Universität Bremen

Spatial Cognition in Surgical Practice: Exploring the Influence and Development of Spatial Cognitive Processes in Laparoscopic Skill Learning

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Tina Vajsbaher

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1. Gutachter: PD Dr. rer. nat. Holger Schultheis
2. Gutachter: Prof. Dr. med. Dr. phil. Manfred Herrmann
Externer Betreuer: Prof. Dr. med. Nader Francis

Dedicated to my *mother* and in loving memory of my *father* and

Prof Christan Freksa

Statutory Declaration

(On Authorship of a Dissertation)

I, *Tina Vajsbaher-Kelc,* herewith formally declare that I have written the submitted dissertation independently with no outside support or assistance. I have used only the sources, data, and support clearly mentioned and described in the thesis's acknowledgement section. Any literal quotations from others are clearly marked throughout the thesis. This PhD thesis has not been submitted for conferral of degree elsewhere.

I confirm that the publication of this thesis will not infringe on any rights of third parties.

Bremen,

Signed ____

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Abstract

Primum non nocere ("first, do no harm") serves as a reminder that patient safety and wellbeing lie at the heart of any medical practice. Yet, it also advocates the importance of conducting high-quality research to better understand how patient safety could be maximised. Laparoscopy is a minimally invasive surgery that offers numerous advantages to the patient, yet, at the surgeons' expense. This technically demanding technique is plagued with a unique set(s) of visuospatial and psychomotor complexities, all rending laparoscopy difficult to learn, perform and master. As a consequence, patient safety can become compromised. The central role of spatial cognition in enabling laparoscopic skill acquisition and improving performance has already been established. Yet, several critical questions remain; (1) **which s**pecific spatial cognitive skills are important for laparoscopy (2) how these relate to laparoscopic **expertise,** and (3) how these develop, and influence, the acquisition of laparoscopic competence **over time** in *actual residency surgeons currently training in the operating theatre*. This doctoral thesis aimed to address these empirical shortcomings by comprehensively exploring how, and in which context, spatial cognitive processes develop and influence skills acquisition in laparoscopic surgery. Four distinct, yet interrelated, exploratory studies were conducted to determine (1) the current status quo of laparoscopic education in Germany, (2) establish a conceptualisation and classification framework of laparoscopic competence, (3) explore whether laparoscopic surgeons of varying expertise levels are expert patial thinkers, and (4) longitudinally explore the develop and influence of visuospatial abilities on laparoscopic skill acquisition over 27 months. The findings reveled that whereas different abilities are called on at different stages of laparoscopic skill acquisition, spatial visualisation shows an enduring influence over laparoscopic performance and is closely related with laparoscopic competence and expertise. Together, these findings carry important theoretical and clinical implications for both psychology and surgical education alike, as they inform our empirical understanding of the malleability and structure of spatial processes and how these develop and influence the acquisition of laparoscopic competence in the operating theatre.

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1

BACKGROUND AND MOTIVATION

This chapter introduces the concept of spatial cognition and laparoscopy and highlights the main motivations and objectives for the research conducted in this thesis.

Spatial cognition refers to the comprehension and transformation of visual representations and its spatial relationships, serving an important function in our ability to perform various behavioural functions; from peeling a potato, driving a car, to performing surgery. The ability to construct mental models of three-dimensional anatomy, plan surgical interventions based on two-dimensional images of anatomy (i.e. MRT, CT scans) and navigate around anatomical structures are all surgical tasks that strongly rely on spatial cognition. Yet, with the advent of laparoscopy surgery, the central role of spatial cognition in the context of surgery has been further prioritised (Hegarty, Keehner, Cohen, Montello & Lippa, 2007; Wanzel, Hamstra, Anastakis, Mutsumoto & Cusimano, 2002).

Laparoscopy (Greek for "*examine the flank")* is a type of a minimally invasive surgery (MIS), where surgical treatments and diagnosis are performed with several small cuts in the abdomen. These small incisions allow for the insertion of ports (i.e. trocar). Through these ports, fibre-optic instruments (i.e. the camera "laparoscope") and other surgical instruments (i.e. graspers, dissectors) are inserted into the abdominal cavity. Insufflation gas (i.e. carbon dioxide) is used to extend the abdominal wall and allow for better visualisation and instrument manoeuvring. The laparoscope illuminates the internal anatomical structures and projects a live video coverage onto a monitor viewed by the surgeons. The long and thin laparoscopic instruments are then used to manipulate the tissue and organs for surgical treatment of a particular disease. A typical laparoscopic setup is illustrated in figure 1.

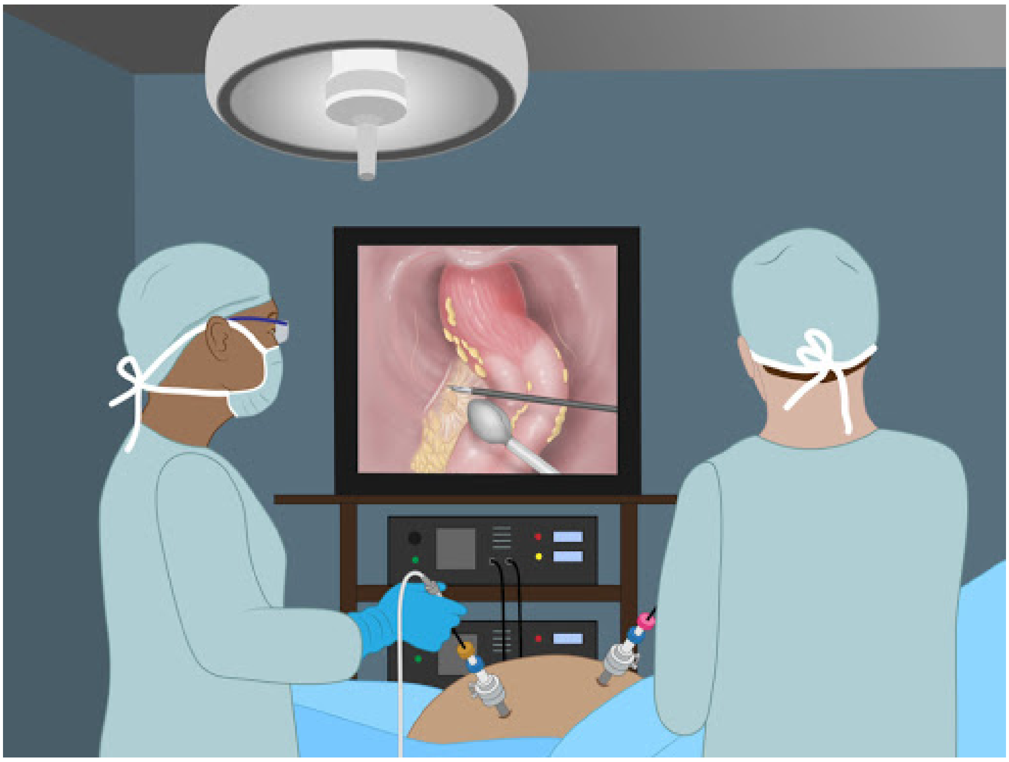


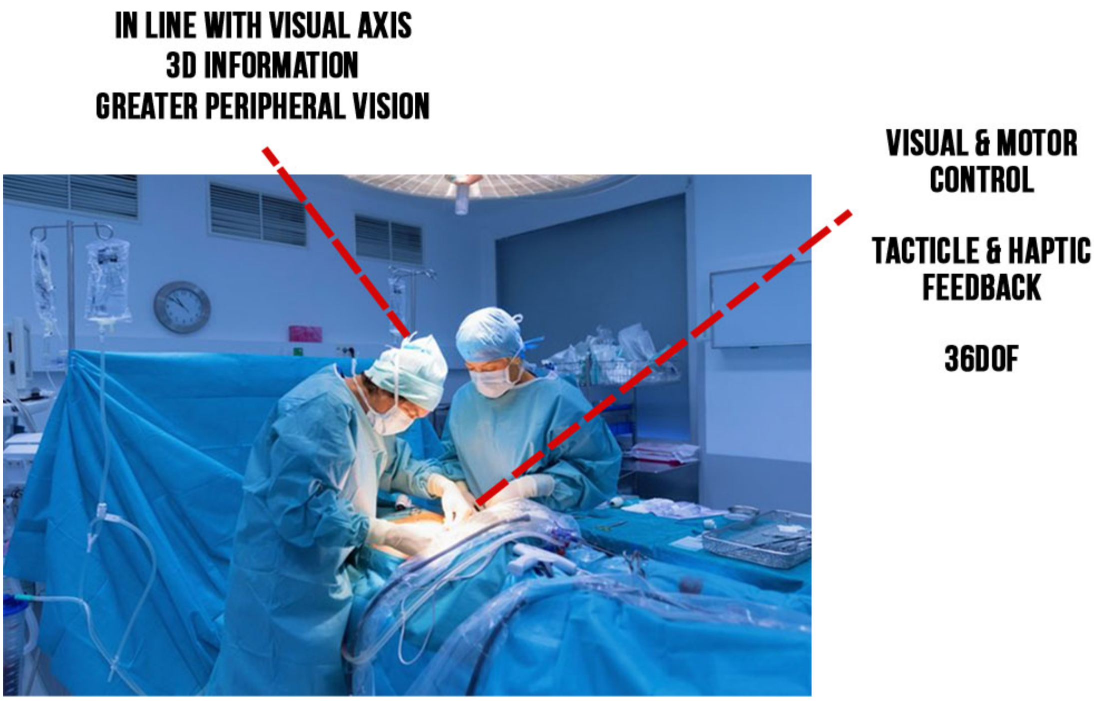
Figure 1. Illustration of the laparoscopic setup Copyright: UT MD Anderson Cancer Center

Compared to the more invasive open surgery, the minimally invasive nature of the laparoscopic technique offers impressive intra-and post-operative advantages for the patients. Some of the most significant benefits include: (1) reduced muscle, tissue and skin damage, (2) reduced rate of internal injury and bleeding, (3) reduction of post-operative infection, (4) decreased post-operative pain and consequent reliance on narcotics, (5) quick recovery (6) early hospital discharge and (7) better cosmetic outcomes (Gerges, Kanazi & Jabbour-Khoury, 2006: Tan, Wolf, Ye, Hafez, & Miller, 2014). These patient-based advantages allowed laparoscopy to become the gold standard approach in the treatment of various disorders of the abdominal, musculoskeletal and pelvic area. Today, nearly 15 million laparoscopic procedures are performed globally every year (Global Industry Analysts, 2018), rapidly replacing traditional open incision approaches (Agha & Muir, 2003). However, the advantages enjoyed by the patients come at significant cognitive and physical costs to the surgeons (Park, Lee, Seagull, Meenaghan & Dexter, 2010);

> *"Any type of surgery, particularly minimally invasive surgery, takes a physical and mental toll on surgeons. We must continuously adapt to ensure the best outcome for patients, often dipping hugely into their own health reserve. We're not going to serve our patients, the public, or the healthcare system well if we have prematurely shortened careers because of the physical and cognitive ravages of what we do."* Dr Adrian Park (Internationally recognised laparoscopic surgeon)

Laparoscopy is characterised by two unique properties that pose significant cognitive and motor challenges. First, the three-dimensional anatomy is seen as a two-dimensional image on the monitor. Second, the procedure is performed using sophisticated instruments and video equipment. To create a more transparent illustration of the unique constraints associated with laparoscopy, the cognitive and physical conditions faced by laparoscopic surgeons will be compared to those faced by open surgeons. See figure 2 for a visual comparison between the two surgical approaches.

OPEN SURGERY



LAPAROSCOPY

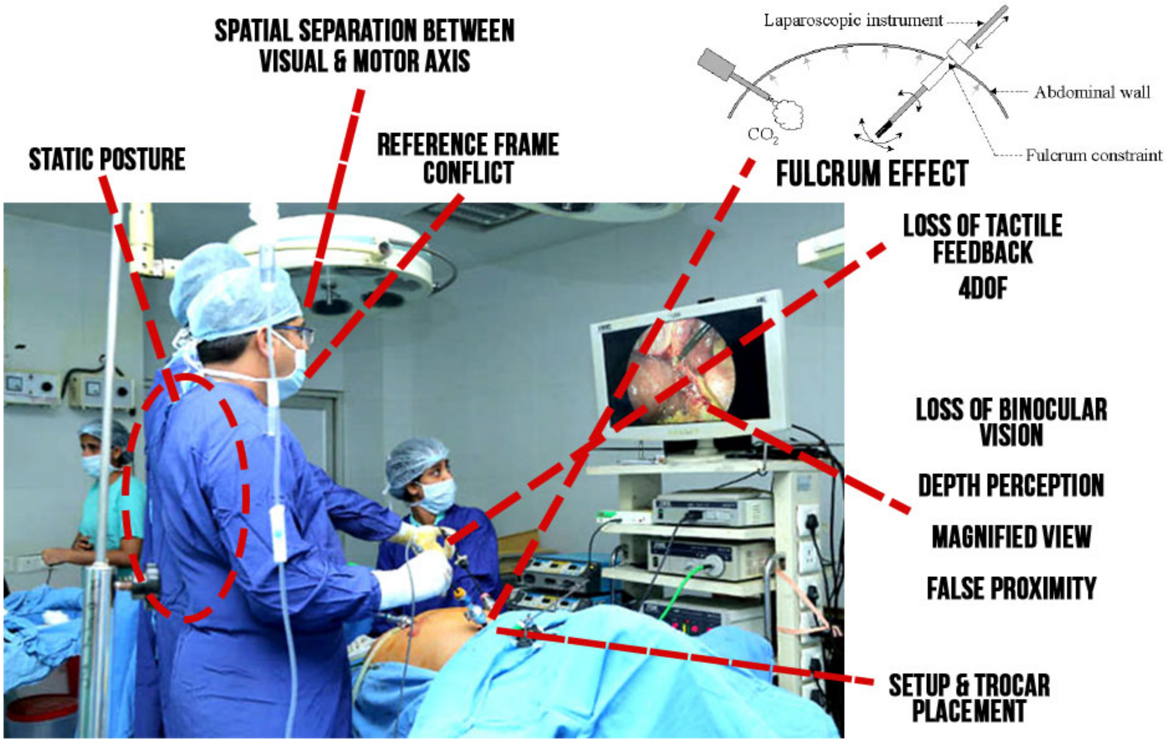


Figure 2. A graphical illustration comparing and describing the cognitive and physical conditions between open surgery and laparoscopic surgery.

Firstly, compared to open surgeons working in a three-dimensional space with a peripheral overview of the operative field, laparoscopic surgeons operate in a three-dimensional space through a magnified two-dimensional projection on a monitor. As a result, depth information is lost and perceptual cues available to the surgeon reduced (Wentik, 2001). The 'flat vision' that results from loss of binocular cues bedevils judgement of depth and spatial relations of anatomy and the position of the instruments in relation to of the anatomy. Spatial orientation and spatial visualisation inside the abdominal cavity can therefore become impaired.

Secondly, open surgeons work in line with their visual and motor axis (i.e. direct visual overview of the hand movements), whereas laparoscopic surgeons face a spatial separation between their vision and motor coordination. In other words, laparoscopic surgeons do not get to monitor the movements of their hands and instruments in direct line with the operative field, as visual attention must remain on the scenes observed on the monitor. To compensate for such spatial separation, laparoscopic surgeons must integrate visual and motor functions into one perceptual channel (i.e. perceptual-motor skills) (Mohamadipanah, Perrone, Nathwani, Parthiban, Peterson, Wise et al., 2019).

Thirdly, open surgeons are afforded 360 degrees of movement with tactile feedback, whereas the instruments used in laparoscopy reduce haptic feedback and restrict the range of motion to 4-6 degrees of freedom (e.g. rotation, up/down angulation, left/right angulation and in/our angulation) (Schostek, Schurr & Buess, 2009). The loss of sensory feedback and restricted motor control hampers the surgeon's ability to gauge important information such as the temperature of the tissue, its texture, and the forces applied through laparoscopic instruments. Such lack of haptic feedback must, therefore, be compensated through vision.

Lastly, as yet another consequence of the laparoscopic instruments, the surgeon must learn to operate in mirrored condition. Once the tools are inserted through the trocars, the ports act as a fulcrum and a steadying point. The friction between the instruments and the ports cause a perceptual illusion of inverted movements on the monitor. This is called the *Fulcrum effect* (Lin & Chen, 2013): physical movement of the tool in one direction is viewed on the monitor as moving to the opposite direction (i.e. the physical movement to the right is displayed on the monitor as the movement to the left). Such image inversion and the disparity between the surgeon's line of sight and the camera's orientation present a particular spatial cognitive challenge, especially for novice surgeons training in laparoscopy (Gallagher, Smith, Bowes, Seymour, Pearson, McNatt et al., 2003).

Together, these complexities render laparoscopy notoriously challenging to learn, perform and master (Subramonian, DeSylva, Bishai, Thompson & Muir, 2004). As a result, patient safety is often compromised (Galagher & Smith, 2003). Considering these aforementioned complexities all relate to processing of visual and spatial information, it is a feasible presumption that spatial cognition may play a central role in one's ability to compensate for the encountered complexities and contribute towards safe and efficient laparoscopic performance. I will refer to this type of visual and spatial processing and its related abilities as *visuospatial ability* and *visuospatial abilities*, throughout this doctoral thesis

1.1. The motivation for exploring visuospatial ability in laparoscopy

To date, a growing body of literature contributed to the current understanding that visuospatial ability is positively related to outcomes of laparoscopy surgery (Hegarty et al., 2007; Wanzel et al., 2002). Yet, the true extent and nature of its influence remains unclear. In particular, we currently lack empirical understanding as to (1) which specific visuospatial abilities play a role in promoting laparoscopic intraoperative performance of actual surgeons in the operating theatre, (2) which visuospatial abilities (if any) characterises laparoscopic expertise and (3) how these visuospatial abilities develop and influence laparoscopic skill learning over time. Visuospatial ability has been shown to promote overall better laparoscopic performance on surgical simulators (Wanzel et al., 2002). However, conversely, the ability has also been linked to laparoscopic ineptitude, and consequently, operative errors and complications (Galagher & Smith, 2003). Better understanding of the role of visuospatial ability in the context of laparoscopy is therefore of apparent and pressing importance. Surgical errors represent a serious public health concern (Kim, Donalisio da Silva, Gustafson, Nogueira, Harlin & Paul, 2015). Today, around 200 million surgeries are performed annually worldwide. Yet despite revised training curriculums and patient safety guidelines, the rate of surgical errors remains unacceptably high (Earnshaw & Alderson, 2014). *The err is inevitably human*; however, with better understanding of the underlying processes, their influence over laparoscopic performance and the acquisition of laparoscopic skills, these errors can be better addressed and reduced in the scope of surgical training.

