Surgery Open Science 5 (2021) 25–33

Contents lists available at ScienceDirect

Surgery Open Science

journal homepage: https://www.journals.elsevier.com/surgery-open-science

Research review

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

Meagane Maurice-Ventouris, BSc [a], Hellmuth R. Muller Moran, MD [a,b], Mohammed Alharbi, MD [a], Byunghoon Tony Ahn, MEd [a], Jason M. Harley, MA, PhD [a,c], Kevin J. Lachapelle, MDCM, FACS, FRCPSC [a,*]

[a] *Department of Surgery, McGill University, Montreal, Canada*
[b] *Department of Surgery, University of Manitoba, Winnipeg, Canada*
[c] *Research Institute of the McGill University Health Centre, Montreal, Canada*

ARTICLE INFO

Article history:
Received 1 March 2021
Received in revised form 4 May 2021
Accepted 6 May 2021
Available online 12 May 2021

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.
Conclusion: 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.

INTRODUCTION

Visuospatial abilities (VSAs) are important for both surgical- and non–surgical-related tasks, such as laparoscopic interventions and the interpretation of medical imagery [1]. A positive relationship between VSA and technical performance has been reported in the literature [1–5]. In addition, longer learning curves have been observed during laparoscopic suturing [2] and appendectomy [3] 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 nonsurgical specialties.

Although the literature has shown an overall a positive relationship between VSA and technical performance, discrepancies in this relationship have also been reported [6]. A multitude of terms, conflicting definitions, and instruments have been used to describe and measure related visual and spatial processes in the literature [7,8]. 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 [6]. 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 nonsurgical specialties. We have explored these components by conducting a scoping review. Scoping reviews, like systematic reviews,

---

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.

[*] Corresponding author at: Division of Cardiac Surgery, Glen Campus, The Royal Victoria Hospital, 1001 Decarie Blvd, Block C, C07.1284, Montreal, Quebec, H4A 3J1. Tel.: +1 514 934 1934x36873; fax: +1 514 843 1602.
E-mail address: kevin.lachapelle@mcgill.ca (K.J. Lachapelle).

https://doi.org/10.1016/j.sopen.2021.05.001

use structured guidelines to synthesize information [9]. However, they are designed to illustrate the landscape of the literature toward a topic, as opposed to systematically narrow down specific studies to assess their quality and implications [9]. Although 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 [9]. As such, this scoping review seeks to gain insight on the studies exploring the role of VSA in surgical and nonsurgical 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 [10]. The Preferred Reporting Items for Systematic reviews and Meta-Analyses extension for Scoping Reviews (PRISMA-ScR) checklist was also consulted [11].

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 nontrainees. 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 (ie, 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 2 stages. In the first stage, a preliminary literature review using basic keywords related to VSA and health care (ie, 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 13, 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) [12]. 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, nonsurgical, 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 1 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 (ie, 2010) was 61.54% ($n = 16$). The study types comprised of observational studies ($n = 21$) and experimental studies ($n = 5$). Only 1 study introduced a VSA training intervention [13].

The field of the trainees investigated were surgical ($n = 21$; 80.76%), nonsurgical ($n = 2$; 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 anesthesia [13]. Because the authors considered their population surgical and not mixed, they were marked accordingly for consistency. Because obstetrics and gynecology residents are classified as a surgical speciality by the Royal College of Physicians and Surgeons of Canada [14], 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, whereas 14 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 [15]. 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 [16].

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 Judgment ($n = 1$), 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 [17].

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 [18]. However, it was excluded from analysis because it measured additional aptitudes including general cognitive ability, verbal ability, and numeric ability [18].

PicSOr

Three studies included in our analysis used the PicSOr instrument as a measure of VSA [19–21]. It was also used in a fourth study; however, we did not count it in our analysis because the authors used it to measure a construct they explicitly considered separate from VSA [16].

