these observations is that different aspects of VSA may be differently associated with performance. This relationship may be dependent on whether VSA is involved in a particular task. The literature has reported inconsistencies in the relationship between VSA and technical performance.[26] A recent scoping review showed a lack of consistency in psychometric instruments used and dimensions explored.[58] It seems that most studies do not take into account the particular processes involved, making it difficult to compare results. As seen in this pilot study, not all dimensions may be involved in a task and may help explain these inconsistencies. Preliminary findings reinforce the importance of applying the proposed model so that future results can be more easily compared, and inconsistencies between studies can be reduced. We therefore strongly suggest that future studies utilize the proposed model for testing VSA in surgical research.

Strengths and limitations

Strengths included the selection of psychometric instruments based on a model for testing VSA in surgical research, which contributed to establishing consistency in the field. It also allowed for a holistic assessment of the participant's VSA levels. Due to the pandemic, a convenience sampling was pursued to pilot the study, though this further limited comparisons between residents and medical students. Limitations also included a very small sample which provided insufficient power for running statistical analyses as well as calculating means based on a sample size of two per resident and medical student groups. These preliminary results may therefore be unrepresentative of the actual populations and are difficult to interpret as these emerging trends may change if re-computed with a larger sample size. Although available analyses were not ideal, they were the best approaches to answer or approximate answering the questions of interest given the circumstances. This pilot study therefore represented a template for our future study when more participants will be available, and we will be able to run more robust statistical analyses. An additional limitation was having one trial for the technical task. Including only one trial for the surgical tasks may be an efficient approach only if time is scarce for the population of interest. However, performance may be impacted by factors other than VSA (i.e., unfamiliarly with task and instruments) and the single-trial may therefore not be representative of the participant's true potential.

Future directions

First and foremost, future directions should include running the study with a larger sample size when circumstances permit. This would provide enough statistical power to run inferential statistics and make meaningful interpretations. Secondly, more than one trial for the surgical task should be performed, especially if the population are novices. In such a case, a learning or retention curve could be generated and would illustrate a more accurate picture of trainees' performance. At the very least, researchers should consider multiple trials in which the best score is taken if time is scarce. Thirdly, additional demographic information can be obtained to capture hobbies that may impact participant's VSA levels, such as videogame experience or musical skills. It would also be more appropriate to collect a larger sample from a single group with either surgical residents or novices without surgical backgrounds. The value of using novices would include their accessibility and their limited experience with surgical tasks, since VSA is not unique to surgical performance. Finally, future directions can also explore the predictive relationship between VSA and surgical performance in other surgical tasks. This would allow the field to gain greater knowledge on which processes are relevant in multiple surgical tasks.

Planned analysis for future study

For a future study, we are planning on targeting one of these groups (medical students or residents) and not both to have a fuller sample as soon as the pandemic allows. We would plan to recruit ten participants per predictor variable level (three dimensions of VSA) for a total sample size of 30 (e.g., 10 x 3) in order to achieve sufficient power. With a sample size of 30, we would revisit research question 3 presented in this pilot study. We would run two multiple regression analyses to analyze the predictive relationship between visuospatial levels (independent variables; spatial orientation, mental rotation, and spatial visualization) and performance on the two surgical tasks (dependent variables; peg transfer task and the precision cutting task). Should a future study allow us to include a second group we could answer research questions 1 and 2. For RQ 1, we would suggest running an independent samples t-test to determine if there are any significant differences in spatial orientation, mental rotation, and spatial visualization levels between medical students and residents. For RQ 2, we would also recommend an independent samples t-test to determine if there are any significant differences in surgical performance on the laparoscopic peg transfer and precision cutting tasks between medical students and residents.

Conclusion

This pilot study was the first step in determining which of the VSA processes are involved in the peg transfer and precision cutting tasks in medical students and residents. Although statistical analyses were not possible due to the small sample size, this pilot study served as a template for future research to be conducted when restrictions subside, and it is possible to resume data collection. With further research on the topic, a greater understanding of the relevant dimensions of VSA could be achieved and used to design time and cost-efficient VSA training programs.