1.2. Objectives and aims of this doctoral thesis

This doctoral thesis seeks to break new ground by addressing these aforementioned gaps in the literature and explore the role of visuospatial ability in laparoscopic performance and skill learning of actual surgeons operating laparoscopically in the operating theaters. With its empirical effort, this thesis aims to provide a more pragmatic and comprehensive insight into how visuospatial ability is perceived, demonstrated, acquired and associated with laparoscopic outcomes in the wider scope of laparoscopic education and practice in Germany. In line with these proposed aims, five broad research questions are addressed.

1. How is laparoscopy perceived, practiced and trained in the current German surgical residency system and what institutional and/or educational factors could be influencing over the acquisition of laparoscopic skills?
2. What categorises laparoscopic competence and which underlying skills and abilities are perceived by the surgical educators to make up a competent laparoscopic surgeon?
3. Do laparoscopic surgeons of varying experience levels actually possess better visuospatial abilities and how are these associated with intraoperative laparoscopic performance?
4. How do these visuospatial abilities develop and influence laparoscopic skill learning of residency surgeons over a 27-month period?
5. What is the component structure of visuospatial ability and to what extent are these visuospatial abilities malleable in the context of laparoscopic training?

In addressing these questions, this thesis seeks to contribute important new insights to surgical education and basic spatial cognition research alike, which continues to lack empirical evidence of how spatial processes develop in the context of specialised training over an extended period of time. Exploring the role of visuospatial ability in laparoscopic performance and skill learning lies at the heart of this doctoral thesis. An attempt to place these findings into the broader context requires a better understanding of the current status quo of laparoscopic education in Germany. Understanding what conceptualises laparoscopic competence as also an important prerequisite. As a result, I seek to overcome significant limitations of previous literature with regards to ecological validity. The strength of this thesis lies in the principle that all investigations are undertaken outside the laboratory settings and are predicated on the data gathered from actual laparoscopic surgeons of all expertise levels across Germany.

1.3. Overview of the thesis structure

This current thesis is structured around three major parts. The first part provides an empirical overview of the current state of the art on the topic of spatial cognition in laparoscopic surgery. The second part comprises four exploratory empirical studies conducted against the above-stated aims and objectives. **Study 1** is a survey study exploring the current status que of laparoscopic education in Germany amongst surgical members of the German surgical society (DGCH) and the professional association of German surgeons (BDC). The aim is to better understand how laparoscopy is perceived and taught around the country whilst exploring whether any institutional or educational shortcomings could be bearing influence over the surgeons' acquisition of laparoscopic skills. **Study 2** is a qualitative study using the interpretive phenomenological analysis (IPA) approach. The study aims to explore the perceptions of surgical educators on what conceptualises laparoscopic competence and what set(s) of skills and abilities they attribute to a competent laparoscopic surgeon. **Study 3** is a quantitative study exploring whether laparoscopic surgeons are expert visuospatial thinkers. This question is addressed in two investigations. Investigation 1 aims to determine visuospatial profiles of laparoscopic surgeons of varying expertise levels and quantitively compare these profiles to those of medical laypeople. In addition, the component structure of visuospatial ability is also explored. Investigation 2 aims to quantify the relationship between visuospatial abilities and intraoperative performance of residency surgeons to determine which and to what degree these visuospatial abilities are associated with intraoperative performance and to what degree. **Study 4** is a longitudinal study exploring the development, and influence, of visuospatial abilities on laparoscopic skill learning of residency surgeons over a 27-month period. The thesis concludes with the final discussion section, where all findings and contributions that emerged in the scope of this thesis are synthesised and placed into the broader context of surgical education and practice in Germany.

2

STATE OF THE ART

This chapter provides an overview of the current state of the art on the topic of spatial cognition in laparoscopic surgery

In the late 1980s, the advent of laparoscopic surgery forever changed the landscape of surgical practice we know today. With its innovative and technologically driven approach, the technique revolutionised and forever transformed the modus operandi of surgical care. Today, laparoscopy has become a preferred surgical approach for treatment of various diseases by many around the globe (Agrusa, Romano, Navarra, Conzo, Pantuso, Buono et al., 2017). Yet, the technology that offers great benefits to the patients comes at a significant cost to the surgeons. For a successful and safe laparoscopic performance, a surgeon must learn to overcome significant visuospatial and motor complexities (Subramonian et al., 2004). For that, they require a unique set(s) of skills and abilities that are different from those needed for other surgical interventions (Torricelli & Guglielmetti, Duarte & Srougi, 2011). These laparoscopic skills are not intuitive, innate nor easily imitated, making laparoscopy a notoriously difficult and challenging technique to master. These challenges contribute to what is known in surgical education as a '*long and steep learning curve*': skills are acquired in gradual increments with experience over time (Bansal, Krishna, Misra & Kumar, 2016; Kumar & Gill, 2006). In layman terms, laparoscopic skill acquisition is a long and complex process, whereby only small improvements in the performance outcomes are associated with each laparoscopic case of the surgeon. As a result, the laparoscopic learning curve is associated with prolonged operative times, higher costs and increased rates of operative errors and complications (Cagir, Rangraj, Maffuci & Herz, 1994; Tekkis, Senagore, Delaney & Fazio, 2005).

Research has shown that surgeons in their early phases of laparoscopic learning have the highest rates of operative complications and adverse events (i.e. injury caused to the patient) (Gallagher & Smith, 2003). What's more, studies have shown that roughly 80% of intraoperative complications and errors most often occur in the first 30 laparoscopic procedures completed by the surgeon *after* their residency training. The risk of serious injury to the patient was found to be the highest in the first ten procedures performed by a surgeon (Cagir et al., 1994). In other words, the laparoscopic learning curve is associated with significant and potentially disastrous patient outcomes, including permanent injury to the patient and higher mortality rates (Sharpe, Talamonti, Wang, Prinz, Roggin, Bentrem et al., 2015). Yet, studies have highlighted some interesting individual differences in the learning curves. For example, a study by Grantcharov & Funch-Jensen (2009) found that residency surgeons tend to fall into three categories: (1) surgeons who demonstrate proficiency from the beginning, (2) surgeons who improve but do not attain competence and (3) surgeons who never improve and never attain competence. The authors argued that these results signify the notion that not every surgeon can acquire laparoscopic skills. Similar findings were reported by Louridas, Szasz, Fesco, Zywiel, Lak, Bener, Harris & Grantcharov (2017), who found that medical students with better initial performance on the simulated laparoscopic tasks attained competence in the technique faster than low performing students did, who failed to attain competence even with additional training. These findings, suggesting that individual differences can predict who can acquire laparoscopic skills and who cannot, prompted empirical investigations into which underlying attributes can help to explain these divergences in laparoscopic skill attainment. To date, visuospatial ability has been identified as the most promising culprit (Hegarty et al., 2007; Wanzel et al., 2002).

Visuospatial ability refers to the comprehension, transformation and manipulation of simple and complex visual and spatial information. In spatial cognition research, a distinction is often made between 'large-scale' abilities and 'small-scale' abilities. A large-scale ability refers to cognitive processing of wayfinding and environmental navigation, whereas small-scale ability refers to the processing of mental representation of two-and three-dimensional stimuli (Höffler, 2010; Li, Kong, Ji, Luo, Lan & You, 2019). Together, these processes allow us to perceive and identify objects and other organisms in our environment, locate objects in space, facilitate our understanding of the shape and the characteristics of these objects and guide our motor behaviour and interactions (Spence & Feng, 2010). In the scope of this doctoral thesis the focus is on exploring small-scale visuospatial abilities. Visuospatial ability is often described as a multidimensional cognitive construct consisting of a myriad of different abilities, all responsible for processing visual and spatial information (Castro-Alonso & Uttal, 2019). To date, there is no accepted consensus on what classifies and makes up visuospatial ability. Yet, it is well recognised that visuospatial ability is not a unitary concept (Hegarty & Waller, 2005). Determining the component structure of visuospatial ability has therefore already been emphasised as an important rationale for future research (see overview by Hegarty & Waller, 2005). Differences of opinion aside, most researchers would tend to agree that visuospatial ability comprises of three key abilities: spatial visualisation, mental rotation and spatial perception (Lohman, 1979). Spatial visualisation refers to mental manipulation and transformation of two-and three-dimensional visual and spatial information (Linn & Petersen, 1985). Mental rotation refers to the ability to mentally manipulate and rotate two-dimensional and three-dimensional representations of object in space (Linn & Peterson, 1985), whereas spatial perception refers to the ability to establish spatial relationships between one's own position and the position of other objects or organisms in space (Linn & Petersen, 1985).

Considering the nature of complexities associated with laparoscopy, it seems only natural to presume that a crucial aspect of laparoscopic performance and skill acquisition may be related to the ability to mentally process visuospatial information. The existing literature on the topic has largely confirmed this notion, finding visuospatial ability to play an important role in promoting and influencing laparoscopic performance (Cuschieri, 1995; Harrington, Dicker, Traynor & Kavanagh, 2018; Deary, Graham & Maran, 1992; Gibbons, Baker & Skinner, 1986;

Hall, Ellis & Hamdorf, 2003; Keehner, Lippa, Montello, Tendick & Hegarty, 2006; Oussi, Renman, Georgiou & Enochsson, 2020; Schueneman, Pickleman, Hesslein & Freeark, 1984; Schijven & Jakimowicz, 2004; Wanzel et al., 2002). For instance, the two earliest studies by Gibbons et al (1986) and Schueneman et al (1984) both reported significant correlation between visuospatial ability and surgical technical performance. Similarly, a study by Risucci (2002) reported that surgeons significantly outperformed the general population on visuospatial ability, suggesting that surgeons do appear to be expert spatial thinkers. Visuospatial ability has also been attributed to promoting laparoscopic performance, with studies showing that surgeons with higher visuospatial ability also tend to show better performance outcomes (Schijven & Jakimowicz, 2004; Wanzel et al., 2002). Nevertheless, studies exploring the role of visuospatial ability in the context of laparoscopic training reported largely divergent findings. Studies by Louridas, Quinn & Grantcharov (2016) and by Risucci, Geiss, Gellman, Pinard, & Rosser (2001) both reported that resident surgeons with higher visuospatial abilities showed better laparoscopic performance and acquired laparoscopic skills faster than low aptitude subjects. On the other hand, a study by Ahlborg, Hedman, Murkes, Westman, Kjellin, Felländer-Tsai & Enochsson (2011) found no correlation between visuospatial ability and laparoscopic training outcomes. Similarly, a study by Groenier, Schraagen, Miedema, & Broeders (2014) found no evidence that visuospatial ability predicts the learning curve or is associated with laparoscopic competence. Lastly, a study by Keehner, Tendick, Meng, Anwar, Hegarty, Stoller & Duh (2004) found a significant correlation between visuospatial ability and laparoscopic performance at the initial stages of training, however, that relationship diminished as laparoscopic competence was attained. The authors argued that these results are in line with the skill acquisition theory, which claims that with automatization of the task, the influence of cognition diminishes.

In light of these divergent findings, the exact role of visuospatial ability in the context of laparoscopic surgery remains ambiguous. Additionally, all studies discussed visuospatial ability as a unitary concept. Which specific visuospatial abilities play the most influential role in promoting laparoscopic performance and skill learning remains unclear. Such understanding is deemed important considering each visuospatial ability has its own function and plays its own role in influencing behavioural outcomes. Thus, what appears to be missing is a concise and a systematic synthetisation of research findings on the topic, attempting to gain a better understanding of the level of importance of individual spatial skills and their impact in surgical performance and skill acquisition. My contribution of the first published systematic review on the role of spatial cognition in minimally invasive surgery is presented in the next section 2.1.

2.1. The role of spatial cognition in minimally invasive surgery: A systematic review

The current literature exploring the role of spatial cognition in laparoscopic surgery is highly heterogeneous, posing more questions than answers. This systematic review aimed to enhance our understanding on which spatial cognitive processes are important, and what role they play, in promoting performance and learning in minimally invasive surgery (MIS) (i.e. broad term for laparoscopy). Psychological and medical databases (i.e. MEDLINE PubMed, PsychINFO, ScienceDirect, Elsevier and Web of Science) were searched for articles published between 2006 and 2016 using Boolean terms such as ('spatial cognition') AND ('minimally invasive surgery') as well as specific combinations relating to specific visuospatial processes such as 'Mental rotation' AND 'minimally invasive surgery', for example. Grey literature, such as masters or doctoral dissertations, were also included in the review. Only studies that directly tested and explored spatial cognition in the context of MIS were included. Articles with a strong engineering focus or indirect exploration of spatial cognition were excluded. A total of 6,450 journal articles were identified in the databases and 1,900 articles through Google Scholar. After a rigorous screening process and the removal of duplicates, only 26 articles were found to match the eligibility criteria and were included in the review. See figure 3 for the flowchart depicting the selection process. Due to the heterogeneous nature of the existing literature, a meta-analysis was not possible.

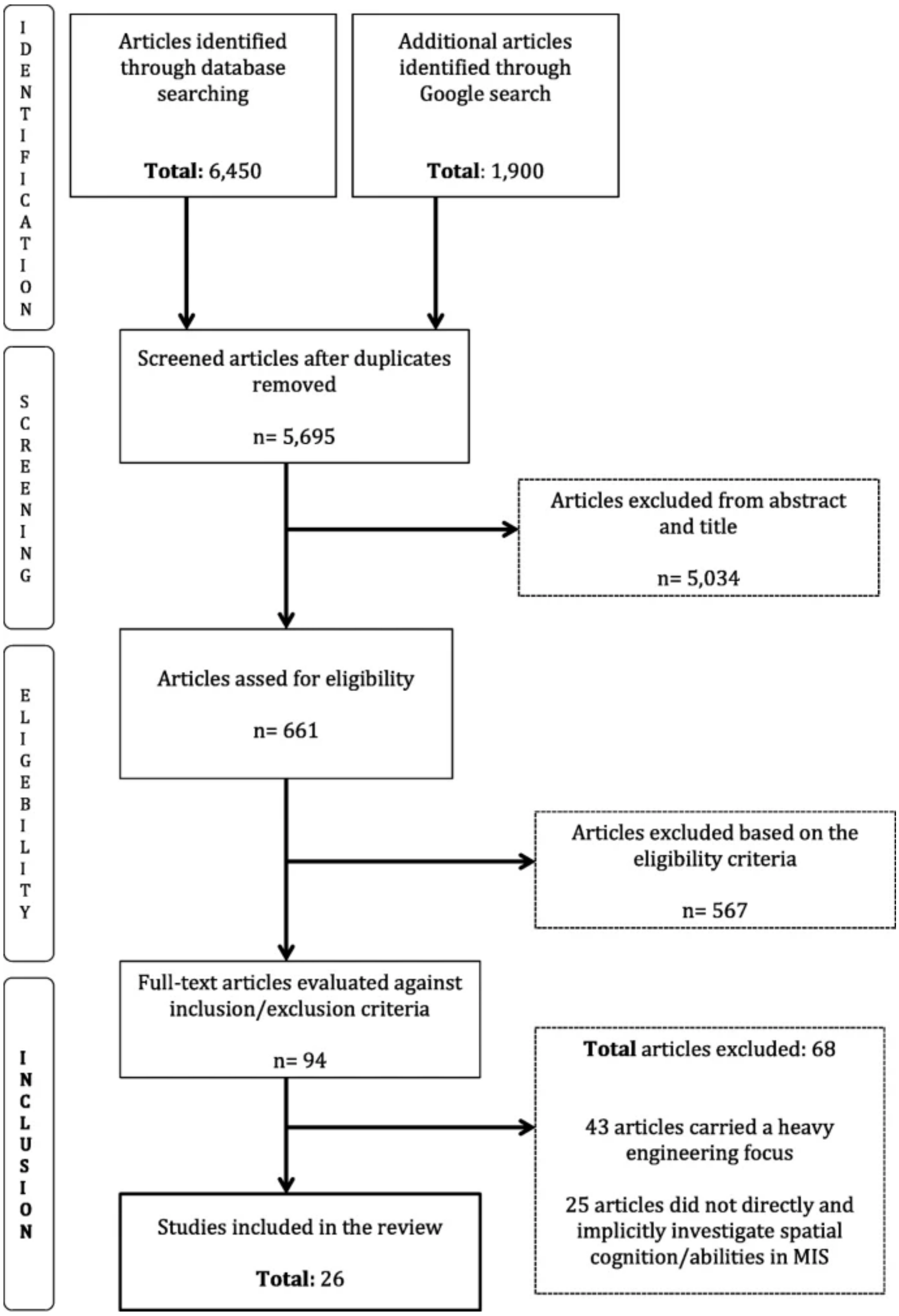


Figure 3. Flowchart illustrating the article selection process

In these 26 included studies in the review, 22 articles were correlational studies (i.e. exploring associations between spatial abilities and MIS performance), and four were experimental studies (i.e. comparing effects of spatial abilities on MIS tasks). Within these, four studies focused on exploring the role of VSA as a whole (Hedman, Ström, Andersson, Kjellin, Wredmark, & Felländer-Tsai, 2006; Keehner et al., 2004; Roach, Mistry & Wilson, 2014; Schlickum, Hedman & Felländer-Tsai, 2016), three explored spatial orientation (Sodergren, Orihuela-Espina, Clark, Teare, Yang & Darzi, 2010; Sodergren, Orihuela-Espina, Clark, Yang & Darzi, 2011; Fan, Dodou, Breedvel & Dankelman, 2014), mental imagery/practice (Komesu, Urwitz-Lane, Ozel, Lukban, Khan, Muir et al., 2009; Arora, Aggarwal, Sevdalis, Moran, Sirimanna, Kneebone & Darzi, 2010; Louridas, Bonrath, Sinclair, Dedy & Grantcharov, 2015) and perceptual and visuomotor ability (Klein, Warm, Riley, Matthews, Gaitonde & Donovan, 2008; DeLucia, Mather, Griswold & Mitra, 2011; Zhang & Cao, 2010). One study explored spatial scanning (Conrad, Shah, Divino, Schluender, Gurland, Shlasko & Szold, 2006), one depth perception (DeLucia, Mather, Griswold & Mitra, 2006), one spatial perception (Hassan, Gerdes, Koller, Dick, Hellwig, Rothmund & Zielke, 2007) and another the visual working memory (Hedman, Klingberg, Enochsson, Kjellin & Felländer-Tsai, 2007). Nine other studies investigated a combination of above abilities in one study (Haveran, Novitsky, Czerniach, Kaban, Taylor, Gallagher et al., 2007; Hsu, Man, Gizicki, Feldman & Fried, 2008; Kolozsvari, Andalib, Kaneva, Cao, Vassiliou, Fried & Feldman, 2011; Keehner et al., 2004; Luursema, Verwey & Burie 2012; Mistry, Roach & Wilson, 2013; Groenier, Schraagen, Miedema & Broeders, 2013; Utesch, 2014; Gronier, Groenier, Miedema & Broeders, 2015). Together, these studies included 1,214 participants: 673 undergraduate students (i.e. psychology or translational medicine), 353 surgical residents (all in 1st year of residency) and 13 experienced surgeons (attending or consultant).