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 [18,22,23] only, and 1 study used Versions A and C [24]. Two additional studies included a MRT instrument but did not specify the version used [17,25].

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

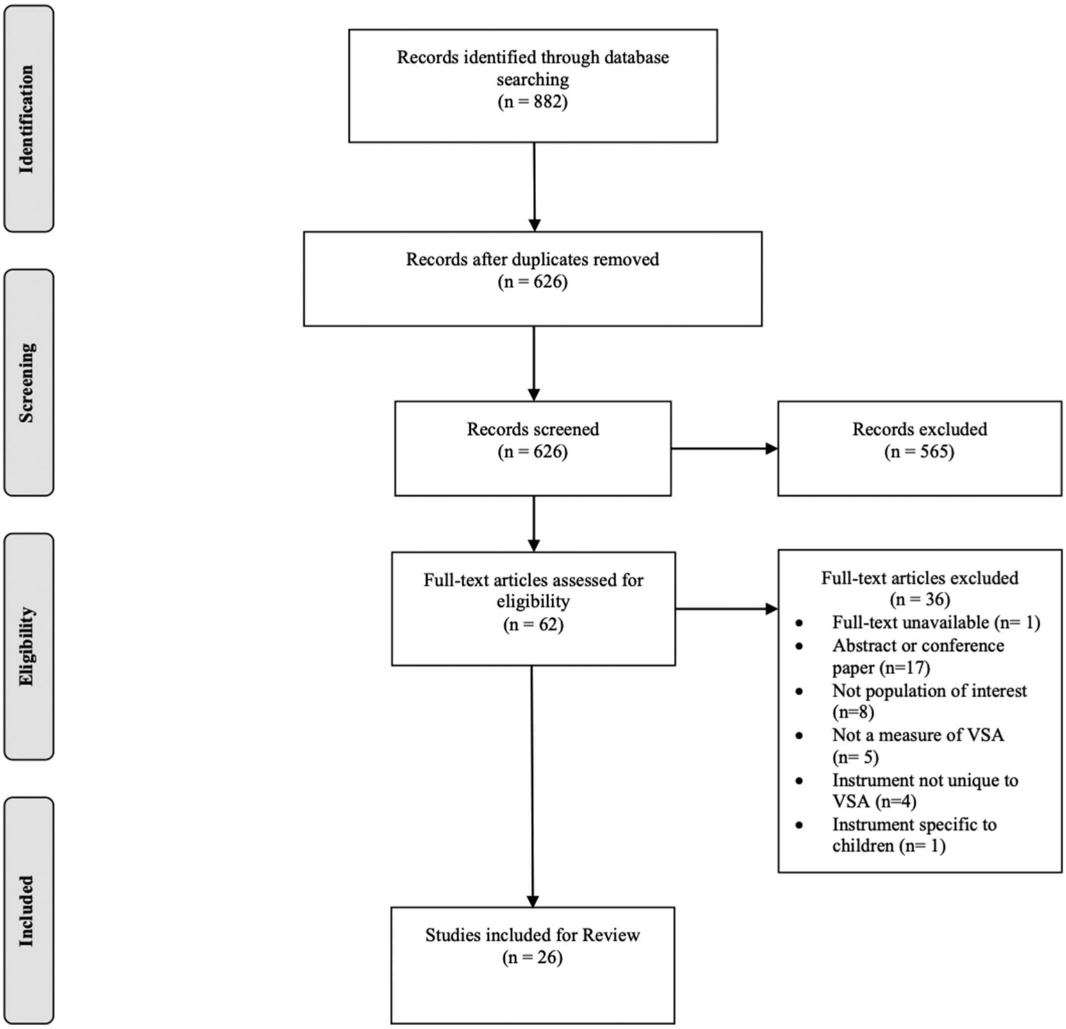

Fig 1. Preferred Reporting Items for Systematic Reviews and Meta-Analyses Study Selection Chart.