Tables

Table 1. Participant demographics		
Variable	Medical Students *n* = 2	Residents *n* = 2
Age, mean (SD), y	23.5 (0.71)	29 (4.24)
Gender		
Male	1	1
Female	1	1
Other	0	0
Handedness		
Left	0	1
Right	2	1
Medical Student		
Yr 1	1	0
Yr 2	0	0
Yr 3	0	0
Yr 4	1	0
Resident		
PGY-1	0	2
Specialty		
Obstetrics and Gynecology	0	1
Plastic and Reconstructive Sx	0	1
Prior Surgical Experience		
Yes	0	2
No	2	0
Prior FLS Experience		
Yes	0	0
No	2	2

Table 2. Mean and standard deviation of VSA scores in medical students and residents

	Medical Students *n* = 2		Residents *n* = 2	
VSA Test	Mean	Standard Deviation	Mean	Standard Deviation
Redrawn MRT	53.69	11.11	43.75	20.62
PFT	63.13	6.19	56.88	9.72
PTSOT	89.27	1.91	79.58	12.67
Overall Score	68.69	7.42	60.07	15.06

Table 3. Mean and standard deviation of surgical scores in medical students and residents

	Medical Students *n* = 2		Residents *n* = 2	
Surgical Task	Mean	Standard Deviation	Mean	Standard Deviation
Peg Transfer	56.5	41.72	116.5	86.97
Precision Cutting	0	0	0	0

Table 4. Raw VSA scores for medical students

	Medical Students $n = 2$	
VSA Test	Participant 1	Participant 2
Redrawn MRT	61.54	45.83
PFT	67.50	58.75
PTSOT Inversed	87.92	90.62
Overall Score	73.32	65.07

Table 5. Raw surgical performance scores for medical students

	Medical Students $n = 2$	
Surgical Task	Participant 1	Participant 2
Peg Transfer	27	86
Precision Cutting	0	0

Table 6. Raw VSA scores for residents

	Residents $n = 2$	
VSA Test	Participant 1	Participant 2
Redrawn MRT	29.17	58.33
PFT	50.00	63.75
PTSOT Inversed	88.54	70.62
Overall Score	55.90	64.23

Table 7. Raw surgical performance scores for residents

	Residents $n = 2$	
Surgical Task	Participant 1	Participant 2
Peg Transfer	55.00	178
Precision Cutting	0	0

Figures

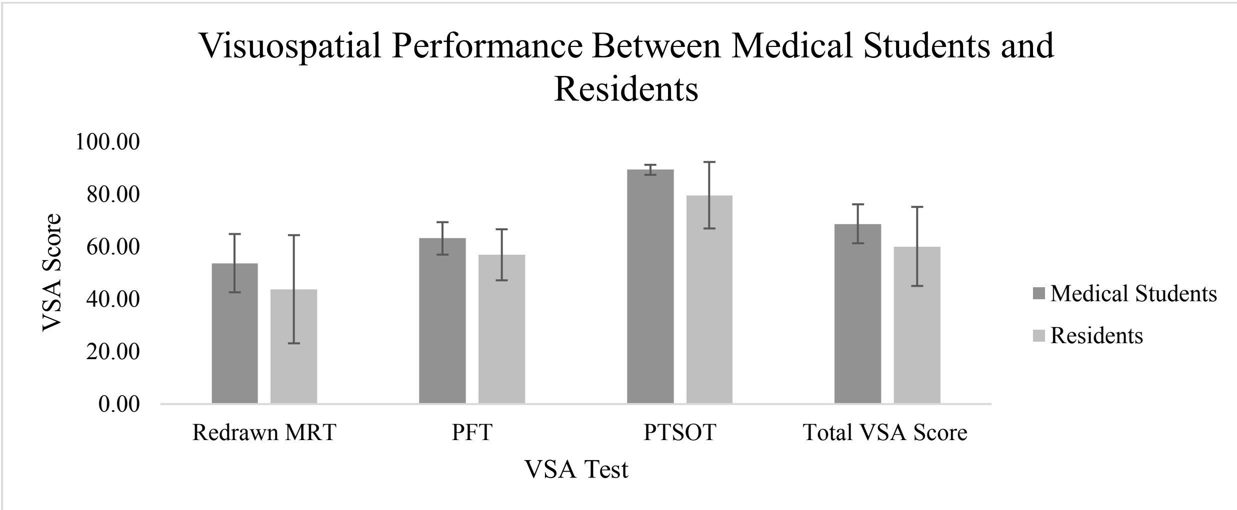

Figure 1. Mean VSA scores (+ SD) of medical students and residents on different psychometric tests. N = 2 per group