The results of the systematic analysis revealed that spatial cognition appears to play a notable role in promoting skill acquisition and performance in MIS, albeit in the simulated tasks and the inexperienced novices only. The consensus in the literature was threefold: (1) visuospatial ability, as a unitary ability, significantly correlates with surgical technical performance, (2) mental rotation (measured by the MRT-A) is positively associated with initial surgical performance of novices only, and (3) individual differences in visuospatial ability did predict initial advantages in the rate of skill acquisition, in that residents with higher abilities acquired MIS related technical skills at a faster rate.

The review additionally highlighted some divergences and methodological limitations in empirical studies. The nature versus nurture debate is a particular example. Whereas some argued that innate abilities of the surgeon promote initial laparoscopic performance (Hedman et al., 2006; Keehner et al., 2008; Roach et al., 2013; Schlickum et al., 2016), others argued that these abilities improved as a direct consequence of laparoscopic practice (Hedman et al., 2006). Several methodological limitations currently hindering our comprehensive understanding on the topic were also noted in the scope of the review. First, all studies were conducted in simulated environments using either a physical box trainer or a virtual reality simulator. This was considered a significant limitation, indicating that there is currently little to no understanding of the relationship between visuospatial ability and actual intraoperative performance. The extent to which simulation tools accurately represent the cognitive, emotional, and technical complexities experienced in real operating situations are put into question. Second, the participants in these studies were largely medical students, surgical laypeople or very inexperienced surgical residents. Cognitive data from actual surgeons of all expertise levels is therefore currently missing. In particular the data from expert laparoscopic surgeons is lacking. Third, all studies explored the relationship between spatial cognition and simulated performance in the scope of either a one-time simulation session or a short training period (i.e. maximum 4 weeks). How spatial cognitive abilities develop and influence MIS skill learning over an extended period of time that may resemble the duration of actual surgical residency remains unaddressed. Together, these methodological limitations highlight that we currently have little to no understanding of the role of spatial cognition as it pertains to performance and learning outcomes of actual surgeons operating and training in the operating theatres. Such lack of empirical insight in naturalistic settings (i.e. operating theatre) warrants further investigations on the topic as apparent and pressing.

For more detailed information about the systematic review and its findings refer to my publication Vajsbaher, Schultheis & Francis (2018).

STUDY 1

Status Quo of Laparoscopic Education: A National Survey of German Surgeons

This survey study explores the perceptions and views of German surgeons on the topic of laparoscopic education, in an attempt to determine how laparoscopy is perceived, trained and taught across the country.

1 Introduction

Prior to understanding how laparoscopic skills are acquired and shaped by visuospatial ability, we must first understand the wider context in which these skills are developed. Healthcare policies and educational structures are known to bear influence over surgical training and its outcomes (Baker, Misra, Neil, Manimala, Kuy & Gantt, 2013). Accounting for these institutional and educational influences is therefore an important prerequisite for a more comprehensive understanding of surgical skill acquisition. Such understanding is particularly important when exploring skill acquisition in the context of the German training system. Unlike in other countries, surgical training in Germany is entirely work-based, lacks a clear structured training curriculum and is heavily influenced by the bureaucratic system (Drossard, 2019). To lay down the foundation for our later understanding of how laparoscopic skills are acquired by residency surgeons currently training in German hospitals, the current structure of surgical training in Germany ought to be first considered.

In Germany, surgical residency is regulated at the national and regional level. At the national level, the basic structure is regulated by the federal medical association, i.e. "Bundesärztekammer" (BÄK). The association is responsible for outlining and regulating the code of practice and training for all medical specialities in the form of a WBO model ("Weiterbildungsordnung"). In respect to the surgical residency training, the association regulates and determines the basic structure of the training system, such as the duration of training and the learning outcomes. That is, they determine what, and how many, tasks and procedures must be completed in the scope of training. Yet, the responsibility for implementing these national regulations and certifying training outcomes comes down to medical associations of each state in Germany ("Landesärztekammer"). In other words, surgical residency in Germany is not certified on the national level, but rather on the state level. As a result of bureaucracy, surgical training and certification regulations do differ slightly among the individual states. Surgeons have long criticised the structure of surgical training in Germany. Previously, the structure was categorised by a five-year basic training and a four-year late specialisation period and was argued as being too excessive by many. Such criticisms led to BÄK radically restructuring the entire surgical training system in 2005. The new structure is now characterised by a short two-year basic training period (*common trunk*), followed by a four-year specialisation period (*special trunk*) (Ansorg, Krones, Schröder, 2006). The overview of the current residency training structure is illustrated in the figure 1.1 below.

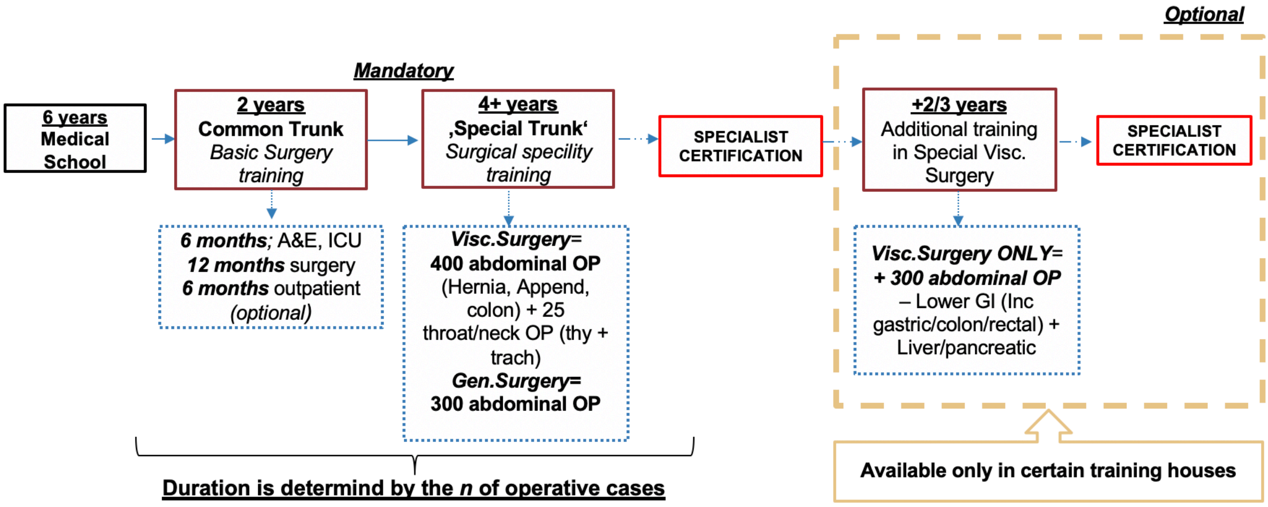


Figure 1.1. A schematic overview of the German surgical residency structure

Common trunk is a two-year training period in basic surgery, structured around clinical rotations across all surgical departments and ambulatory services. During this period, residency surgeons are expected to acquire basic knowledge and understanding pertaining to all aspects of surgical patient care and management. Considering the focus on patient-care, intraoperative training during this period is highly uncommon. After the common trunk period, residency surgeons can then select a speciality for further training. The *Special Trunk* is a four-year specialisation period. During this period, residency surgeons are tasked with acquiring all the necessary competencies needed to deliver high-quality patient care in their chosen surgical speciality. Surgical competence is assessed through a successful completion of all pre-specified number of diagnostics, therapeutic, surgical and non-surgical interventions (see figure 1.1.). These must be documented in the form of a catalogue ("Logbuch") provided by BÄK and signed off by the overseeing senior surgeon. Once the resident has satisfied all the requirements stated in the catalogue, one can apply for a specialist certification examination ("Facharztprüfung"). By successfully passing the examination, the title "specialist surgeon" ("Facharzt") is awarded and the career in surgery is attained. Yet in visceral surgery, a surgeon may opt for additional specialisation, granting one expertise in the more advanced surgical interventions, including laparoscopic procedures such as esophagogastroduodenoscopy. This optional three-year specialisation period is called *Specialized Visceral Surgery* ("Spezielle Viszeralchirurgie").

Yet, despite the restructuring of the surgical training system, the level of dissatisfaction among surgeons has risen over the last few years (Stiller & Kulka 2007). First, the current timeframe of six-years is deemed unrealistic by many. In reality, it takes most residency surgeons around eight to nine years to complete their training (Stiller & Kulka, 2007). This is because the duration of training is contingent on attaining the pre-specified number of tasks and procedures. Yet, the ability to do so is itself contingent on various institutional factors, including availability of operative cases, the distribution of cases, prevalence of the diseases, time spent on rotations and even the number of residents in the program. Second, the overall structure of surgical training has received extensive criticism from German residency surgeons. A survey study by Schröder (2006) reported that 57% of residency surgeons expressed high dissatisfaction with the unstructured training system. In respect to the quality and quantity of operative teaching, 63% of residents reported receiving surgical education not up to par with their needs and expectations. In another survey study, Ansorg et al. (2006) reported that 82% of residents felt as though their clinical directors responsible for their surgical education are not interested in their training progress (Ansorg et al., 2006). These reports can be mainly attributed to the number-based approach that the German surgical system follows, which provides residency surgeons with no overview of the specific and measurable learning objectives to strive for. In other words, the system equates competence with experience. How the resident learns and how well they are learning is entrusted onto the already overwhelmed clinical directors of respective clinics.

In light of these survey findings, we current have a general understanding of how residency surgeons perceive the general structure of the German surgical residency system. What now remains unclear is how laparoscopy is being trained and taught across the country. Considering laparoscopy is a challenging technique with a prolonged learning curve (Kim et al., 2015), understanding how laparoscopic skills are acquired in the scope of the surgical training system in Germany is needed. An introduction of laparoscopy in the scope of surgical residency has already been identified as a useful tool for combating the prolonged learning curve associated with the technique (Murgueitio, Cuevas, Diaz-Castrillion, Pinzon & Molina, 2019). Ensuring laparoscopic surgeons are adequately trained is critical considering lack of experience has already been identified as the leading causes of laparoscopy-based operative errors and complications (Krizek, 2000). Yet, the current status quo of laparoscopic education in Germany is unclear. As a result, we currently lack insight into the extent to which the bureaucratic and inhomogeneous surgical training system promotes and influences the acquisition of laparoscopic skills. Such lack of insight has already been described as one of the most significant issue facing German surgical education today (Axt, Johannik, Storz, Mees, Röth & Kirschniak, 2016).

This exploratory survey study aims to contribute such new insight by exploring the current status quo of laparoscopic education in Germany as perceived by surgeons nationwide. The primary objective of this study is threefold. First, to explore how laparoscopy is taught across the country. Second, to explore factors that surgeons view as contributing to the difficulties in the acquisition of laparoscopic skills. And third, to explore which, if any, institutional and educational factors may bear influence over the residents' ability to master laparoscopy in the scope of the German training system. Knowledge of the latter two constructs will further facilitate the interpretations of results from the longitudinal study conducted in the scope of this thesis, where laparoscopic skill learning of German surgical residents over time is explored.

2 Method

2.1 The 'Spatial Cognition in Laparoscopic Learning' Survey

Between September 2017 and January 2018, an online survey titled "Spatial cognition in laparoscopic learning" (in German "Raumkognition beim laparoskopischen Lernen") using a SurveyPlanet[1] platform was administrated to professional members of the German Society of Surgeons (*Deutsche Gesellschaft für Chirurgie* (DGCH)) and the Professional Association of German Surgeons (*Berufsverband der Deutschen Chirurgen* (BDC)). The survey targeted all practising and in- training laparoscopic surgeons around Germany. Following a purposive homogeneous sampling technique, no formal inclusion and exclusion criteria was defined. All surgeons currently practising, or in residency training, in Germany were invited to participate. The collaboration with the DGCH and BDC was sought for two primary reasons. First, the DGCH is one of the oldest and most influential surgical societies in Germany. Second, the BDC is one of the largest surgical institutions in Germany. Both societies are actively involved in offering surgeons across the nation with additional educational services whilst promoting and establishing new surgical standards and recommendations across all surgical specialists. Together, both societies have approximately 23,115 members of varying experience levels and surgical specialities.

A three-part survey containing 20-questions using a series of binominal, five-point Likert scale, matrix rating scales and one open-ended question was devised. These questions were carefully selected for collection of three surgeon-specific data: 1) demographic information and professional background, 2) surgical and laparoscopic experience, 3) attitudes and opinions of the role of spatial cognition in laparoscopy and laparoscopic education in the context of the current German training system. Section 1 (demographics) utilised a series of dichotomous, multiple-choice and rating scales to collect demographic information including age, gender, professional characteristics (e.g. seniority level of the surgeon) and

[1] https://surveyplanet.com

surgical specialisation. Section 2 (surgical experience) utilised a series of Likert-rating scales to collect data on the experience levels with laparoscopy. Section 3 (attitudes and opinions) included a series of Likert-scales, a matrix table scales and an open-ended question to collect insight into the difficulties associated with learning laparoscopy and the potential external influences bearing impact over such learning. The last open-ended question in the survey aimed to better understand what the surgeons view as being the biggest problem in learning laparoscopy in the context of the current surgical training system in Germany. See appendix 1 for the copy of the survey.

The survey took less than 10 minutes to complete. Limiting the survey to 20-questions and a maximum 10-minute limit mitigated some of the typical responding errors that can occur in survey studies, including drop-outs, motivation, response burden and content validity (Rolstadt, Adler, Ryden, 2011). Using an online survey design was also viewed as the best option for data collection, as it allowed for a faster distribution and greater flexibility and accessibility appropriate for the targeted population in this study. To protect the confidentiality and the anonymity of the participants, the survey was set to incognito mode. The anonymous mode recorded no person-specific data (e.g. name, address, employment, address, etc.) nor did it collect a digital footprint (Email address, I.P., etc.).

The initially designed survey was refined in collaboration with a clinical director and an expert laparoscopic surgeon (M.M), the vice-president of the BDC society (Dr.med. Jörg-Andreas Rüggeberg), the managing director (R.D) and the doctoral supervisor (H.S). The final version of the questionnaire was tested and piloted in collaboration with the managing director of the BDC, whose role was to advise on factual information and economical usage of the survey.

2.2 Survey distribution process

The online survey was distributed and advertised by both the DGCH and BDC. The call for participation template included information of b) the aim of the project,

c) thematic description of the study, d) my contact details and e) the link to the online questionnaire. The DGCH advertised the participation template on the main page of their website (https://www.dgch.de) under the 'Mitteilung der DGCG (Notifications from the DGCH)' section. The BDC advertised and distributed the questionnaire link using various platforms. Firstly, the call for participation was announced on the main page of their website (and their social media platforms (Facebook, Twitter). Secondly, all BDC members registered under the surgical division of general and visceral surgery, gynaecology, urology, orthopaedics and trauma surgery, were invited to participate via an email sent on behalf of the BDC. Finally, the call for participation was also advertised on the BDC email newsletter and their magazine' Passion Chirurgie'. A sample size of 400 potential responders was estimated across both societies.

2.3. Data analysis

The assumption of normality was evaluated to determine the distribution of the survey data for all 19 quantitative measures collected. A Shapiro-Wilk test ($p < 0.00$) confirmed all measures to be non-normally distributed. Non-parametric descriptive statistics such as frequencies (percentages), the median value and the interquartile range (IQR) will be used as the primary measure of central tendency to describe and visualise the data. Non-parametric Mann-Whitney *U* test will be used to explore group differences in survey responses. The data was analysed and visualised using IBM SPSS statistical package (version 26) and Microsoft Excel (version 16.16.27).

3 Results

3.1. Response rate and participants

A total of 48 surgeons responded to the questionnaire, three DGCH members and 45 BDC members. The sample size included 25 females (52%) and 23 males (48%). Among the participants, 12 (25%) were resident surgeons *(Assistenzärzte),* 13 (27%) were specialist surgeons (*Fachärzte)*, 16 (33%) were consultant surgeons

(*Oberärzte),* and 7 (27%) were clinical directors (*Chefärzte*). The sample included 20 (20%) visceral surgeons, 7 (14.6%) general surgeons and 21 (43.8%) general and visceral surgeons. The mean age was 46 years (*SD* = 12.04), with ages ranging from 25-70 years. The mean laparoscopic experience among resident surgeons was four years (*SD* = 1.93), and 12 years (*SD* = 7.77) among the specialists, consultants and clinical directors. Although the survey welcomed participation from any surgeon with laparoscopic experience, only general and visceral surgeons participated in this study.

From the estimated sample of 400 responders, only 12% responded. Considering the questionnaire was advertised by the BDC via emails, social media and societies magazine, the insufficient exposure of the survey was not to blame for the low response rate. I speculate that the low participation could be attributed to surgeons showing little interest on the topic of spatial cognition in laparoscopy. Regardless, the number of participants did satisfy the recommended sample size for minor sub-groups, which recommends a sample size of 20 to 50 to achieve an accurate representation of that sample (Sudman, 1985).

3.2 Overview of the demographic and professional profiles of the participants

The junior surgeons were predominantly female (80%), and senior surgeons were predominantly male (78%). Junior surgeons were mainly specialised in visceral surgery only (60%) whereas senior surgeons specialised in both general and visceral surgery (70%). The residents reported performing only one laparoscopic case a week, specialists surgeons an average of six cases a week and consultant surgeons reporting an average of 10 cases per week. Descriptive statistics highlighting the samples demographic and professional characteristics are illustrated in table 1.1.

Table 1.1. Descriptive overview of subjects' demographic and professional profiles

	Junior surgeons (*n*= 25)		Senior surgeons (*n*= 23)	
	RS (*n* = 12)	SAS (*n* = 13)	CON (*n* = 16)	CD (*n*= 7)
Gender	9 (75%) Female	11 (85%) Female	11 (70%) Male	7 (100%) Male
Specialisation				
Visceral surgery	7 (58%)	8 (61%)	4 (25%)	1 (14.3%)
General surgery	3 (25%)	2 (15.4%)	2 (12.5%)	0
Both general and visceral surgery	2 (16.7%)	3 (23.1%)	10 (62.5%)	6 (85.7%)
LAP per week	*Median* = 1	*Median* = 6	*Median* = 10	*Median* = 3

Abbreviations: RS (Resident Surgeon); SAS (Specialist surgeon); CON (Consultant Surgeon); CD (Clinical Director*);* LAP (Laparoscopic procedures)

3.3. Training in laparoscopic surgery

These questions were designed to capture the experience levels and confidence ratings on operating with the laparoscopic technique. First, surgeons were asked to give an estimate of how many laparoscopic cases, in total, they believe they performed during their residency. Resident surgeons were asked to estimate the total number of laparoscopic cases they have completed thus far. Residency surgeons reported performing an average of 20 (IQR=13) laparoscopic cases to date. The specialist's surgeons reported performing an average of 100 laparoscopic cases (*IQR* = 168) during their residency training. Consultant surgeons and clinical directors reporting having to complete an average of 270 laparoscopic cases (*IQR* = 250) during their residency. The boxplot comparing the estimated levels of laparoscopic experience gained during surgical residency are illustrated in figure 1.2.