Table 1
Synthesis of data and study characteristics

Article	*Study type*	*Field*	*Specialty*	*VSA terminology*	*Instruments*	*Dimension of VSA*
Luko et al, 2019 [13]	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 [34]	Observational study	Mixed	–	Visual Spatial Ability, Visual Spatial Aptitude	Spatial reasoning practice test 1 from online source	–
De Witte et al, 2018 [35]	Experimental study	Surgical	–	Spatial Ability	Vandenburg and Kuse MRT, Spatial Orientation Test	SO, MR
Henn et al, 2018 [36]	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 [37]	Observational study	Surgical	Obstetrics and Gynecology, General Surgery, Urology	2D–3D Visual Spatial Ability, Visuospatial Perception, Visuospatial Aptitude, Visuospatial Ability, Spatial Perception	CCT, CRT, MPT, Surface Development Test	–
Milam et al, 2018 [38]	Experimental study	Surgical	Cardiothoracic, General Surgery, Neurosurgery, Otolaryngology Head and Neck Surgery, Ophthalmology, Orthopedics, Plastics, Urology, Vascular	Visual–Spatial Processing	Vandenburg and Kuse MRT	MR
Henn et al, 2017 [19]	Observational study	Surgical	–	Perceptual Ability	PIcSOr	–
Louridas et al, 2015 [20]	Observational study	Surgical	General Surgery, Orthopedic Surgery, Urology, Plastic Surgery, Vascular Surgery, Neurosurgery, Cardiac Surgery, Ear Nose and Throat	Visual Spatial Ability, Visual Spatial Skill, 2D–3D Visual Spatial Ability	PicSOr, CCT, CRT	–
Sheikh et al, 2014 [17]	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 Judgment (with a subcategory of field dependence)
Ahlborg et al, 2013 [23]	Experimental study	Surgical	Obstetrics and Gynecology	Visuospatial Ability	Redrawn Vandenburg and Kuse MRT, Subversion A	–
McDonald et al, 2013 [15]	Observational study	Nonsurgical	Internal Medicine	–	BVMT-R	Visual Spatial Learning and Memory
Ahlborg et al, 2012 [22]	Observational study	Surgical	Obstetrics and Gynecology	Visuospatial Ability	Redrawn Vandenburg and Kuse MRT, Subversion A	–
Nugent et al, 2012 [39]	Observational study	Surgical	–	Visual Spatial Aptitude, Visual Spatial Ability	CRT, MPT	–
Nugent et al, 2012 [16]	Observational study	Surgical	–	Visual–Spatial Aptitude, Visual Spatial Ability, Perceptual Ability	CRT, MPT	SO, SS
Smith et al, 2012 [40]	Observational study	Nonsurgical	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 [41]	Observational study	Surgical	–	Spatial Ability, Visual Spatial Ability, Spatial Skill	3D-Cube Paper-and-Pencil Test of Mental Rotation	–
Langlois et al, 2009 [24]	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 [42]	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 [43]	Observational study	Surgical	–	Visuospatial Ability	CRT	–

Table 1 (*continued*)

Article	*Study type*	*Field*	*Specialty*	*VSA terminology*	*Instruments*	*Dimension of VSA*
Stefanidis et al, 2006 [21]	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
Strom et al, 2006 [18]	Experimental study	Surgical	–	Visual–Spatial Ability	Redrawn Vandenburg and Kuse MRT, Subversion Unspecified	–
Wanzel et al, 2003 [25]	Observational study	Surgical	Plastic + Oral and Maxillofacial Surgery	Visual–Spatial Ability	MRT (Unspecified Version), Surface Development Test, Gestalt Completion Test, Phase Discrimination Test	Edge and Surface Extraction, Whole Object Recognition, Mental Visualization Involving 2D and 3D Spatial Rotations and Translations
Wanzel et al, 2002 [44]	Observational study	Surgical	–	Visual–Spatial Ability	Snowy Pictures' Test, Gestalt Completion Test, Shape Memory Test, CCT, Form Board Test, Vandenburg and Kuse MRT	–
Risucci et al, 2000 [45]	Observational study	Surgical	General Surgery	Visual Perception, Visual–Spatial Perception	Form Completion Subtest, The Orientation Subtest, The Touching Blocks Subtest	–
Harris et al, 1994 [46]	Observational study	Mixed	Surgery, Anesthesiology, General Medicine, and Psychiatry	Visuospatial Ability	Embedded Figures Task	–
Steele et al, 1992 [47]	Observational study	Surgical	–	Visuospatial Ability, Visuospatial Skill, Spatial Ability	Hidden Figures Test	–