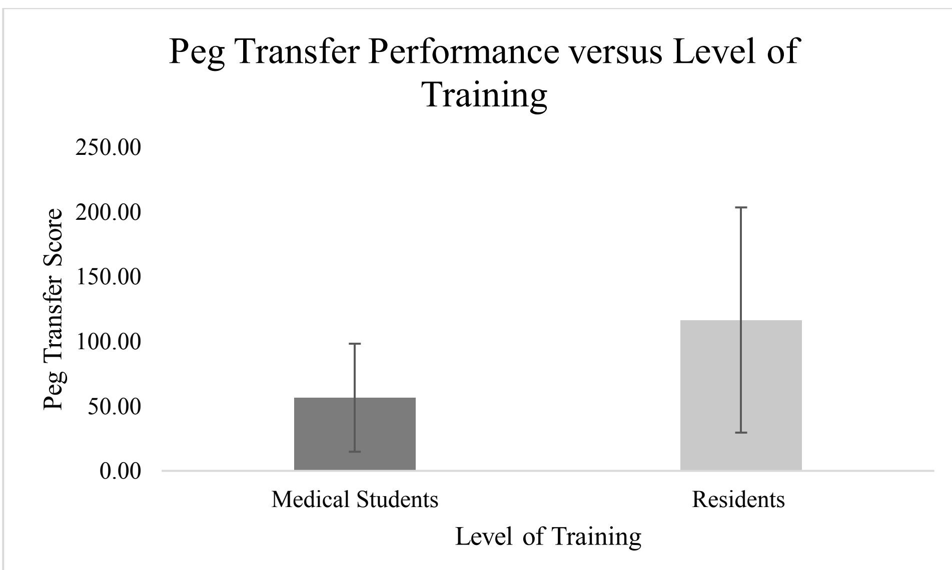

Figure 2**.** Mean peg transfer score (+ SD) of medical students and residents. N = 2 per group.

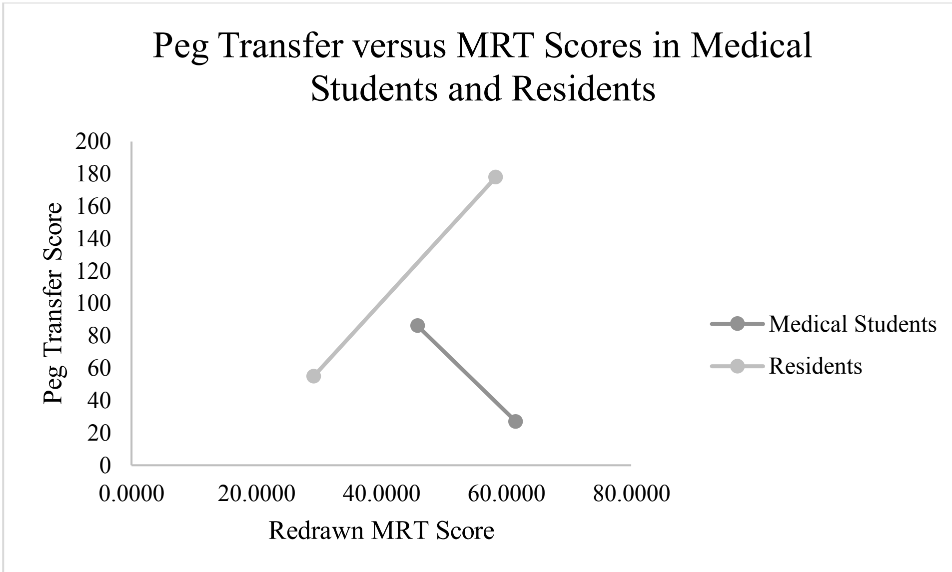

Figure 3. Relationship of redrawn MRT score with peg transfer score in medical students and residents. Each circle represents a single participant.