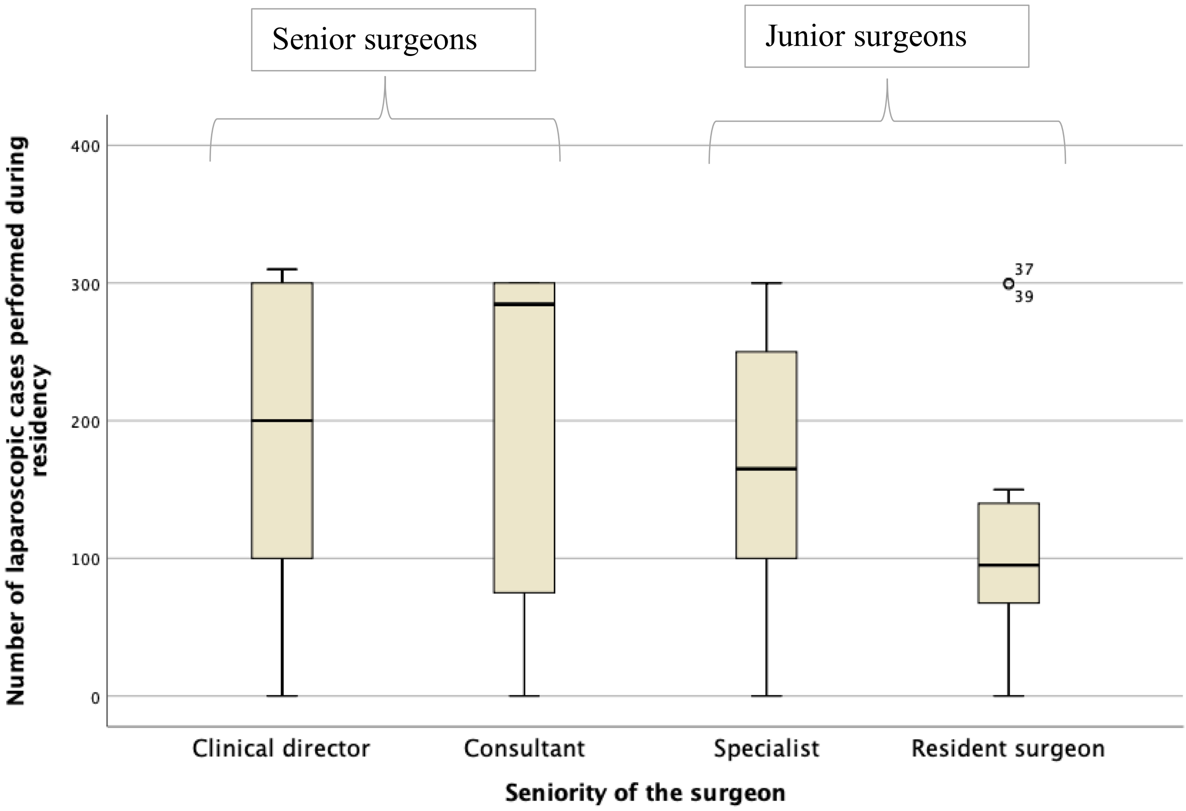


Figure 1.2. Boxplot comparing laparoscopic experience gained during residency training between senior and junior surgeons

Surgeons were then asked to think back to the end of their residency and rate the degree of confidence they had in operating a laparoscopic case as the main operator unsupervised. Residents were asked to rate their current confidence if they were to operate unsupervised. A 5-point Likert scale was used to explore their responses: 1. Very confident, 2. Confident, 3. Neutral, 4. Unsure, and 5. Very Unsure. When comparing differences in the degree of confidence in operating with laparoscopy after residency surgeons, senior surgeons expressed high confidence levels (Median= 2, IQR = 1), whereas junior residents reported lower confidence (Media*n*= 3, IQR = 4). The boxplot illustrating the rates of confidence with operating laparoscopic cases unsupervised after residency training is shown in figure 1.3 below.

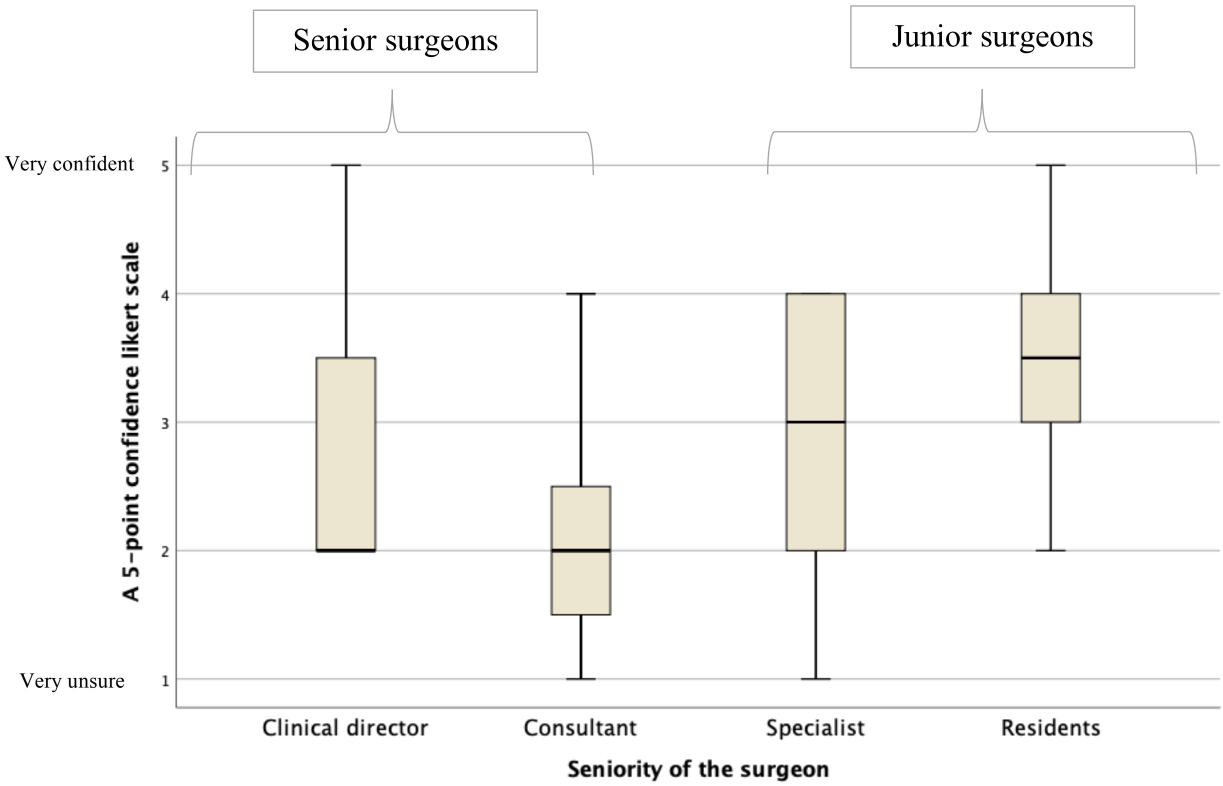


Figure 1.3. Distributional responses for confidence levels in operating laparoscopically after residency

3.4. Perceptions on difficulties and challenges associated with laparoscopy

These questions aimed to explore the perceived challenges and difficulties that surgeons associate with performing laparoscopy. First, it was of interest to examine which specific skills the surgeons find as most challenging when operating with laparoscopy. The surgeons were asked to rate the level of difficulty associated for each one of the three categories of skills: technical skills, spatial cognitive skills and non-technical skills (i.e. soft skills). These were explored using a 5-point Likert scale (1. Very difficult, 2. Difficult, 3. Neutral, 4. Easy, 5. Very easy). All participants rated technical skills (Median = 2, IQR = 2) and spatial cognitive skills (Median = 2, IQR = 1) as most challenging. The non-technical skills were rated as 'neutral' (Median = 3, IQR = 2).

Second, a Mann-Whitney *U* test was performed to explore differences in skill difficulty ratings between junior surgeons and senior surgeons. A significant group difference between ratings of junior surgeons and senior surgeons on spatial cognition was observed. Junior residents rated spatial cognitive skills (U= 210.00, p = 0.01) as significantly more challenging than the senior surgeons. A significant group difference in difficulty ratings on technical skills were also observed, with senior surgeons rating technical skills as significantly more difficult than junior surgeons (U=190.00, p = 0.03). No group difference in difficulty rating on non-technical skills were observed (U= 140.00, p = 0.39). The difference in mean ranks between the two surgical groups on technical, spatial cognitive and non-technical skills are illustrated in table 1.2.

Table 1.2. Mann-Whitney U values for group differences on difficulty ratings of technical, spatial cognitive and non-technical skills

N = 48	Senior surgeons	Junior surgeons
	Mean rank	**Mean rank**
Technical skills	12.75	10.04
Spatial cognitive skills	9.60	13.00
Non-technical skills	9.65	10.14

Following on the previous question, the surgeons were then asked to rate the perceived degree of difficulty of each one of the four laparoscopic-specific set of technical and cognitive skills. These included (1) orientation and navigation, (2) lack of tactile feedback, (3) bimanual coordination, (4) insertion of trocars and (5) structure identification. These specific set(s) of skills were chosen based on the consensus of the participating senior surgeons who helped in the development of this survey. A 5-point Likert rating scale (1. Very challenging, 2. Challenging, 3. Neutral, 4. Not challenging. 5. Easy) was utilised to explore the responses.

A Mann-Whitney *U* test was performed to evaluate the differences in difficulty rating responses between junior and senior surgeons. Significant group differences across most skills was observed. Junior surgeons rated skills of 'internal orientation and navigation' (U= 148.00, p = 0.01), 'internal structures identification' (*U*= 177.00, *p* = 0.02) and 'bimanual coordination' (*U*= 181.50, *p* = 0.02) as significantly more challenging than did senior surgeons. No significant group differences were observed on technical skills of 'trocar insertion' (*U* = 228.00, *p*= 0. 20) and the 'lack of tactile feedback' (*U* = 206.00, *p* = 0.67). The largest mean rank difference between the two groups was observed on cognitive factors, as illustrated in table 1.3.

Table 1.3. Mann-Whitney U values for group differences in skill difficulty ratings

n = 48	Orientation and navigation	Lack of tactile feedback	Bimanual coordination	Insertion of trocars	Structures identification
	Mean rank	Mean rank	Mean rank	Mean rank	Mean rank
Senior surgeons	18.43	20.96	19.89	21.91	19.70
Junior surgeons	30.08	27.76	28.74	26.88	28.92

3.5. Identifying possible influences impacting laparoscopic education in Germany

The last question of the survey explored the surgeon's views and opinions on the most significant challenges faced by the resident surgeons learning laparoscopy in the context of the German surgical training system today. The purpose of this open-ended question was to give the surgeons the possibility to further elaborate on their closed-ended answers or express other views and opinions on the topic in general. Out of 48 participants, 19 (39.6%) participants provided an answer to this question, among them three resident surgeons (15.8%), eight consultant surgeons (42.2%), four specialists (21.0%) and four clinical directors (21.0%). Examples of some of the provided qualitative responses per seniority group are provided below.

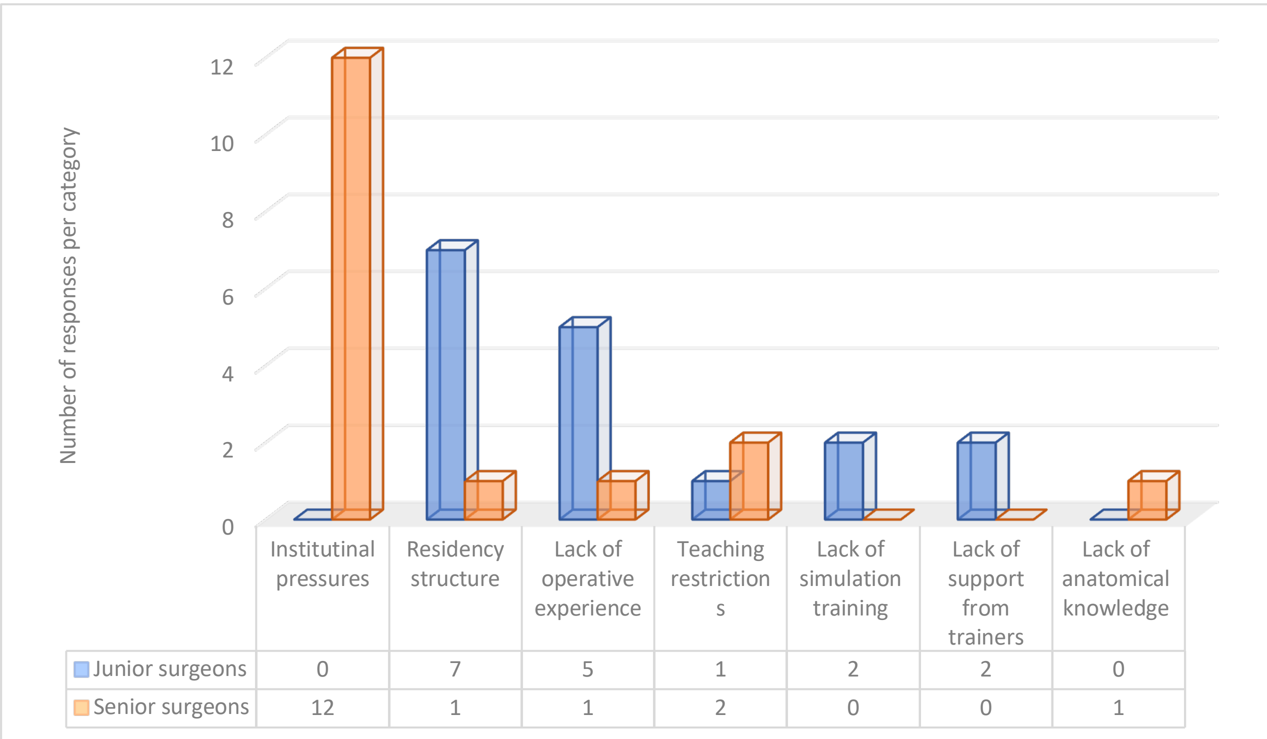
"I am nearly done with my residency and the idea of operating laparoscopically alone makes me a little anxious. The truth is we spend far too little time operating and when we do it's mostly assisting in little tasks. It's all down to your luck with the supervisor; some will actually allow you to operate and learn, whilst others will only allow you to hold the camera and observe." – Final year surgical resident

"I find it more stressful to teach laparoscopic surgery than I do open surgery. Firstly, it is much harder to actually demonstrate what I am teaching, and secondly, apart from yelling STOP!!, I have little to no direct control over the trainees' actions. Usually at that point the damage has already been done though." - Consultant general and visceral surgeon

"We know that not everybody has the skills to work as a visceral surgeon and the days of using patients as the 'tests subjects' must end. First, I would advocate for a workshop training certificate, as a mandatory requirement for selection onto a training program in visceral surgery; and secondly for residents already in training; just as a pianist has to invest 1,000 hours of practice before stepping onto the big stage and perform in front of a large audience, so should the surgeons. The era of using patients as learning tools is no longer realistic, nor ethical. – Clinical director of the department of general and visceral surgery

3.5.1. Identification of institutional and educational factors impacting laparoscopic education

A general inductive approach to coding survey's open-ended responses was used categorise responses into core themes. For the purpose of theme visualisation, principles of the generalisation design (Mayring, 2001) was followed to recode the qualitative responses into categories which were then counted quantitatively. The inductive coding approach follows the principles of grounded theory, whereby all themes and categorises emerged directly as the result of my interpretation of the raw data (Thomas 2006). The hand-selected thematic categories were extracted through a repeated word-by-word analysis of the responses. Excel spreadsheet was used to recode the core themes identified and assign numeric values of each response that corresponds with one or more core themes. The methods described by Srnka & Koeszegi (2007) were used as a guiding reference. The process called for 1) identification of core thematic categories that summarise the responses, 2) categorisation of the single-level themes into meaningful and detailed schemes based on the responses (i.e. dissatisfaction with training curriculum), 3) coding process of the emerged themes, whereby numeric units are assigned to each category and the number of responses for each category and quantitatively counted, finally 3) visual representation of the data. Factors perceived by surgeons as affecting laparoscopic education in Germany today include: 1) organisation and institutional shortcomings (e.g. time and cost pressure, centralisation of surgery etc.), 2) residency structure (e.g. unstructured and lacking concept), 3) lack of intraoperative experience (e.g. reduced operative exposure), 4) laparoscopic teaching restrictions (e.g. lack of intraoperative control), 5) lack of simulation training, 6) lack of teaching support and 7) resident surgeons lack of anatomical knowledge. A graphical illustration depicting the identified core factors and the corresponding number of responses discussing each factor is illustrated in figure 1.4 below.



	Institutinal pressures	Residency structure	Lack of operative experience	Teaching restriction s	Lack of simulation training	Lack of support from trainers	Lack of anatomical knowledge
Junior surgeons	0	7	5	1	2	2	0
Senior surgeons	12	1	1	2	0	0	1

Figure 1.4. Identified factors perceived as affecting laparoscopic education in Germany today

4 Discussion

The results of this survey contribute new insight on the current status quo of laparoscopic education in Germany. The findings have highlighted some important influences believed to be impacting laparoscopic skill acquisition in Germany today. First, junior surgeons reported gaining insufficient experience in laparoscopy during their residency training. As a result, they reported low confidence levels in operating with the technique as the main operator (i.e. alone). Second, junior surgeons view laparoscopy-specific spatial cognitive skills as far more challenging to acquire than technical skills. Third, clear differences between the expectations of junior surgeons and the opinion of senior surgeons were discovered. Junior surgeons believe that the current structure of the German residency system, lack of support from the surgical educators and an overall lack of operative experience are all factors hindering their efforts to acquire laparoscopic skills. Yet, senior surgeons believe that institutional limitations (i.e. cost and time pressures), surgeons lack of anatomical knowledge and the overall difficulty in teaching laparoscopy are all influencing factors keeping junior surgeons out of the operating theatre.

Together, these findings appear to suggest that the current status que of laparoscopic education may not be producing a new generation of competent and confident laparoscopic surgeons. As a result, it appears as if the old approach to surgical education is no longer rendered compatible with the needs and the expectations of the new generation of surgeons. A call for a paradigm shift in laparoscopic education is highlighted, whereby based on the findings of this study more training efforts should be paid towards addressing spatial cognitive complexities associated with laparoscopy. In an attempt to discuss these findings in a more comprehensive manner, the discussion section was divided into two section. The first section will discuss the current and future status quo of laparoscopic education and the second section will discuss the call for a paradigm shift in laparoscopic education.