Information not specified (–).
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.

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 [1], 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 [19–21] but was separated from the VSA measures in a fourth study according to the authors [16]. 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 [6], 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 [26], 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 [26], 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 [13]. 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 [27]. Egocentric transformations have been said to involve the spatial orientation process [28,29]. 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 [28,29]. We have therefore divided object-based spatial transformations into simple and complex transformations. Simple object-based transformations constitute a very simple mental operation, while complex object-based transformations include multiple mental operations [28–30]. As the name describes, the

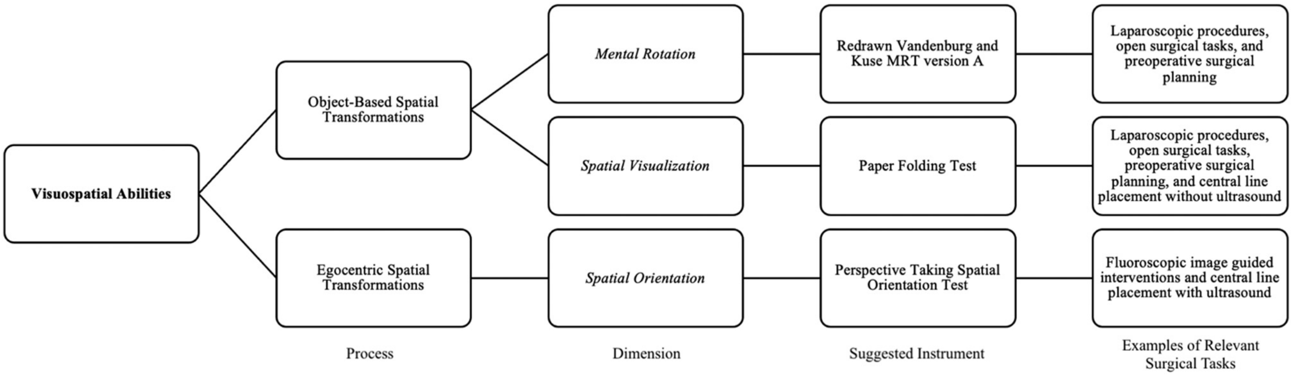

Fig 2. Proposed model for testing VSA in the surgical field.

mental rotation process involves rotating an object mentally and has been depicted as a simpler process [28–30]. On the other hand, spatial visualization is typically more complex and comprises multiple operations [28–30]. 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 [31]. It is an updated version of the spatial orientation test that has demonstrated discrimination from mental rotation tests [29]. 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 [32]. It is an updated version of the original Vandenburg and Kuse MRT test, providing complete and clear items that had faded over time [32]. We also suggest using version MRT(A) of the test, as the MRT(C) is composed of much more difficult items [32]. We believe the increase in difficulty is unnecessary for the purpose of measuring simple transformations. If researchers plan to measure mental rotation at 2 points in time, MRT(B) should be used at retest [32]. This version reduces practice effects by presenting identical items from MRT(A) in a different sequence [32]. Finally, we propose measuring spatial visualization using the Paper Folding Test, as its purpose aligns with that of complex transformations [33].

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.