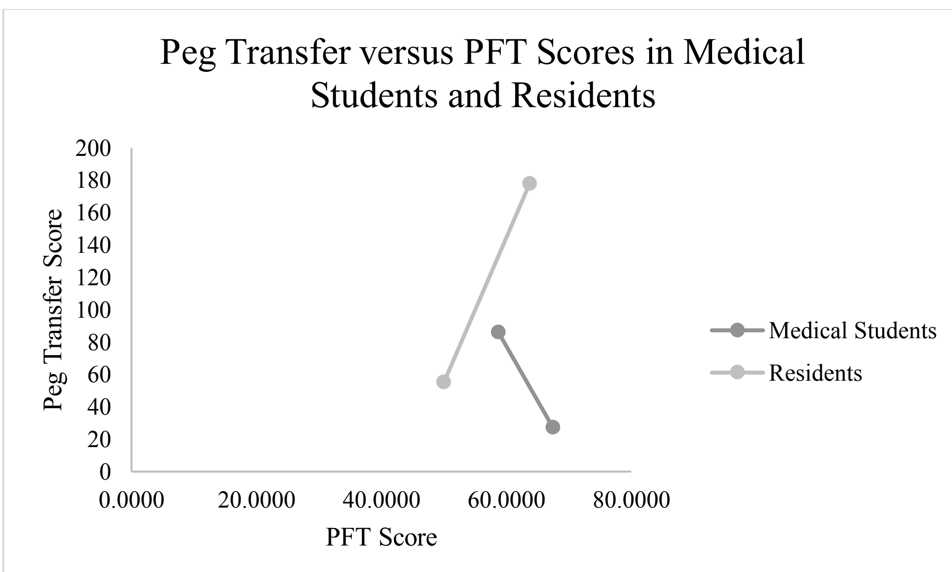

Figure 4. Relationship of PFT score with peg transfer score in medical students and residents. Each circle represents a single participant.

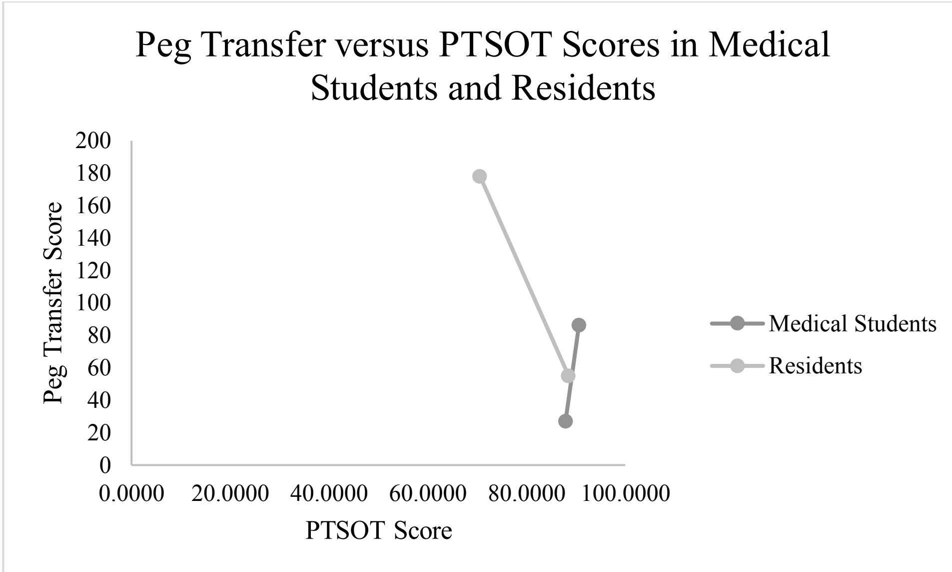

Figure 5. Relationship of PTSOT score with peg transfer score in medical students and residents. Each circle represents a single participant.