4.1. The changing status quo of surgical education in Germany.

The data captured in this study provided new insights into how the current generation of surgeons entering the workforce may be challenging the status quo of surgery in Germany. One of these challenges being the ever-growing gender disparity in the field. The" old" status quo in surgery can be directly observed just by looking at the demographic and professional characteristics of the senior surgeons who participated in this study. They are male, specialised in both general and visceral surgery and hold senior leadership positions in their departments. In other words, they represent the old stereotypical cliché of surgery being an "old-boys" club. The new generation of surgeons, however, are predominately female and specialised in visceral surgery. These demographic characteristics nicely reflect the ongoing demographic shift taking place in the field of medicine today. As of right now in Germany, 93.946 students are enrolled in medical schools around the country. Out of these students, 61% are female, and 39% are male (Kassenärztliche Bundesvereinigung, 201). For means of comparison, in 1998, women made up around 48% of students entering medical school, whereas in 2016 women made up over 60% of all medical students (Bundesärztekammer, 2017). Nevertheless, even with the increased number of women entering the field of medicine, their interest in surgery remains low. Today, females only make up around 20% of the surgical workforce (Bundesärztekammer, 2018). Thus, considering the future of surgery in Germany is inevitably female, greater institutional and community-based efforts are needed to make the field of surgery a much more inviting and attractive option for the future generation.

4.2. Call for a paradigm shift in laparoscopic education

The changing status quo in surgery could also be bearing a notable influence over educational outcomes, calling for a paradigm shift in laparoscopic education. As shown by the results of this study, junior surgeons appear dissatisfied with the unstructured residency system and lack laparoscopic experience, confidence in the technique and support and guidance from the surgical educators. Residency surgeons in this study reported operating an average of one laparoscopic case per week, which if compared to the consultants 10 cases per week, is staggering low. Such discrepancy in numbers raises the question as to whether this is a common issue throughout the country or whether these number are clinic specific. Although this study cannot provide a definitive answer, the results are consistent with previous survey studies conducted in Germany. For example, numerous studies have reported surgical residents in Germany expressing dissatisfaction with (i) training being highly unstructured (Schrem, Machtens, Kleine, 2003) (ii) quality and quantity of teaching (Schröder, Bollschweiler, Leers, Vivaldi & Hölscher, 2005) and (iii) little operative teaching exposure (Ansorg et al., 2006). Thus, it appears that the results captured in this study may represent the opinion of many around the country, pointing towards a potential nation-wide institutional issue. Senior surgeons in this study argued that the main institutional factor keeping resident surgeons out of the operating theatres is the issue of time and costs. In hospitals around Germany, it is typical for surgical clinics to rent hospitals operating theatres. Thus, the snowball effect: The more complicated procedure, the longer the duration, the bigger the cost. This comes at a significant disadvantage to the residents, as intraoperative teaching of laparoscopy is associated with longer operating time (Agha & Muir, 2003). How much practice a resident receives is therefore also depended on the economic wellbeing of the hospital in which they train in. Laparoscopy is a challenging and difficult surgical technique to acquire and master, contingent on extensive training to overcome the learning curve. Against the background of this study's findings, the level of laparoscopic competence acquired by some German residency surgeons is called into question. Future research is strongly encouraged to take a more systematic approach in exploring the true quality of laparoscopic surgeons that the German residency system is producing.

In summary, the results of this survey study highlight that greater institutional and educational efforts are required to re-think how laparoscopic surgery is taught across the country. One possible alternative to intraoperative learning is simulation training. Simulation training tools (both virtual and box) have already been proposed as a useful alternative to intraoperative training, as technical skills show high transferability from simulated environments into the operating theatre

(De Win, Bruwaene, Kulkarni, Van Calster, Aggarwal, Allen et al., 2016; Palter & Grantcharov, 2014). Its use, however, remains highly heterogeneous across Germany however (Huber, Kirschniak & Johannink, 2017). To date, the focus in surgical training is predominantly on technical (i.e. dexterous) skills. Nevertheless, the findings of this study underline that younger surgeons find spatial cognitive skills to be more challenging compared to senior surgeons, who find technical skills more demanding to acquire. The underlying mechanism driving these group differences in difficulty perceptions are unclear. However, considering that younger surgeons in this study were predominantly female, one possible explanation could lie in gender itself. Spatial cognition is notorious for highlighting gender differences in spatial reasoning tasks, all favoring males (see review by Levine, Foley, Lourenco, Ehrlich & Ratliff, 2016). Considering these gender differences could perhaps explain why females find spatial components of laparoscopy more challenging. Yet, studies exploring gender differences in laparoscopic skill attainment has been mixed, with some finding clear gender differences in laparoscopic skill learning favoring males (Donnon, DesCôteaux & Violato, 2005; White & Welch, 2012), whereas others found no gender difference at all (Flyckt, White, Goodman, Mohr et al., 2017). Whether these gender differences in laparoscopic skill attainment are related to gender differences in spatial cognition, however, remains unexplored. Nonetheless, these findings do highlight that a more careful balance between teaching and assessing for both cognitive and technical skills is needed. In the context of live operation, educator can promote cognitive skill training through various methods including asking the resident to visualise the planned procedure pre-operatively (i.e. mental imagery), verbalise thoughts throughout the procedure on what they see and what they are doing and use probing questions to allow the resident to reflect on the situation and action taken.

Conclusion

This current survey study contributed new insights on how the current status quo of laparoscopic education in Germany is driving the need for a paradigm shift in surgical education. Factors such as the unstructured surgical residency program, lack of operative experience and confidence in the technique, and insufficient guidance from surgical educators have all been identified as hindering laparoscopic skill acquisition. Surgical educators and institutions should reconsider the traditional approaches to surgical education and enhance the current education practices through curricular structure, teacher-based approach and inclusion of alternative training tools that allow the surgeons to acquire both cognitive and technical skills outside the operating theatre. Only with such effort can we ensure that patient safety is maintained throughout the generations to come. An ongoing demographic shift has also been captured in this study. This raises the question as to whether gender may have to be considered in the scope of laparoscopic education. Whether females are at any disadvantage at attaining laparoscopic skills and the associated visuospatial abilities will be clarified in the scope of this doctoral thesis.

Generalizability of the findings

Although this study focused on laparoscopic education in Germany, the findings are consistent with those reported around the world. First, the ever-changing status quo is not unique to Germany, as the same uprising trend in females entering medicine has been reported globally (Davis, Risucci, Blair & Sachdeva, 2011; Ovaere & Jansen, 2017). Attracting women to surgery will therefore soon become a global issue. Second, insufficient operative experience in laparoscopy and consequently lack of confidence in the technique has also been reported around the globe (Furriel, Laguna, Figueiredo, Nunes & Rassweiler, 2013; Kolkman, Wolterbeek & Jansen, 2005). Reconsidering how laparoscopy is taught and how competence can be gained is therefore an important issue on the global scale. Yet, before understanding how competence is gained, one must first understand what laparoscopic competence actually is.

STUDY 2

What makes up a competent laparoscopic surgeon?

This qualitative study using the interpretative phenomenological analysis (IPA) approach explores surgical educators' perceptions on what conceptualises surgical competence and what make up a competent laparoscopic surgeon.

1 Introduction

The results from study one shed new insight pertaining to various challenges and organizational and educational factors currently keeping residency surgeons out of the operating theatres around Germany and the world. If resident surgeons are kept from operating laparoscopically due to the undesired consequences of their ineptitude in the technique, then it is critical to better understand what laparoscopic competence actually is, from the viewpoint of surgical educators themselves. That is, which set(s) of skills and abilities do surgical educators contribute towards a competent laparoscopic surgeon? Further considering that these educators are directly responsible for certifying competence in Germany, gaining such insight is an important step towards enhancing our overall understanding on the component structure of laparoscopic competence. Yet, such overall understanding is currently missing.

In the context of laparoscopic education, gaining insight into how laparoscopic competence is conceptualised by surgical educators is of added importance. First, no formal guidelines or requirements in training laparoscopy is provided in the current German surgical residency program. Although some surgical societies and associations do provide structured theoretical and practical courses, these remain optional and costly. Attending such programs is further contingent on the residents' own ambition and motivation and the hospital's goodwill. Second, no formal guidelines or proposed didactic structures for teaching laparoscopy is currently available. How laparoscopy is taught, and by whom, is not regulated. With this in mind, it is common practice for all certified surgeons to take on the role as a trainer, regardless of one's level of experience. Laparoscopy has already been identified as challenging to teach. A handful of train-the-trainer programs aiming to 'teach' surgical educators how to 'teach' laparoscopy are available in Germany today. Yet, these courses are not popular nor are they mandatory. Third, the current training system in Germany follows the 'old' apprenticeship model. As a result, resident surgeons across the country currently have no point of reference as to what competencies they are expected to acquire and what they should be able to do and demonstrate at the end of their residency. In other words, a clear and structured overview of the core competencies needed for laparoscopy is currently missing (Drossard, 2019). The responsibility for intraoperative training and certification of competence is entrusted to the already overwhelmed clinical directors and senior surgeons. How these senior surgeons perceive and conceptualize laparoscopic competence is therefore an essential prerequisite to our understanding of how competence is demonstrated in the operating theater.

As previously mentioned, there is paucity in the literature on what conceptualizes and makes up laparoscopic competence. However, there have been several attempts at conceptualizing surgical competence in general. To date, three prominent surgical competency frameworks from America, United Kingdom and Canada are currently informing surgical education practices around the world. In America, surgical residents are guided by the competency framework proposed by the Accreditation Council of Graduate Medical Education (ACGME) and American Board of Medical Specialties (ABMS). They both conceptualise surgical competence as demonstrating competent patient care, medical knowledge, professionalism, system-based learning and interpersonal and communication skills. In England, the Royal College of Surgeons of England (Irish, Carr, Sowden, Douglas & Patterson, 2011) provided a more comprehensive list of abilities that underpin surgical competence. They state a competent surgeon should possess (1) good technical knowledge and clinical expertise, (2) communication skills and adaptive behaviour, (3) leadership and team skills, judgement under pressure and (4) decision-making, situation awareness, problem-solving and professional integrity. In Canada, on the other hand, the Royal College of Physicians and Surgeons of Canada devised a more structured CanMEDS framework which describes the roles of a competent surgeon. That is, a competent surgeon is a medical expert, communicator, collaborator, manager, health advocate, scholar and a professional. The CanMEDS framework is arguably the most popular framework used by surgical educators across the globe, even serving as a foundation for the newly devised and soon-to-be-implemented competency-based residency curriculum in Germany (Steinhaeuser, Chenot, Roos, Ledig & Joos, 2013).

Albeit devised in good faith, these proposed competency frameworks have been heavily criticized by surgical educators as being too theoretical and simplistic, difficult to objectively measure in practice, hard to implement into the training curriculums, and not individual-based (Ellaway, 2016; Huddle & Heudebert, 2007; Whitehead, Austin, Hodges, 2011). In other words, it has been argued that these proposed frameworks do not accurately reflect the complexity and multidimensionality of surgical competence, nor do they address the day-to-day challenges faced by resident surgeons (Ellaway, 2016). Additionally, one can also criticise the common approach in the literature, which holds a common belief that by conceptualising the concept of surgical competence in general, one covers skills and abilities that apply to all operative techniques and approaches. A study by Cuschieri, Francis, Crosby & Hanna (2001) recognised these limitations in the existing frameworks and set out to better understand which skills and abilities make up a competent surgeon from the perspective of master surgeons. A Delphi reiterative process [2] with an expert panel of 44 surgical educators was utilized to achieve this aim. The authors concluded that master surgeons attribute cognition (i.e. intelligence and knowledge), innate dexterity (i.e. technical skills) and personality (i.e. decision-making, integrity, emotional stability, empathy etc.) as the most important attributes of a competent surgeon. Innate dexterity was emphasized as the strongest determiner of surgical competence, with cognition and personality being of secondary importance. In their discussions on endoscopic surgery (e.g. laparoscopy), the panel of experts further identified the ability to interpret and manipulate images (i.e. visuospatial ability) as an additional core aptitude underpinning competence. In context of endoscopy, visuospatial ability was highlighted as the core ability. The results of this study highlight that the component structure of laparoscopic competence may differ to that proposed for surgical competence in general.

This study focused primarily on providing a broad overview of aptitudes that underlie surgical competence, with visuospatial ability identified as only one

[2] An opinion polling process, structured in three steps: (1) an initial collection of views and opinions captured via questionnaires, (2) an interactive workshop where the data from the questionnaires is debated and (3) the final opinion-deciding questionnaire to conclude the final outcomes.

additional component for endoscopic interventions. A more fine-grained understanding of what defines and underlines laparoscopic competence remains unanswered. This current study aims to address the highlighted gap in the literature by exploring surgical educators' perception of what defines and conceptualizes laparoscopic competence. This will be achieved in two steps. First, interpretative phenomenological analysis (IPA) (Smith & Osborn, 2008) will be used to provide a detailed phenomenological account of surgical educators' views and perceptions on what defines and conceptualizes laparoscopic competence. One cannot presume that every educator will share the same belief and approach towards laparoscopic education, thus 'giving voice' to individual surgeons may amplify our understanding of what laparoscopic competence actually looks like. To the best of my knowledge, this is the first ever attempt at providing phenomenological insight on the topic of laparoscopic competence in current literature. Second, the delineated competencies emphasised by the senior surgeons will be used to devise and propose a first overview of a competency framework for laparoscopy. Together, these could shed further insight into what some surgical educators look for when certifying competence in the technique. Additionally, against the background of the longitudinal study conducted in the scope of this thesis, the results of this current study may also prove helpful when making inferences about the observed learning outcomes. For these purposes, all surgical educators taking part in this current study are from Klinikum Bremen-Mitte and Pius Hospital Oldenburg, the same departments taking part in the longitudinal assessment of laparoscopic intraoperative skill learning as introduced in study three and study four of this thesis.

2 Method

2.1. Participants

Overall, 13 subjects took part in this study; three expert surgical educators and ten interdisciplinary professionals sitting on the expert panel for the validation of the proposed competency framework. The expert panel included eight senior surgeons and two psychologists. The surgical educator cohort consists one clinical director, with 17 years of laparoscopic teaching experience, and two consultant surgeons, one with 15 years of teaching experience and the other with 12 years. These three expert educators were recruited based on their extensive experience in teaching laparoscopy and overseeing laparoscopic education in their respective clinics. The overview of the demographic and professional characteristics of the surgical educators is illustrated in table 2.1. The IPA relies on a small and homogeneous sample size (between 1 to maximum 10 participants). The sample size in this current study is therefore deemed as sufficient for achieving its proposed aims (Smith et al., 2008; Smith, 2011). No financial compensation was offered in exchange for participation.

Table. 2.1 Participants professional demographics and characteristics

Participant	Position	Specialization	Years of laparoscopic experience	Years of teaching experience
"Dr B"	Clinical director	Special Visceral Surgery*	17 years	20 years
"Dr J"	Consultant Surgeon	Special Visceral Surgery*	15 years	15 years
"Dr H"	Consultant Surgeon	Visceral Surgery	12 years	12 years

Notes: *Special Visceral Surgery ("Spezielle Viszeralchirurgie") refers to an (optional) advance specialization training ("Zusatzweiterbildung") in visceral surgery. *Abbreviations:* M; Male.

2.2. Interpretative Phenomenological Analysis (IPA)

The IPA is a qualitative analysis aiming to explore how individuals make sense of a certain phenomenon. In this study, the IPA approach will allow for a detailed exploration of viewpoints and opinions of educators away from any institutionalised biases or hospitals own philosophies. As described by Smith (2011), the IPA is concerned with studying human experience and how these are perceived. Its theoretical principles are based on the premises that even in the same environment, different people experience situations radically different. The strength of the IPA lies in its ideographic and purposive sampling technique, which aims to uncover and not merely describe. The IPA does not aim to generalise its findings to the wider population (Smith et al., 2008), but rather aims at providing an 'insider's view' into the opinion of the few. This qualitative methodology using an in-depth interview as means of data collection was deemed as the most suitable approach for gaining such insight.

2.2.1. Semi-structured interview

Semi-structured interviews were used as the main method of data collection, allowing for a more flexible and open dialogue with the educators (Smith, 2011). All questions were geared towards exploring the educator's experiences and opinions/attitudes on three main topics of interest: (i) categorizing surgical and laparoscopic competence, (ii) exploring the dimensions of laparoscopic competence and (iii) exploring the modus operandi of laparoscopic education in their clinics. The interview protocol included 30 questions, all serving as a guide for facilitating dialogue on a specific topic (see appendix 2 for the semi-structured interview protocol). An example of some of the main interview questions is provided in the table 2.2 below. Prior to the interviews, the face validity of the interview questions were revised by the doctoral supervisor (H.S), a surgeon specialised in surgical education (N.F), a clinical researcher specialised in visceral surgery (V.U), an expert visceral laparoscopic surgeon (M.M) and a student assistant working on the project (L.C.M).

Table 2.2 Examples of the interview protocol questions

1	How would you define surgical competence in general?
2	In your opinion, what makes up a competent laparoscopic surgeon?
3	Which skills and abilities do you look for in a competent laparoscopic surgeon?

2.2.2. Interview process

Face-to-face interviews took place between 10.11.2018 and 19.01.2019. All three surgical educators received verbal and written information about the data collection process prior to the interviews. The given consent granted permission for the interviews to be audio recorded and the transcribed data used for analysis and publication purposes (see appendix 3 for the data collection consent form). All interviews were conducted individually at each educator's respective hospital. As a result of this method, interviews were often interrupted by pagers, phone calls or clinical staff walking into the room. In these situations, the audio recording was paused and a brief summary of the question and their answer was provided before continuing with the interview. As a result of these interruptions, the interviews varied in length and depth. All interviews were conducted in German, to facilitate a natural dialogue with the educators' native language. The interviews were audio-recorded on a password-locked iPhone and saved onto a password-protected file on the office computer.

2.2.3. IPA Analysis

All interviews were transcribed using the verbatim approach (i.e. translated word-by-word). The transcripts were then subjected to a *back-translation process:* text was translated from German into English after which the translated text was re-translated back into German by a student assistant (L.C.M) who did not see the original translation. This quality-based process ensured the translated versions of the transcripts were accurate and of good quality. This was an important step considering the results of the IPA analysis are reported in English. Subsequently, the IPA analysis was conducted on the English version of the transcripts using the step-by-step procedure described by Smith et. al., (2008). (1) *"reading and re-reading"* of each transcript, documenting any thoughts and observations which may have occurred while engaging with the text, (2) *initial note-taking* for documenting the semantic content of the narratives, (3) *identifying the emerging themes* relevant to the whole topic and each specific question, (4) *looking for connections across the identified themes* by organizing the themes based on the study's research questions, using the means of abstraction (grouping similar themes together in a super-ordinate category), polarization (looking for differences in the themes) and contextualization (clustering super-ordinate categories based on the research questions) and finally (5) *identifying patterns across the superordinate themes across all cases.* To ensure the analysis was rooted in data, reflexivity was exercised throughout the analysis process. This was achieved by means of reflexive noting and bracketing technique, whereby any interpretations made from the text were noted and subsequently reviewed, to ensure the interpretations were not influenced by my own experiences or beliefs (Husserl, 1999).