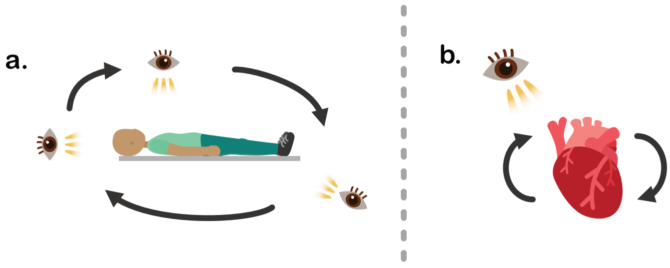

Fig 3. Illustration of (A) egocentric spatial transformations and (B) object-based spatial transformations.

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

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 2 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 2 out of 4 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.

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 [10,11], 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 [10]. 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.

Author Contributions

Meagane Maurice-Ventouris: Conceptualization, Formal analysis, Investigation, Writing – original draft. **Hellmuth R. Muller Moran**: Conceptualization, Investigation, Writing – review & editing. **Mohammed Alharbi**: Conceptualization, Writing – review & editing. **Byunghoon Tony Ahn**: Conceptualization, Writing – review & editing. **Jason M. Harley**: Conceptualization, Supervision, Writing – review & editing. **Kevin J. Lachapelle**: Conceptualization, Supervision, Writing – review & editing.

Acknowledgements

We would like to thank Andrea Quaiattini for helping with the development of the search strategy (Liaison Librarian at Schulich Library of Physical Sciences, McGill University).

Conflict of Interest

All authors report no conflicts of interest.

Funding Sources

This work was supported by the Adair Chair Surgical Education, Montreal, QC (fund number 234943) and the Canadian Institutes of Health Research Canada Graduate Scholarship – Master's program.

Appendix A

Search Strategies.
Database name: Ovid Embase + Embase Classic.
Platform: Ovid.
Database coverage: 1947–present.
Date last searched: January 13, 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* or technique* 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* or technique* 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 or 19 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, 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* or technique* 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* or technique* 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 or 19 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.

References

[1] Hegarty M, Keehner M, Cohen C, Montello D, Lippa Y. The role of spatial cognition in medicine: applications for selecting and training professionals; 2007.

[2] Buckley CE, Kavanagh DO, Nugent E, Ryan D, Traynor OJ, Neary PC. The impact of aptitude on the learning curve for laparoscopic suturing. Am J Surg. 2014;207(2):263–70. https://doi.org/10.1016/j.amjsurg.2013.08.037.

[3] Buckley CE, Kavanagh DO, Gallagher TK, Conroy RM, Traynor OJ, Neary PC. Does aptitude influence the rate at which proficiency is achieved for laparoscopic appendectomy? J Am Coll Surg. 2013;217(6):1020–7. https://doi.org/10.1016/j.jamcollsurg.2013.07.405.

[4] Hassan I, Gerdes B, Koller M, et al. Spatial perception predicts laparoscopic skills on virtual reality laparoscopy simulator. Childs Nerv Syst. 2007;23:685–9. https://doi.org/10.1007/s00381-007-0330-9.

[5] Shafqat A, Ferguson E, Thanawala V, Bedforth NM, Hardman JG, McCahon RA. Visuospatial ability as a predictor of novice performance in ultrasound-guided regional anesthesia. *Anesthesiology*. 2015;123(5):1188–1197. doi:https://doi.org/10.1097/ALN.0000000000000870.

[6] Anastakis D, Hamstra S, Matsumoto E. Visual-spatial abilities in surgical training. Am J Surg. 2000;179:469–71. https://doi.org/10.1016/S0002-9610(00)00397-4.

[7] Cornu V, Schiltz C, Pazouki T, Martin R. Training early visuo-spatial abilities: a controlled classroom-based intervention study. Appl Dev Sci. 2019;23(1):1–21. https://doi.org/10.1080/10888691.2016.1276835.