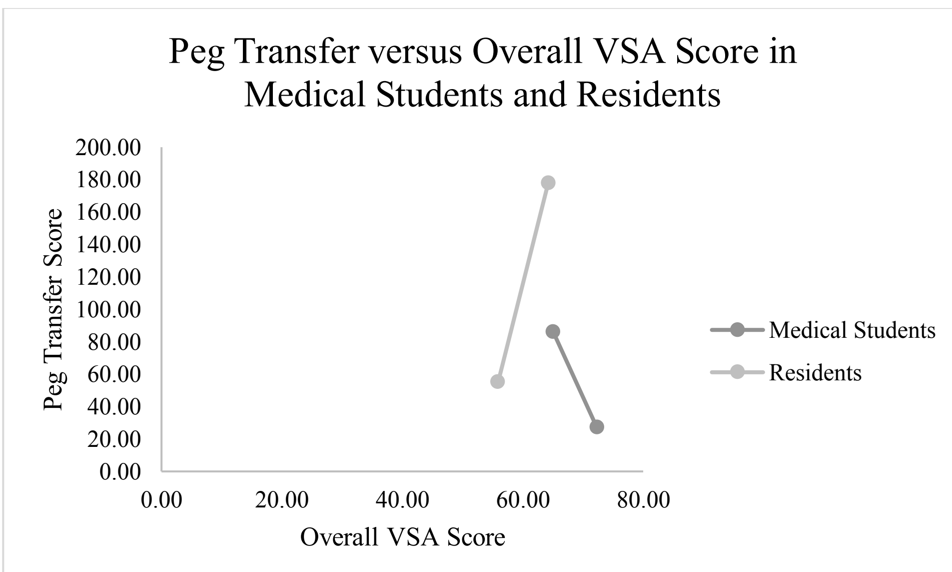

Figure 6. Relationship of overall VSA score with peg transfer score in medical students and residents. Each circle represents a single participant.

Chapter 8: Thesis Conclusion

Summary

This thesis provides a landscape of VSA research in the surgical field, including an overview of the testing methods, operationalization of VSA, and training interventions found in the literature. It also proposes a model for testing VSA in future surgical research and applies that model to a pilot study.

Although VSA may play an important role in technical skill acquisition for surgical tasks, a misunderstanding of the relevant VSA processes coupled with inconsistent results in the literature has been reported. The first objective of this thesis was to provide an overview of the field through a structured literature review by documenting the psychometric tests, terminology, dimensions, and training interventions found in the literature. Twenty-six articles were included. A total of 34 psychometric instruments were identified and not one was used in all studies. Sixteen different VSA terms were identified, and 16 studies failed to mention the specific VSA processes being investigated. Only one study explored the effects of VSA training. The inconsistencies found in the literature made it difficult to understand which processes are relevant to a surgical task since results between studies were harder to compare.

In order to increase consistency in future research, we completed our second objective which was to propose a model for testing in the field of surgery. A model for future research was proposed in hopes of rectifying these inconsistencies. This model used interpretations of previous work to suggest the VSA processes that aligned with the surgical field. An instrument for each process was also proposed. The use of this model would not only improve consistency in the field but also permit researchers to determine which processes of VSA are relevant for surgeons and should therefore be trained.

Without an adequate understanding of these processes, it becomes difficult to design time and cost-efficient interventions. Residents are very busy; designing a training module that would include training irrelevant processes would become inefficient.

The third objective of this thesis was to apply the model to a pilot study. We wanted to determine whether the spatial orientation, spatial visualization, and mental rotation processes were involved in the peg transfer and precision cutting tasks in medical students and residents. An experimental study was designed, and ethical approval was obtained. However, barriers regarding recruitment and data collection were faced due to the current COVID-19 pandemic. We collected data from a very small sample of four participants: two medical students and two residents. No statistical analyses were possible due to this small sample size and the results were therefore presented as mean comparisons. Medical students had higher VSA scores in comparison to residents and residents had higher scores on the surgical tasks compared to medical students. Predictions could not be made regarding the relationship between VSA and surgical skill. Improvements in the study design were proposed for future studies. Although we could not draw significant conclusions from our pilot study, it did help inform us on how we would proceed in a future study.

Although the aggregate of our findings does not fully answer our hypothesis that visuospatial abilities are fundamental to surgical skill and can be learned through training, it is definitely a start in the right direction. By correcting the inconsistencies found in the field of surgery, future studies will be comparable, and this will enable researchers to determine which processes of VSA are or are not relevant for surgeons. A greater understanding of the relevant subcomponents would be determined and used to inform the design of future VSA training interventions. Should they be trainable, not only would our hypothesis be confirmed but these results would have the potential to greatly contribute to residency training programs.

Future research

Future research should continue to use the proposed model when testing VSA in the surgical field. The use of the proposed model will help future research achieve uniformity and avoid additional discrepancies between studies. In addition, the pilot study presented in this thesis would need to be reproduced with a larger sample size to run statistical analyses and draw (potentially) statistically significant conclusions. Researchers should also consider incorporating a learning or retention curve, or at the very least multiple trials for the surgical task. This would help control for potential effects caused by the unfamiliarity of the instruments and task, as well as permit researchers to obtain a greater idea of one’s performance. The collective of these suggestions would permit researchers to further understand the relationship between individual VSA processes and technical performance. This knowledge would allow for the creation of a VSA training, which has the potential to greatly benefit residency programs.

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