2.3. Competency framework for laparoscopic surgery

For the construction of the competency framework, all verbatim transcripts were re-analysed and all identified competencies and their corresponding behavioural indicators extracted. The initial coding and extraction of the competencies from the transcripts followed the qualitative card-sorting method (as described by Morse & Field, 1996). In the first phase, all emphasised behaviours, skills, abilities or traits were extracted and written on individual cards. In the second phase, all cards were sorted and grouped into several broad categories (i.e. core competencies) based on their functional similarities. That is, all cognitive-based skills were grouped under cognitive skills category. In the third phase, all individual competencies from each broad category were further sorted and grouped into more specific sub-categories. For example, all visuospatial skills from the cognitive pile were grouped together into one 'visuospatial' category. This characterisation approach provided a more comprehensive overview of the overall structure and organization of the individual competencies. Finally, all extracted core competencies and sub-domains were categorized based on the number of mentions throughout the transcripts. Competencies emphasised by all three educators were included into the final framework. The final extracted dimensions and sub-domains were cross-referenced by two independent researchers (M.M & N.F) and an interdisciplinary panel of experts.

2.3.1. Expert panel demographics

The competency framework was subject to the validation process from an interprofessional panel of experts. The panel consisted of ten professionals from various fields: eight general and/or visceral surgeons (five consultant surgeons, one surgical fellow and two surgical residents) and two psychologists (one cognitive psychologist and one applied neuropsychologists). The task of the expert panel was to state their agreement on the component structure (i.e. the extracted core competencies and sub-domains) and the extracted behavioural indicators. Each member of the expert panel first received a copy of the framework. The panel discussions surrounding the framework were held over emails. The overview of the demographic and professional information of the expert panel subjects are shown in table 2.3.

Table 2.3. Demographic and professional information of the expert panel

Position	N	Gender	Years of practice	Year of lap experience	Country of practice
Consultant surgeons	5	M	19 years	16 years	Germany/ Austria/ UK
Surgical fellow	1	F	10 years	8 years	UK
Surgical resident	2	M	6 years	4 years	Germany
Psychologist	2	F	12 years	0 years	UK

Abbreviations: N= number of participants; M= male; F= female; lap = laparoscopy; UK= United Kingdom

3 RESULTS

The results of this study are presented in two sections: The findings from the IPA are discussed in section 3.1 and the competency framework for laparoscopic surgery is proposed and discussed in section 3.2.

3.1 The IPA findings

In reviewing the transcripts from the surgical educators, four superordinate themes were developed from the analysis: (1) 'Surgical competence extends beyond the operating theater', (2) 'Metacognition signifies laparoscopic competence', (3) 'Knowledge of anatomy as the prerequisite to laparoscopic competence' and (4) 'When to, and when not to, use the laparoscopic technique demonstrates laparoscopic competence'. Together these superordinate themes reflect the core categories that were emphasized by all educators throughout their interviews on the topic of what defines surgical competence and what conceptualizes and makes up a competent laparoscopic surgeon. The main outcomes of the IPA demonstrate that surgical educators perceive surgical competence as holistic, whereby competence is demonstrated across all stages of surgical care process. The knowledge of anatomy was described as the prerequisite to laparoscopic competence, which is then signified by metacognition and demonstrated through the surgeon's decision-making process as to when to, and when not to, operate with the laparoscopic technique. All generated superordinate themes and the underlying quotations extracted from the transcripts are described in table 2.4 below.

Table 2.4. The superordinate and subtheme identified in the IPA

Superordinate themes	Quotations from the transcripts
'Surgical competence extends beyond the operating theater'	• 'Operative success depends on the correct diagnosis and extraction of surgical indications' • 'Differential diagnosis based on a cluster of symptoms is an important ability' • 'Specialized knowledge of disease and surgical treatment is key to surgical competence' • 'Surgical competence is demonstrated perioperatively' [3]
'Metacognition signifies laparoscopic competence'	• 'Knowing the consequence of one's actions is a sign of laparoscopic competence' • 'Learning from mistakes and mistakes of others' • 'Reflect on/in action and monitor the progress carefully' • 'Awareness of one's strength and weakness drive laparoscopic success' • 'Competence means reflecting on one's skills and abilities and adapt accordingly.' • 'Know why, when and what one is doing'
'Knowledge of anatomy as the prerequisite to laparoscopic competence'	• 'Laparoscopic competence begins with competent knowledge of human anatomy' • 'Knowing 3D organs before operating in 2D' • 'Important for the correct identification and orientation inside the body'
'When to, and when not to, use the laparoscopic technique demonstrates laparoscopic competence'	• 'Know limitations and strengths of laparoscopy' • 'Correct use of the instruments • 'Know the boundaries to laparoscopic technique' • 'What is achievable and what not'

[3] The term *perioperative* refers to the three phases of surgical care; preoperative, intraoperative and postoperative care.

Theme 1. ***'Surgical competence extends beyond the operating theater'***

On a fundamental level, the educators unanimously felt that specialised clinical knowledge of the diagnostic and therapeutic process is an important prerequisite of surgical competence. Such knowledge was discussed by all as the necessary foundation of competence, upon which decisions and execution relating to the operative treatment relay on;

> *"Surgical competence begins with the accurate diagnosis…then goes through the balance of differential diagnoses, to select the correct and* [the most] *appropriate surgical procedure*" [Dr. H]

> *"I would define surgical competency in general as the ability to recognise and diagnose conditions based on the clusters of symptoms, and use these to appropriately extract indications for surgery. This is the first step. To determine which operative technique to use and utilise the technique appropriately and efficiently is the second step*" [Dr. J]

> *"In my opinion, surgical competency is demonstrated through the initial diagnosis and indications for surgery. These must be absolutely correct*" [Dr. B]

No educators conceptualised surgical competence as relating strictly to intraoperative performance. Dr. J discussed intraoperative performance in respect to the procedural knowledge of knowing "*how a procedure should be executed and carried out*", whilst Dr. B discussed intraoperative performance in respect to demonstrating "*a competent execution of the intraoperative treatment".* All educators felt that surgical competence follows a certain holistic narrative, whereby competence should address various professional activities of the surgeon, and not just specific tasks. Dr. H and Dr. J both discussed demonstrating appropriate knowledge at both the preoperative and intraoperative stages as important. Dr. B, nonetheless, strongly emphasized that surgical competence addresses all professional activities of the surgeon (i.e. perioperative care model). Suggesting that believes surgical competence is demonstrated in perioperative model, competence must be demonstrated from the patient's admission (preoperative), to the patient's treatment (intraoperative) and the patients discharge (postoperative);

> *"Surgery consists of three stages … the pre-operative diagnostic stage, the operative treatment and the post-operative care at the intensive unit or wards. That is surgical competency"* [Dr. B]

Theme 2. '*Metacognition signifies laparoscopic competence'*

The educators expressed belief that laparoscopic competence is not determined by merely having a set(s) of knowledge and skills, but rather by the surgeon's ability to assess, monitor and reflect on one's own performance and abilities. Overall, two metacognitive processes were highlighted as important; meta-knowledge, which is the awareness of one's skill and abilities and meta-regulation, which is self-reflection and monitoring on and in action. Together, these metacognitive processes were discussed as signifying laparoscopic competence. Meta-knowledge was described by the educator's ability to be aware of what you know, and what you don't, described by the educators as;

> "[What makes up a competent laparoscopic surgeon] is *knowing one's own strengths and weaknesses"* [Dr. J]

> *"*[Laparoscopic competence] *means surgeons assessing their own abilities and plan therapeutic approaches that reflect these"* [Dr. H]

> *"The surgeon must know what he is doing, where is he doing it, and how his doing it"* [Dr B]

Meta-regulation was best described by Dr B, who expressed the notion that surgical competence entails utilizing prior knowledge for monitoring of one's cognition and the existing state of knowledge during tasks;

> "[During the procedure] *it is important to monitor each step to know 'yes, this is it'…so the approach can be optimised. This is critical for ensuring safe* [laparoscopic] *treatment"* [Dr. B]

> "[To label a resident as competent in laparoscopy*] they must show curiosity and self-reflection. So, this means… how fast can someone learn from their mistakes? Can they learn from mistakes from others? How fast can they identify their own mistakes and correct them? It's about the curiosity of their own mistakes...and the ability to monitor and self-reflect on those during the process. That's what I look for in a competent surgeon'* [Dr. J]

Theme 3. '*Knowledge of anatomy is the prerequisite to laparoscopic competence'*

The knowledge of anatomy was identified and numerously emphasized by all as a critical component of laparoscopic competence, without which a successful performance would not be possible. Dr. B strongly associates the lack of anatomical knowledge with the inability to operate laparoscopically;

> *"A* [competent] *laparoscopic surgeon must master anatomy. Someone who doesn't know anatomy cannot operate laparoscopically. What helped me was my experience in open surgery and my love for anatomy."* [Dr. B]

Dr. J and Dr. H, on the other hand, merely felt that knowledge of anatomy is an important facilitator of laparoscopic performance, helping one to correctly identify anatomical structures, guide their actions and orientate oneself inside the body;

> *"Competency means, as I said, knowing the anatomical structures…, the normal anatomy … and its possible variations … and apply these in a targeted and low-risk manner"* [Dr H]

> *"Anatomy is of course very important for laparoscopy… if you know your anatomy, you can learn to identify layers in situs more easily which will help you operate more smoothly*" [Dr J]

Theme 4. *When to, and when not to, use the laparoscopic technique demonstrates laparoscopic competence*

The ability to know when to, and when not to, use the laparoscopic technique was identified by the educators as the key observable trait of a competent laparoscopic surgeon. Dr. B for example believes that the ability to do so is what distinguishes a competent laparoscopic surgeon from a skilled one;

> "[A competent laparoscopic surgeon must] *know the limitations of the laparoscopic procedure to be able to say 'I can tackle this laparoscopically'. At a certain point in time, he must be able to say 'It doesn't work, I must convert* [to open procedure]'. *This, in my opinion, is the most important ability that distinguishes a competent laparoscopic surgeon from a skilled one"* [Dr. B]

Dr. H believes that laparoscopic competence entails knowing the limitations of the technique and using such knowledge to continually update one's intraoperative progress, in an attempt to recognise when the treatment is no longer solvable by the technique and a conversation to an open procedure is needed;

> *"What I think is important is to say or to realise when something is not solvable with the* [laparoscopic] *technique so that one can convert* [to open procedure]" [Dr. H]

Dr. J, on the other hand, attributes the knowledge of the laparoscopic technique as fundamental, as he believes that it dictates all aspects of laparoscopic performance, from the preoperative decision as to which procedure should be laparoscopically tackled, decisions relating to where to operate and finally, the decision as to when the technique is no longer useful in achieving a set therapeutic goal;

> "[A competent laparoscopic surgeon] *must master knowing when the laparoscopic approach is useful, how it can be useful and when the technique is no longer useful. The last one is very important"* [Dr. J]

3.2 Competency framework for laparoscopic surgery

3.2.1 Expert panel review

The expert panel's validation of the framework yielded clarity on aspects that were initially overlooked. Six experts stated their approval and agreement with the initial structure of the framework without any additional recommendation for change. Four experts, however, did make a few recommendations. Three senior surgeons suggested to rename the core dimension of 'clinical competence' into 'professionalism', arguing that the listed sub-domains relate more to professional skills than they do clinical skills. The dimension of clinical competence was subsequently renamed into professional skills. One psychologist argued that psychomotor skills, which were initially under the technical skills dimension, should be moved under the cognitive skills dimension. The initial rationale for underpinning psychomotor skills under technical skills was based on the notion that the identified skills such as instrument handling and the execution of surgical tasks (i.e. suturing, dissection) are based on the psychomotor execution, and therefore belong under the same category. Categorising psychomotor skills under technical skills is also a common practice in the surgical literature. Upon a group discussion between the two psychologists on the expert panel and myself, a convincing argument drove the re-classification of psychomotor skills under cognitive skills. Technical skills identified by the educators refer to the laparoscopic-specific bimanual dexterity and instrument handling, whereas psychomotor skills refer to the more sophisticated execution of precise motor responses through higher-level cognitive processing of attention (i.e. executive control) and problem-solving skills. In this sense, psychomotor skills were found to be a better fit residing under cognitive skills as oppose to technical skills. Based on these suggestions, the framework was modified and sent back to the expert panel for review. Out of ten panel members, seven experts (70%) accepted the final revision of the framework. Three experts (30%) did not provide a written confirmation but did verbally confirm they accept and agree with the final version of the framework.

3.2.2. Final competency framework of laparoscopy surgery

Overall, six core competencies and 16 sub-domains were emphasised by the educators as making up a competent laparoscopic surgeon: (1) metacognition, (2) cognitive skills, (3) technical skills, (4) knowledge, (5) professional skills and (6) soft skills. Although all extracted attributes were emphasised as important for shaping laparoscopic competence, they were not attributed a particular order of importance by the senior surgeons. Thus, the current order of extracted attributes does not represent a hierarchical structure of laparoscopic competency as determined by the surgical educators, but rather my own broad categorization based on the generated themes. To validate my initial efforts, all participating senior surgeons and a multidisciplinary panel of experts were asked to review and state their agreement on the current component structure of the framework, the categorization of core competencies and sub-dimensions and the extracted examples for each sub-dimension. All generated core dimensions, sub-dimensions and behavioural examples represent the order of emphasis are listed in table 2.5 below and a graphical depiction of the competency framework illustrated in figure 2.1 below.

Table 2.5. Core competencies of the laparoscopy framework

Core dimension	Sub-dimension	Themes from the transcript
Metacognition	*Meta knowledge*	Knowledge of one's own abilities', capabilities, strengths and weakness
	Meta regulation	Self-monitoring, self-reflection, adaptive behavior, evaluation of outcomes
Cognitive skills	*Visuospatial skills*	Mental transformation (2-D into 3-D), spatial perception, spatial orientation
	Higher-order skills	Decision-making, problem-solving, situational awareness
Technical skills	*Basic surgical skills*	Suturing, dissection, needle handling, dissection, knot tying, trocar insertion
	Laparoscopic instrument handling	Knowledge of electrosurgery
Knowledge	*Specialized knowledge*	Human anatomy and topography, knowledge of diseases, diagnostics, surgical indications
	Technical knowledge	Laparoscopic instrument and its use, camera angle and optical rotations, boundaries of laparoscopy
	Foundational knowledge	General knowledge of medicine and clinical practice
Professional skills	*Patient centered-care*	
	Evidence-based approach	
	Deliberate practice	
Soft skills	*Personality traits*	Patience, perseverance, resilience, curiosity, motivation and ambition
	Personal skills	Endurance, diligence, frustration tolerance and work ethic
	Interpersonal skills	Communication, team-work, verbal leadership skills, active listening

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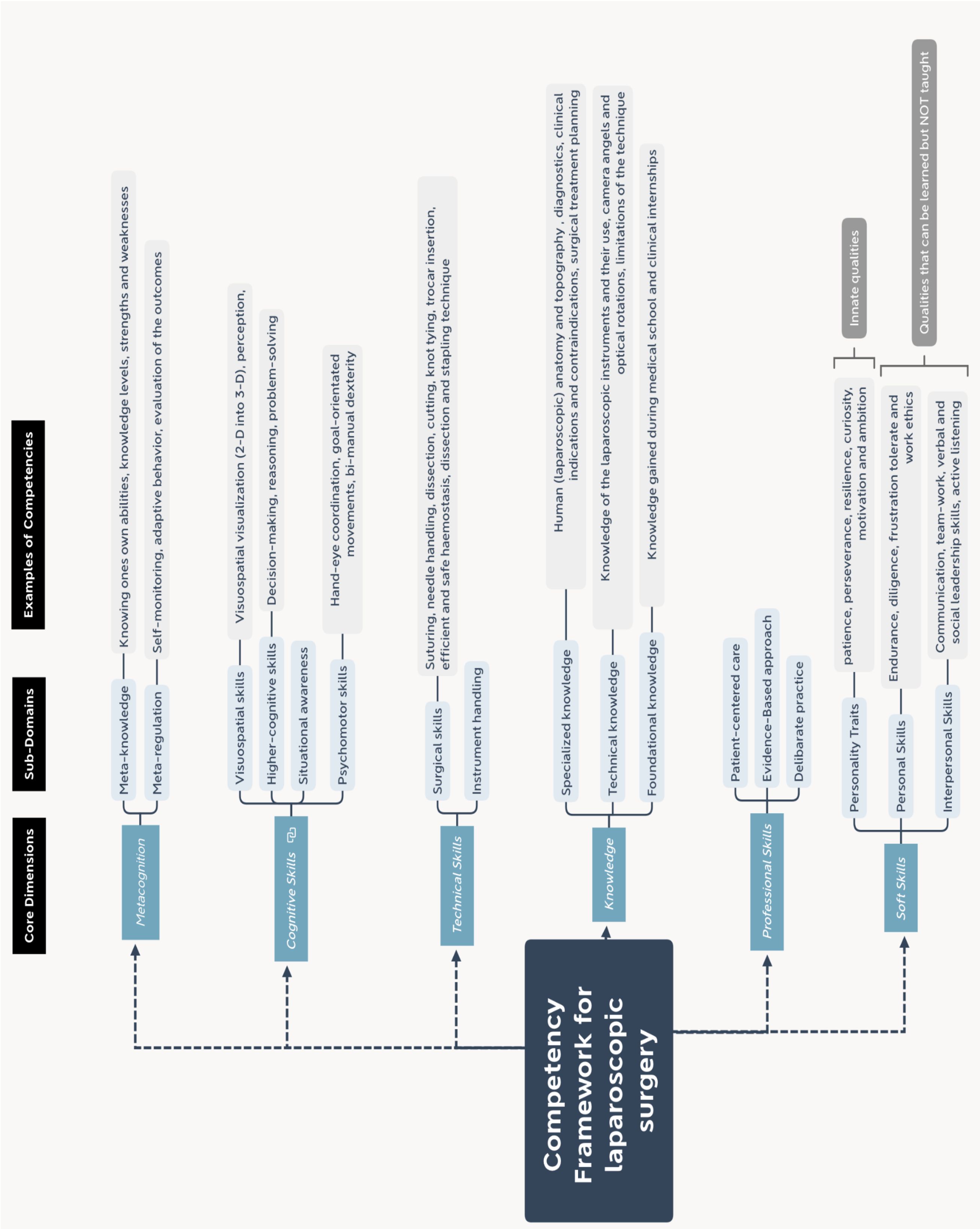


Figure 2.1. Illustration of the hypothesised competency framework for laparoscopic surgery

3.2.2. Definitions and descriptions of core competencies in the framework

1.) Metacognition

In Latin, the prefix 'meta' translates to 'above'. The term metacognition, therefore, refers to an 'overarching' high-level cognitive ability used to monitor, plan and assess one's understanding and performance on/in action. Within the transcripts, metacognition was highlighted in the statements as '*the surgeon must reflect and monitor their progress'* and '*the surgeon must know what he is doing, where is he doing it and how he is doing it*'. Two key components of metacognition were highlighted by the educators: meta-knowledge and meta-regulation. Metacognitive knowledge refers to the awareness of one's knowledge, that is, awareness of what one knows and does not know. This was expressed as the surgeon's ability to '*know one's own strength and weaknesses*' and '*assessing their own abilities'.* Metacognitive regulation refers to one's ability to be aware, monitor and control cognitive processes in action, discussed in the context of '*it is important (for the surgeon) to monitor each step to know 'yes, this is it'...so the (approach) can be optimized*' or '*chose therapeutic approaches based on one's own strengths and weaknesses*'.