[8] Carroll JB. *Human cognitive abilities: a survey of factor-analytic studies*. Cambridge: Cambridge University Press; 1993. doi:DOI: https://doi.org/10.1017/CBO9780511571312.

[9] Munn Z, Peters M, Stern C, Tufanaru C, Mcarthur A, Aromataris E. Systematic review or scoping review? Guidance for authors when choosing between a systematic or scoping review approach. BMC Med Res Methodol. 2018;18. https://doi.org/10.1186/s12874-018-0611-x.

[10] Arksey H, O'Malley L. Scoping studies: towards a methodological framework. Int J Soc Res Methodol. 2005;8(1):19–32. https://doi.org/10.1080/1364557032000119616.

[11] Tricco AC, Lillie E, Zarin W, et al. PRISMA Extension for Scoping Reviews (PRISMA-ScR): checklist and explanation. Ann Intern Med. 2018;169(7):467–73. https://doi.org/10.7326/M18-0850.

[12] Ouzzani M, Hammady H, Fedorowicz Z, Elmagarmid A. Rayyan—a web and mobile app for systematic reviews. Syst Rev. 2016;5(1):210. https://doi.org/10.1186/s13643-016-0384-4.

[13] Luko L, Parush A, Matanes E, Lauterbach R, Taitler A, Lowenstein L. An efficient single-session spatial skill trainer for robot-assisted surgery: a randomized trial. *J Minim Invasive Gynecol*. 2019;27(3):728–737.e2. doi:https://doi.org/10.1016/j.jmig.2019.05.014.

[14] Specialty training requirements in obstetrics and gynecology. http://www.royalcollege.ca/rcsite/documents/ibd/obstetrics-and-gynecology-str-e. Published 2016. Accessed June 8, 2020.

[15] McDonald J, Potyk D, Fischer D, et al. Napping on the night shift: a study of sleep, performance, and learning in physicians-in-training. *J Grad Med Educ*. 2013;5(4):634–638. doi:https://doi.org/10.4300/JGME-D-12-00324.1.

[16] Nugent E, Joyce C, Perez-Abadia G, et al. Factors influencing microsurgical skill acquisition during a dedicated training course. *Microsurgery*. 2012;32(8):649–656. doi:https://doi.org/10.1002/micr.22047.

[17] Sheikh AY, Keehner M, Walker A, Chang PA, Burdon TA, Fann JI. Individual differences in field independence influence the ability to determine accurate needle angles. *J Thorac Cardiovasc Surg*. 2014;148(5):1804–1810. doi:https://doi.org/10.1016/j.jtcvs.2014.05.008.

[18] Strom P, Hedman L, Sarna L, Kjellin A, Wredmark T, Fellander-Tsai L. Early exposure to haptic feedback enhances performance in surgical simulator training: a prospective randomized crossover study in surgical residents. Sur g Endosc. 2006;20(9):1383–8. http://ovidsp.ovid.com/ovidweb.cgi?T=JS&PAGE=reference&D=med6&NEWS=N&AN=16823652.

[19] Henn P, Gallagher AG, Nugent E, et al. A computerised test of perceptual ability for learning endoscopic and laparoscopic surgery and other image guided procedures: Score norms for PicSOr. *Am J Surg*. 2017;214(5):969–973. doi:https://doi.org/10.1016/j.amjsurg.2017.01.025.

[20] Louridas M, Quinn LE, Grantcharov TP. Predictive value of background experiences and visual spatial ability testing on laparoscopic baseline performance among residents entering postgraduate surgical training. *Surg Endosc*. 2015;30(3):1126–1133. doi:https://doi.org/10.1007/s00464-015-4313-8.

[21] Stefanidis D, Korndorffer JRJ, Black FW, et al. Psychomoto. r testing predicts rate of skill acquisition for proficiency-based laparoscopic skills training. Surgery. 2006; 140(2):252–62. http://ovidsp.ovid.com/ovidweb.cgi?T=JS&PAGE=reference&D=med6&NEWS=N&AN=16904977.

[22] Ahlborg L, Hedman L, Rasmussen C, Fellander-Tsai L, Enochsson. Non-technical factors influence laparoscopic simulator performance among OBGYN residents. *Gynecol Surg*. 2012;9(4):415–420. doi:https://doi.org/10.1007/s10397-012-0748-2.

[23] Ahlborg L, Hedman L, Nisell H, Fellander-Tsai L, Enochsson L. *Simulator* training and non-technical factors improve laparoscopic performance among OBGYN trainees. *Acta Obstet Gynecol Scand*. 2013;92(10):1194–1201. doi:https://doi.org/10.1111/aogs.12218.

[24] Langlois J, Wells GA, Lecourtois M, Bergeron G, Yetisir E, Martin M. Spatial abilities in an elective course of applied anatomy after a problem-based learning curriculum. *Anat Sci Educ*. 2009;2(3):107–112. doi:https://doi.org/10.1002/ase.84.

[25] Wanzel KR, Hamstra SJ, Caminiti MF, Anastakis DJ, Grober ED, Reznick RK. . Visual-spatial ability correlates with efficiency of hand motion and successful surgical performance. Surgery. 2003;134(5):750–7. http://ovidsp.ovid.com/ovidweb.cgi?T=JS&PAGE=reference&D=med5&NEWS=N&AN=14639352.

[26] Vajsbaher T, Schultheis H, Francis NK. Spatial cognition in minimally invasive surgery: a systematic review. BMC Surg. 2018;18(1):94. https://doi.org/10.1186/s12893-018-0416-1.

[27] Zacks J, Rypma B, Gabrieli JD, Tversky B, Glover GH. Imagined transformations of bodies: an fMRI investigation. Neuropsychologia. 1999;37(9):1029–40. https://doi.org/10.1016/s0028-3932(99)00012-3.

[28] Kozhevnikov M, Hegarty M. A dissociation between object manipulation spatial ability and spatial orientation ability. Mem Cognit. 2001;29(5):745–56. https://doi.org/10.3758/BF03200477.

[29] Hegarty M, Waller D. A dissociation between mental rotation and perspective-taking spatial abilities. Dermatol Int. 2004;32(2):175–91. https://doi.org/10.1016/j.intell.2003.12.001.

[30] Linn MC, Petersen AC. Emergence and characterization of sex differences in spatial ability: a meta-analysis. Child Dev. 1985;56(6):1479–98. https://doi.org/10.2307/1130467.

[31] Friedman A, Kohler B, Gunalp P, Boone AP, Hegarty M. A computerized spatial orientation test. Behav Res Methods. 2020;52(2):799–812. https://doi.org/10.3758/s13428-019-01277-3.

[32] Peters M, Laeng B, Latham K, Jackson M, Zaiyouna R, Richardson C. A redrawn Vandenberg and Kuse mental rotations test: different versions and factors that affect performance. Brain Cogn. 1995;28(1):39–58. https://doi.org/10.1006/brcg.1995.1032.

[33] Ekstrom RB, French JW, Harman HH, Dermen D. Manual for kit of factor-referenced cognitive tests. Princeton, NJ: Educational Testing Service; 1976.

[34] Nayar SK, Musto L, Fernandes R, Bharathan R. Emotional intelligence predicts accurate self-assessment of surgical quality: a pilot study. *J Surg Res*. 2019;245:383–389. doi:https://doi.org/10.1016/j.jss.2019.07.051.

[35] De Witte B, Di Rienzo F, Martin X, Haixia Y, Collet C, Hoyek N. Implementing cognitive training into a surgical skill course: a pilot study on laparoscopic suturing and knot tying. *Surg Innov*. 2018;25(6):625–635. doi:https://doi.org/10.1177/1553350618800148.