2.) Cognitive skills

The category of 'cognitive skills' encompasses various emphasised lower and higher-level mental processes required for laparoscopy. Metacognitive processes, albeit cognitive in nature, were not characterised under cognitive skills due to the fundamental differences that underlie them. Cognition broadly refers to the process of collecting and processing information, whereas metacognition broadly refers to the knowledge of such information processing (Shea, Boldt, Bang, Yeung, Heyes & Frith, 2014). For laparoscopy, the key cognitive skills emphasised were visuospatial skills, decision-making, situational awareness and psychomotor skills. These were further characterized by the educators as following the perioperative model. Visuospatial skills, situational awareness and psychomotor skills were attributed to operative performance, whereas decision-making, reasoning and problem-solving were deemed as crucial throughout the perioperative process. From the identified cognitive skills, educators most frequently emphasised visuospatial skills throughout the transcripts. A particular emphasis was placed on spatial visualisation, referring to the mental transformation of three-dimensional objects from a two-dimensional viewing platform. This ability was discussed by the educators as one of the most challenging, yet important, attributes underlying laparoscopic performance, as is highlighted in the educator's accounts below.

"The most difficult thing in laparoscopy is getting used to the 2-D visualisation...so... moving the instruments in various axis as seen from the two-dimensional monitor... the time between cognition and action is something that takes time and practice to master. Once you get the feeling for how the three-dimensional organs appear on the two-dimensional screen...and how they look like from different angles...you will be more able to identify anatomical layers and most importantly move around the layers, which makes the rest of the procedure clearer....if there is bleeding or inflammation the visualization is distorted...which means you lose your orientation and you must convert...so you have to be very aware of the environment and make quick and correct decisions" [Dr. J]

"The difficulty with laparoscopy is the two-dimensional visualization...you have to always re-think everything in your head. The lack of haptic feedback is also difficult to compensate for...the surgeon must rely on his vision to know if the tissue is soft, hard, did I miss it? It all comes down to maintaining the awareness of what is happening...to be able to re-think everything you see into 3D and make correct decisions based on what you see" [Dr. B]

"With the laparoscopy what you see in the camera or on the screen must be translated into your hands...this is what many find difficult...to translate the three-dimensional image of the stomach from the 2D image... not the left- right movement but estimating the depth is what causes problems… the "How far do I have to go in with my instruments to reach something inside? This means rethinking 2D to 3D and have situational awareness" [Dr. H]

3.) Knowledge

Knowledge was described as an important foundation upon which laparoscopic competence builds on, in a hierarchical order. At the lowest level is foundational knowledge, which encompasses a broad range of medical knowledge and basic skills acquired during medical school and/or clinical internships. The second level deals with technical knowledge, which refers to knowledge of the laparoscopic equipment (e.g. instruments, camera angles and optical rotations) and the corresponding technical limitations of the technique. Lastly, at the top tier lies specialised knowledge, a category that includes knowledge of human anatomy and typography, diagnostic and clinical indications suggesting a laparoscopic approach and devising a treatment plan that can be achieved by using this technique. Examples of the educators' accounts on the importance of knowledge are provided below.

"Knowledge of human anatomy is critical for any surgical field. In laparoscopy, in addition, what is also essential is knowledge of typography of the abdominal wall...this is needed for the correct placement of trocars. [Competence] *begins with basic knowledge which is gained during the medical school. The really good ones* [residents] *will already enter residency with some fundamental knowledge of surgery and its principles"* [Dr. J]

"[Laparoscopic competence] *depends on knowledge of anatomy, the diagnostic process and therapeutic approaches. Most often catastrophes don't occur because of the surgeon but because he has chosen the inappropriate procedure"* [Dr. H]

"There are a lot of instruments used in laparoscopy...so it's critical [for the surgeon] *to knowing precisely how they work"* [Dr. B]

4.) Technical skills

When discussing operative performance, technical skills were identified as important for laparoscopic competence, albeit indirectly. Its importance was mostly hidden in statements such as '*execute the procedure competently*' or '*must demonstrate skilled manual performance*'. These technical skills were described as dexterity-based skills, which include basic surgical skills (i.e. suturing) and instrument handling. Together, these technical skills allow the surgeon to coordinate and manipulate laparoscopic instruments, resulting in a competent intraoperative performance as highlighted by the educator's own accounts;

"The first thing is mastering the technical aspects of laparoscopy…basically mastering the instrument handling so you can perform surgical tasks such as suturing under the laparoscopic view. Second is knowing the optical rotations and maintaining the horizon…the angular alignment is critical…if i'm working ventral to the abdominal wall then I have to obviously adjust the optics so I get the view from below" [Dr. J]

"One of the first technical things to learn is handling of the instruments and the camera…after that laparoscopy mainly relies on dissection and perforation which is done through ultrasound equipment or the bipolar dissection tools. This requires having the knowledge and experience to use these correctly" [Dr. H]

"[A competent surgeon] *must master how to tie knots, cut tissue and learn how to handle the instruments. This is the first requirement before operating on a live patient"* [Dr. B]

5.) Professional skills

Professional skills such as following a patient-centered approach, practicing evidence-based care and engaging in deliberate practice were also highlighted as important attributes of a competent laparoscopic surgeon. These traits were discussed in the context of the career-based competency, traits which add professional value and credibility to the surgeon as a competent care provider and member of the medical community. As described by the educators below, these skills ensure that the surgeon commits to lifelong learning and personal development and bases one's surgical practice around the code of ethics and a sense of duty of service, where patients care and concerns are placed above the surgeon's own self-interest;

"It's always important for the surgeon to consider whether laparoscopy is a reasonable choice for a certain patient with a certain clinical characteristic, which is based on the best available scientific evidence" [Dr. J]

"Good, in surgery everything comes down to experience, so one must always continue to learn to master it. This takes time. You are not born with these skills. There are surgeons who can acquire laparoscopic skills faster, and there are those who need time, but without deliberate practice and experience, it won't work" [Dr. B]

"There is a saying we live by, which our boss likes to say… the patient is most important!" [Dr. J]

"The patient is the number one priority" [Dr. B]

6.) Soft skills

Personal attributes used to describe the characteristics and/or qualities of a competent laparoscopic surgeon, or one's level of interaction with others, were all grouped under the category of soft skills. Throughout the transcripts, the educators attributed three person-specific soft skills to a competent laparoscopic surgeon: personality traits, personal skills and interpersonal skills. In respect to the personality traits, qualities such as patience, perseverance, resilience, curiosity, motivation and ambition were highlighted. In respect to the personal skills, the educators attributed endurance, diligence, frustration tolerance and work ethics to a competent surgeon. Finally, interpersonal skills, such as good communication, teamwork and leadership skills, were also emphasized as significant. The accounts from the educators' discussing the importance of soft skills in the context of laparoscopic competence are provided below.

"The ability to communicate effectively is critical, definitely" [Dr. H]

"A competent surgeon is someone who is diligent and emphatic, someone who shows curiosity and ambition." [Dr. J]

"A surgeon must have good people skills. Someone who walks into the patients' room right after the operation screaming is not a good surgeon" [Dr. B]

4 DISCUSSION

This present study contributes first phenomenological insights into the conceptualisation of laparoscopic competence from the perspectives of surgical educators and has put forward a first hypothesised competency framework of laparoscopic surgery.

The findings revealed that surgical educators conceptualise surgical competence following a holistic integrative approach (Drisko, 2015; Hager, 1994). Namely defining competence as a complex integration of knowledge, cognitive abilities, technical skills and personal traits that become evident in the clinical performance at each phases of surgical care. Their views are largely consistent with those proposed by the existing competency models (e.g. ACGME, CanMEDS), which argue that surgical competence extends beyond the operating room and encompasses a wide range of observable behaviours and characteristics - from knowledge, to technical skills to personal and interpersonal traits. However, what distinguishes conceptualisation from surgical educators to those proposed by the existing models is the notion of process vs outcomes. The educators in this study view surgical competence as a process of how competencies collectively contribute towards competent behaviour at each stage of surgical care, whereby the existing models merely account for the observable behavioural outcomes that demonstrate competence in practice. In other words, the educators believe that surgical competence is not merely possessing a set of traits and abilities, but rather, is the process of how these traits and abilities are integrated to arrive at correct diagnosis, devise an appropriate treatment plan, demonstrate a skilful operative performance and deliver safe postoperative therapy. They follow a holistic view which argues that competence cannot be observed, but rather can be inferred through performance (Drisko, 2015). These narratives contribute new insights into the evaluation and certification process of a few surgical educators in Germany. They also highlight the apparent divergence between what some surgical educators view as competence and what the German training system defines as competence. The highlighted divergence is between the holistic process as described by the educators versus the experience number-based approach described by the German training system. If these observed divergences bear any clinical significance remains to be explored. In particular it would be interesting to determine whether resident surgeons certified as competent by the German system would also be certified as competent by the educators themselves. Such understanding would carry significant implications for surgical education in Germany. Additionally, these narratives also raise an interesting point for discussion pertaining to surgical assessment and training. Although the holistic approach is better at reflecting the complexities of the real-life surgical scenarios, the highlighted integration process is difficult to assess. More empirical effort is needed to clarify how certain ill-defined competencies involved in the integration process could be objectively measured. To date, surgical competence is mainly assessed using objective measures focusing on rating specific set(s) of surgical skills and abilities that underlie operative performance only (Datta, Mandalia, Mackay, Chang, Cheshire & Darzi, 2002; Fritz, Stachel & Braun, 2019; Mitchell, Arora, Moneta, Kret, Dargon, Landry, Eidt et al., 2014).

In respect to laparoscopic competence, the educators believe that competent behaviour starts with knowledge of the human anatomy, is signified by the surgeon's metacognitive skills and is demonstrated in the decision-making pertaining to when, and when not to, operate with the laparoscopic technique. The placed importance on knowledge of human anatomy was unsurprising, considering understanding anatomy under the laparoscopic view is what drives safe and effective laparoscopic performance (Muavha, Ras & Jeffery, 2019). As emphasized by one educator, "*someone who doesn't know anatomy cannot operate* *laparoscopically."* In the context of laparoscopy, knowledge of anatomy is crucial for making the correct diagnosis (e.g. differentiating between variations of structures), identify and navigate around anatomical landmarks and manipulate the tissue (Tubbs & Sing 2015; Mikhail, Scott & Hart, 2014). The emphasised significance of metacognition, on the other hand, was an unexpected finding. Metacognition is known to play an important role in the development of professional competence (Wilhelmsson, Pelling, Uhlin, Dahlgren, Faresjo & Forslund, 2012), yet, its importance in laparoscopy is not widely recognised in surgical education literature. From the transcripts, two metacognitive processes were emphasised by the educators as signifying laparoscopic competence; meta-knowledge and meta-regulation. Meta-knowledge stands at the core of metacognition and dictates individual's awareness of their own cognition (i.e. awareness of one's knowledge and lack thereof). Meta-regulation, on the other hand, refers to observing, reflecting and monitoring in/on action in a given situation. Namely, it allows an individual to actively monitor and regulate one's thinking and behaviour in a goal-directed manner (Dominguez, 2001). Considering laparoscopy is a challenging technique to perform and master, there is some merit to the proposition that metacognition may play an important role. For example, it seems reasonable to presume that metacognitive abilities may facilitate surgeon's comprehension of the complexity of the surgical case at hand. These processes could help the surgeon dictate which particular declarative or procedural knowledge ought to be applied to a specific surgical situation (DePaola & Slavkin 2004; Turns & Noel Van Meter, 2011). Metacognition could also play an important role in promoting surgical autonomy (i.e. a confident and independent surgeon). Self-reflection and self-monitoring abilities are known to contribute towards autonomous learning and behaviour (Turner, 1989). Additionally, self-reflection and self-monitor could also contribute towards the surgeon's ability to correctly gauge the difficulty of the task, monitor their comprehension of the situation, reason in/on action, plan ahead, evaluate their success and adapt their behaviour or strategies when needed (Hartman, 2013; Schraw, 2009). The notion that metacognition signifies laparoscopic competence does conceptually hold some merit.

Metacognition could also be linked to the educators' attributed importance of knowing when to, and when not to, use the laparoscopic technique. This decision-making process relies on a careful and ongoing monitoring of one's performance such as reflecting on the process, retrieving relevant knowledge and cognitive strategies, assessing one's capabilities, detecting errors and prompt correction. This brings forward a point for speculation that perhaps the information gathered during such metacognitive evaluation could be used to form judgements, make decisions and guide actions as to whether the surgical problem should be tackled laparoscopically or through an open incision. Decision to convert from laparoscopy to open surgery is a particular example where metacognition could play an important role. In laparoscopy, conversion mainly occurs due to either the misperception of human anatomy or operative complication and error (Coomarasamy, Shafi & Chan, 2016). In such cases, the failure to make accurate and swift decisions to convert can compromise patient safety. A study by Dominguez (200) aimed to better understand the decision-making process underlying laparoscopic conversion. In her study, experienced and resident surgeons were shown a video of difficult and risky laparoscopic cholecystectomy (gallbladder removal). The video of the operation was high-risk, as it included a distended gallbladder, thickened wall and gallstones and the pericholecystic fluid, all factors indicating inflammation and consequent poor visualisation of anatomy under the laparoscopic view. She asked her participants to provide a live commentary on what they observed and whether the procedure should be converted to open incision. Her study showed that experienced surgeons were more aware of the limitations of laparoscopy and were, therefore, consequently more active in monitoring the progress of the operation. Experienced surgeons were more actively monitoring the screen for anatomical landmarks that would indicate whether the procedure should be converted. All made the correct decision to convert. Resident surgeons, on the other hand, predominantly failed to notice the risks in the procedure, nevertheless, expressing higher levels of comfort with continuing the procedure laparoscopically. There was, however, one similarity between the experienced surgeons and resident surgeons that made the correct decisions to convert: metacognitive abilities. Dominguez (2003) argued that surgeons who correctly identified the critical landmarks and made the correct decision to convert also made more metacognitive statements. These surgeons were found to closely monitoring and tracking each step of the operation whilst demonstrating self-reflection in the process. These findings give further support to the notion that metacognition may, perhaps, play an important role in shaping laparoscopic competence.

In respect to what makes up a competent laparoscopic surgeon, the educators' attributed six core competencies and 15 underlying skills and abilities to the concept of laparoscopic competence. Together, these constructed the first hypothesised competency framework for laparoscopic surgery. The attributes making up a competent laparoscopic surgeon were identified as metacognition (e.g. meta knowledge and meta regulation), cognitive skills (e.g. visuospatial, psychomotor, decision- making), specialised knowledge (e.g. human anatomy and laparoscopic technology), technical skills (e.g. basic surgical skills and instrument handling), professional skills (e.g. patient centred-care) and soft skills (e.g. communication and empathy). A successful demonstration and integration of these identified skills and traits across each step of laparoscopic patient care leads to one being certified as a competent laparoscopic surgeon.

Implications of the findings

The results revealed that surgical and laparoscopic competence are conceptualised following the holistic integrative approach, suggesting competence cannot be directly observed but can be inferred from performance. These findings carry some important considerations for surgical education and future researchers on the topic.

First, visuospatial ability was highlighted as one of the core attributes underlying laparoscopic competence. These accounts give further weight to research studies that found that the visuospatial ability is positively associated with laparoscopic competence (Louridas et al., 2016; Risucci, 2002; Spence & Feng, 2010; Wanzel et al., 2002). Nevertheless, the educators placed a particular emphasis on spatial visualisation (i.e. rethinking three-dimensional anatomy into the viewed two-dimensional representation) as one of the most notable attributes of laparoscopic competence. There is ambiguity in the existing literature on which visuospatial abilities play the most important role in promoting laparoscopic performance (Vajsbaher et al., 2008). The results of this findings raise first insights into the conceivable importance of spatial visualisation in shaping laparoscopic competence. Additionally, knowledge of anatomy and metacognition were also identified as core attributes underlying laparoscopic competence. Although these two constructs are not directly accounted for in this thesis, these could be reflected in intraoperative assessments of bi-manual dexterity (e.g. instrument coordination in respect to anatomy), tissue handling (e.g. interaction with anatomy) and autonomy (e.g. safe and independent performance).

Second, the results of this study implicated metacognition as an indicator of laparoscopic competence. These findings highlight an important new avenue for future research in surgical education. Confirming the role of metacognition in the context of laparoscopic competence could carry significant implications for how laparoscopy is trained and taught. For example, metacognitive strategies could be used to encourage residents to critically reflect on their performance in a *meaningful* way, motivating one to become an independent and self-regulated learner. Unlike in other countries around the world, resident surgeons in Germany are seen as employees rather than "students". Without any formal classes or academic input, it is common for the residents to immerse themselves into their role as a care provider as opposed to their role as a learner. Exercising metacognitive strategies could serve as a reminder that their function is to learn, increasing their motivation towards self-initiated learning. Metacognitive teaching strategies could also be implemented into the residency curriculum with little effort. The educators could support residents metacognitive thinking through explicit teaching, guided questioning, reflective practice and self-evaluation practices. With more empirical insight, possible implications of integrating metacognitive principles into surgical training could become more apparent.

Finally, the results of this current study enhanced our overall understanding of what makes up a competent laparoscopic surgeon from the perspective of surgical educators. This framework took the first step in laying down an important foundation for future empirical efforts. The goal of surgical education is to ensure that future generation of surgeons can provide safe and efficient surgical care. By devising a competency framework which reflects these expected standards, the process of assessment, training and certification could be further facilitated in a more structured manner. Additionally, such a structured overview of the expected learning objectives and competencies can assist resident surgeons in clarifying, organising and prioritising their own laparoscopic skill learning and provide them with means to evaluate their own progress. Future researchers are encouraged to expand on this framework and design a competency framework that could be used to inform current training practices.