[36] Henn P, Gallagher AG, Nugent E, et al. Visual spatial ability for surgical trainees: implications for learning endoscopic, laparoscopic surgery and other image-guided procedures. *Surg Endosc*. 2018;32(8):3634–3639. doi:https://doi.org/10.1007/s00464-018-6094-3.

[37] Hinchcliff E, Green I, Destephano C, et al. Visuospatial aptitude testing differentially predicts simulated surgical skill. *J Minim Invasive Gynecol*. 2018;25(6):1044–1050. doi:https://doi.org/10.1016/j.jmig.2018.01.031.

[38] Milam LA, Cohen GL, Mueller C, Salles A. Stereotype threat and working memory among surgical residents. *Am J Surg*. 2018;216(4):824–829. doi:https://doi.org/10.1016/j.amjsurg.2018.07.064.

[39] Nugent E, Hseino H, Boyle E, et al. Assessment of the role of aptitude in the acquisition of advanced laparoscopic surgical skill sets: results from a virtual reality-based laparoscopic colectomy training programme. *Int J Colorectal Dis*. 2012;27(9):1207–1214. doi:https://doi.org/10.1007/s00384-012-1458-y.

[40] Smith HM, Kopp SL, Johnson RL, Long TR, Cerhan JH, Hebl JR. Looking into learning: visuospatial and psychomotor predictors of ultrasound-guided procedural performance. *Reg Anesth Pain Med*. 2012;37(4):441–447. doi:https://doi.org/10.1097/AAP.0b013e318257a551.

[41] Rosenthal R, Hamel C, Oertli D, Demartines N, Gantert WA. Performance on a virtual reality angled laparoscope task correlates with spatial ability of trainees. *Indian J Surg*. 2010;72(4):327–330. doi:https://doi.org/10.1007/s12262-010-0118-0.

[42] Wanzel KR, Anastakis DJ, McAndrews MP, et al. Visual-spati. al ability and fMRI cortical activation in surgery residents. Am J Surg. 2007;193(4):507–10. http://ovidsp.ovid.com/ovidweb.cgi?T=JS&PAGE=reference&D=med6&NEWS=N&AN=17368300.

[43] Enochsson L, Westman B, Ritter EM, et al. Objective assessment of visuospatial and psychomotor ability and flow of residents and senior endoscopists in simulated gastroscopy. Surg Endosc. 2006;20(6):895–9. http://ovidsp.ovid.com/ovidweb.cgi?T=JS&PAGE=reference&D=med6&NEWS=N&AN=16738978.

[44] Wanzel KR, Hamstra SJ, Anastakis DJ, Matsumoto ED, Cusimano MD. Effect of visual-spatial ability on learning of spatially-complex surgical skills. *Lancet (London, England)*. 2002;359(9302):230–231. http://ovidsp.ovid.com/ovidweb.cgi?T=JS&PAGE=reference&D=med4&NEWS=N&AN=11812562.

[45] Risucci D, Geiss A, Gellman L, Pinard B, Rosser JC. Experience and visual perception in resident acquisition of laparoscopic skills. C urr Surg. 2000;57(4):368–72. http://ovidsp.ovid.com/ovidweb.cgi?T=JS&PAGE=reference&D=prem1&NEWS=N&AN=11024253.

[46] Harris CJ, Herbert M, Steele RJ. Psychomotor skills of surgical trainees compared with those of different medical specialists. Br J Surg. 1994;81(3):382–3. http://ovidsp.ovid.com/ovidweb.cgi?T=JS&PAGE=reference&D=med3&NEWS=N&AN=8173905.

[47] Steele RJ, Walder C, Herbert M. Psychomotor testing and the ability to perform an anastomosis in junior surgical trainees. Br J Sur g. 1992;79(10):1065–7. http://ovidsp.ovid.com/ovidweb.cgi?T=JS&PAGE=reference&D=med3&NEWS=N&AN=1422721.