Limitations

This study is not without limitations. I acknowledge that the response bias that may have emerged during the interview couldn't have fully been eliminated. All educators in this study were aware of my research interest of exploring the role of spatial cognition in laparoscopy surgery. Some could therefore argue that their knowledge of my interest could have driven them to discuss spatial cognitive processes only for these purposes. Although such an assumption cannot fully be dismissed, it must be noted that certain steps were taken to avoid such predicaments. Interview questions were deliberately formulated using a semi-structured approach, utilising a broad set of questions such as 'what do you believe makes up a competent laparoscopic surgeon' and "what do you look for in a competent resident surgeon?". Thus, although bias was not fully eliminated, I do argue it was minimised. Finally, I similarly acknowledge that personal bias during the IPA analysis and the construction of the themes couldn't have been completely eliminated. Yet, to minimise its effects, reflexivity was practiced throughout the analysis and all theme generation and were always reviewed by an additional individual (L.C.M) with no previous knowledge on the topic of spatial cognition in laparoscopy.

Conclusion

In conclusion, this study is the first to contribute a phenomenological insight into the conceptualisation of laparoscopic competence from the perspective of educators and the first to propose a hypothesised component structure of laparoscopic competence. The results from the IPA analysis highlighted that surgical educators conceptualised surgical competence as a complex integration of knowledge, skills, abilities and personal traits demonstrated in clinical performance at every stage of surgical care. Laparoscopic competence was conceptualised as starting with knowledge of anatomy, signified by metacognition and demonstrated with accurate decision making on when to, and when not to, operate laparoscopically. These results highlight that laparoscopic competence cannot be observed but can rather be inferred through performance. These findings carry important considerations for surgical education. The results also reveal that a competent laparoscopic surgeon is made up of metacognition, cognitive skills, knowledge, technical skills, professional skills and personal skills. A successful integration of these skills and traits throughout all stages of laparoscopic care signifies a competent laparoscopic surgeon. Visuospatial ability was particularly emphasised by the educators as the core component of laparoscopic competence. With this in mind, the next step is to determine whether laparoscopic surgeons of all expertise levels do actually possess better visuospatial skills than medical laypeople and explore the influential role of visuospatial ability over intraoperative performance of residency surgeons.

STUDY 3

Laparoscopic surgeons are expert visuospatial thinkers: Fact or fiction?

This study aims to determine whether visuospatial ability can predict and distinguish between laparoscopic surgeons of all expertise levels and explore how these abilities relate to intraoperative laparoscopic performance of residency surgeons.

1 Introduction

The results from study two demonstrate that surgical educators view visuospatial ability as one of the core components of laparoscopic competence. Spatial visualisation was particularly emphasised as a notable attribute of a competent laparoscopic surgeon. However, the true extent of its influence over intraoperative performance remains largely unclear. Significant methodological limitations are currently clouding our understanding of the role of visuospatial ability in laparoscopic performance (Vajsbaher et al., 2008). What is currently known about the influence of visuospatial ability is based on research findings where medical laypeople and inexperienced residency surgeons were tested on simulation-based tasks. As a result, there is a lack of insight into whether actual laparoscopic surgeons, in particular surgeons with the expertise in the technique, actually possess good visuospatial abilities.

The question concerning whether visuospatial abilities bear any influence over actual intraoperative performance of residency surgeons of all experience levels is yet to be analysed. Nevertheless, numerous studies exploring the relationship between the visuospatial ability and performance on simulated tasks of largely inexperienced residents and medical laypeople have already shown a positive association over performance outcomes (Ahlborg et al., 2012; Harrington et al., 2018; Keehner et al. 2006; Risucci, 2002; Wanzel et al., 2002). Whether the same influence can be observed in the scope of actual intraoperative laparoscopic performance remains unanswered. In addition, the question as to whether visuospatial abilities can help distinguish between surgeons with different levels of laparoscopic experience also remains unclear.

To date, there have been few empirical efforts paid towards exploring visuospatial profiles of surgeons in general. The reported findings so far have been largely divergent. One of the earliest studies exploring visuospatial profiles of master (i.e. highly experienced) surgeons was conducted by Francis, Hannah, Cresswell, Carter & Cuschieri (2001). In their research attempt, 20 senior surgeons and 20 medical students completed a series of psychometric tests assessing eye-hand coordination test, manual dexterity test and the visuospatial ability (e.g. spatial relations ability). Their results revealed that master surgeons do not possess better visuospatial abilities compared to medical students. In fact, the results revealed that master surgeons showed worse performance on the visuospatial test than the medical students. However, it is interesting to note that studies exploring visuospatial performance of surgeons using a larger sample size yielded different results. A study by Risucci (2002) aimed to determine whether surgeons possess better visuospatial abilities than the general population. In his study, 301 senior surgeons and residency surgeons were tested on multiple visuospatial batteries (e.g. Cognitive Laterality Battery) and compared to the normative sample. The results revealed that surgeons significantly outperform the general population when measuring spatial visualisation. These findings were further confirmed by Henn, Gallagher, Nugent, Seymour, Haluck et al. (2018), who administrated three visuospatial batteries (e.g. Card Rotation test, Cube Comparison test and Map-Planning test) to 239 residency surgeons and 61 control subjects. Consistent with the findings by Risucci (2002), their results revealed that resident surgeons significantly outperformed the control group on all visuospatial measures.

In summary, many empirical uncertainties are currently hindering our understanding of the true impact and influence of visuospatial ability in laparoscopic performance. In particular, we currently lack knowledge and understanding as to 1) which (if any) visuospatial abilities categorises an expert laparoscopic surgeon, 2) whether laparoscopic surgeons of varying experience levels actually possess better visuospatial abilities than medical laypeople, and 3) how visuospatial abilities influence intraoperative laparoscopic performance of residency surgeons of all training levels. This current study aims to address this gap in the literature and break ground by contributing new insight into whether laparoscopic surgeons of all experience levels are expert visuospatial thinkers and whether visuospatial abilities do bear influence over actual intraoperative laparoscopic performance of residency surgeons across all years of training. To do so in a more concise and comprehensive manner, both research questions will be addressed in two separate investigations. Investigation one seeks to explore visuospatial profiles (i.e. aptitude performance) of 43 practicing laparoscopic surgeons of all expertise levels (i.e. from a resident who just started training to the most senior laparoscopic surgeon in the department) and quantitatively compare these profiles to a group of medical laypeople (i.e. control subjects). The aim is to determine whether expert (i.e. senior) surgeons are in fact expert visuospatial thinkers and whether visuospatial ability can help to distinguish between surgeons of varying expertise levels and the control group. These findings also seek to contribute new insight to spatial cognition research into the component structure of visuospatial ability, which is currently under debate. Investigation two builds on the longitudinal study by exploring the associations between visuospatial performance and intraoperative laparoscopic performance of 26 residency surgeons across all training years. Baseline visuospatial and intraoperative assessment data from residency surgeons and control subjects will be used as means of analysis. The aim of this investigation is to determine whether visuospatial abilities, do in fact, bear any influence over actual intraoperative performance. Together, both investigations seek to break new ground on the topic by drawing inferences directly from a group of actual laparoscopic surgeons, across all expertise levels, inside the operative settings.

Investigation 1. Establishing visuospatial profiles of laparoscopic surgeons

This investigation explores the visuospatial cognitive profiles of laparoscopic surgeons of varying levels of laparoscopic expertise. The aim is to determine (1) the component structure of visuospatial ability, (2) whether laparoscopic surgeons possess better visuospatial abilities compared to medical laypeople, (3) whether visuospatial abilities can distinguish between an expert laparoscopic surgeon, a resident surgeon and a control subjects, and finally, (4) whether laparoscopic experience can predict aptitude performance of surgeons.

1 Method

1.1 Participants

Overall, the visuospatial performance of 62 subjects were analysed in the scope of this investigation. The sample included 43 laparoscopic surgeons (26 residency surgeons and 17 senior surgeons) and 19 control group subjects. The residency cohort consists of seven common trunk residents (i.e. 1-2-year residency), ten junior resident surgeons in their 3-4 training year and nine senior resident surgeons in their final year of residency (i.e. 5-6-year residency). The expert surgeon cohort consists of two surgical specialists ("Facharzt"), 12 surgical consultants ("Oberarzt") and three clinical directors ("Chefarzt"). The average years of laparoscopic experience reported amongst residents is 4.8 year (SD = 2) and 18 years (SD = 11) among the experts. The control group consists of students from the University of Bremen and the general population. The sample includes five bachelor computer science students, two master's public health students, ten bachelor psychology students and two individuals from the general population: one fitness trainer and one housewife. The basic demographic information of senior surgeons, residency surgeons and control group participants are illustrated in table 3.1.1 below. The consent form for participations in this study for each cohort group can be found in appendix 4.

Table 3.1.1. Demographic characteristics of the three participating groups

	Senior surgeons n=17	**Residency surgeons** n=26	**Control subjects** n=19
Gender			
Female	4	13	12
Male	13	13	7
Age			
Mean (SD)	48 (3)	33 (4.2)	25 (3.1)
Range	39-67	26-37	21-37

1.1.1. Pair-matched design overview

The aptitude data from resident surgeons and the control group subjects analysed in this investigation are baseline measurements collected in the scope of the longitudinal study (i.e. study four). There, control subjects were pair-matched with residency surgeons currently in laparoscopic training. Considering the structure of the German residency training system (see study one page 28), resident surgeons in common trunk training (i.e. 1-2 year of residency) normally do not assist in, or perform, surgical interventions. Thus, the 19 control subjects in this study were pair-matched with 19 residency surgeons participating in the longitudinal study. The aptitude measures of common trunk surgeons were included in the analysis of this study, albeit not following the matching method. The recruitment of control subjects was as follows: First, any subject interested in participating was initially screened based on the following criteria: a healthy individual with no previous experience of working in the medical profession, no prior experience in psychometric testing and no history of cognitive or neuropsychological impairments. Second, all underwent an initial interview and participated in four aptitude tests (see section 1.2). The variables of gender and similarities in aptitude scores across all tests were then used as a criterion for pair-matching (see appendix 5 for the overview of the pair-match data). Where possible, surgeons and control subjects were also pair-matched on age. Considering the control group was required to participate in regular aptitude testing throughout a period of two years, recruitment was not without its challenges. A strict match design based on age and gender was therefore not always possible. However, all subjects were strictly paired based on a similar pattern of psychometric performance on the four tests. In an attempt to maximise motivation and retainment rate amongst the control participants, a financial compensation was offered (see appendix 6 for the information around financial pay-out of the control subjects). Surgeons did not receive any monetary incentive. Their participation will, however, be rewarded with joint publications of the study's findings.

1.2 Visuospatial aptitude tests

Four previously validated visuospatial psychometric tests were used in this study: (1) the Perspective Taking/ Spatial Orientation Test (PTSOT) (adapted by Hegarty & Waller, 2004), (2) a modified Guay's Visualization of Views Test (GVVT) (adapted by Hegarty, Keehner, Khooshabeh & Montello, 2009), (3) a revised Mental Rotation Test (MRT-A) (Peters, Laeng, Latham, Jackson, Zaiyouna & Richardson, 1995) and the (4) Pictorial Surface Orientation (PicSOr) (Gallagher, Cowie, Crothers, Jordan-Black & Satava, 2003). The number of batteries was purposely limited to four to minimise cognitive fatigue and time spent on aptitude testing. This specific set of aptitude tests were selected based on existing research findings which have shown a positive correlation between laparoscopic performance and these measures (Vajsbaher et al., 2018). All selected measures do appear to closely resemble the multidimensional conditions encountered in laparoscopic surgery (e.g. 2-D into 3-D mental and spatial visualisation, perspective-taking and spatial orientation). The use of these tests will also allow for a better comparison between research findings, considering most of our current understanding on the topic is based on data collected using the MRT-A and PicSOr measures. All aptitude measures were administrated on a computer tablet using the digital writing function to simulate the real pen-and-pencil conditions, allowing for a more environmentally friendly approach to data collection and maximised security of the sensitive data collected.

***1.) The PTSOT** test* depicts a series of two-dimensional images with its directional instructions. Subjects are first instructed to imagine standing next to a specific object on the image (i.e. a tree) and then envision themselves facing another object depicted on the test (i.e. cat). The task is solved by drawing the direction that represents that envisioned direction to a specific object (i.e. point to the flower) onto the circle depicted on the test (see dotted line in figure 3.1.1). The test consists of 12 items with a time-limit of 5 minutes. Participants were not allowed to physically rotate the tablet or their own body.

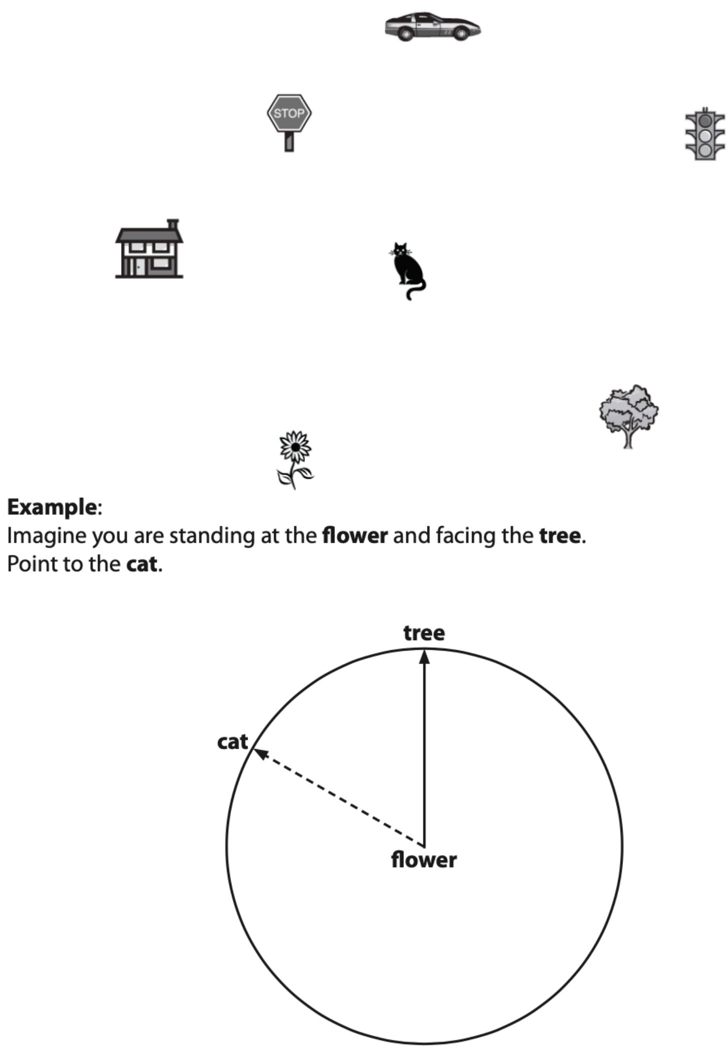


Figure 3.1.1. Example of the solved PTSOT test. The participant must first imagine the directed perspective and based on instruction, draw the imagined direction inside the circle that reflects the appropriate orientation based on the imagined view.

2.) The GVVT is a modified version of the Guay's visualisation of view test (Hegarty et al., 2009). The test depicts a three-dimensional figure drawn in a two-dimensional isometric projection. Subjects are instructed to imagine as if they are looking at a transparent glasshouse. Inside that glasshouse is a floating figure. Outside the 'glasshouse' is a depiction of the floating object from a certain perspective (i.e. target). Subjects are then instructed to state at which corner of the glasshouse must they stand at to view the floating figure from the same perspective as depicted by the target figure (see figure 3.1.2 for the correct answer). The test consists of 24 items with a time-limit of 8-minutes. Participants were not allowed to physically rotate or moving the tablet or their own body.

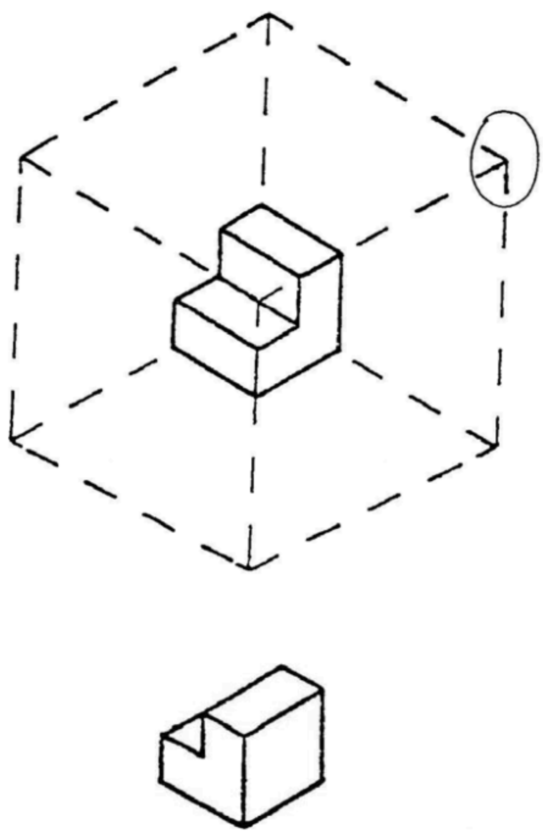


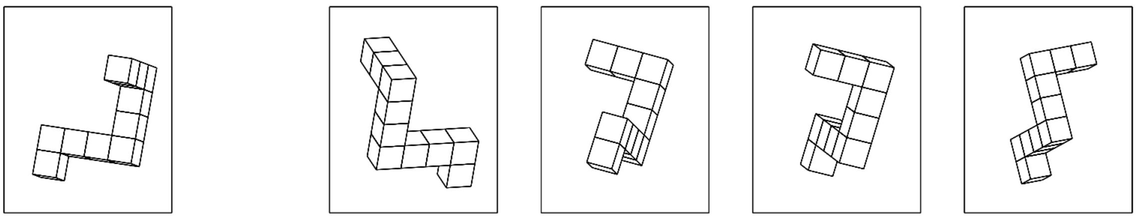
Figure 3.1.2. An example of the GVVT test condition. The participant must mark the corner from which the subject believes that the specific perspective of the targeted object can be seen from.

3.) The MRT-A test is a classic spatial ability test (Peters et al., 1995), depicting three-dimensional geometrical figures in various orientations. Each item consists of five rows. The geometrical figure serving as the 'target' is displayed on the left-hand side of the test, following by four response-choice figures (two distractors and two rotated representations of the same target figures). The participant must look at the target figure on the left and correctly identify two identical rotated figures of the target (as seen in figure 3.1.3). The test comprises of 24 items separated by a short break in-between. The participants have an overall six minutes to complete the entire test: 3 minutes for each part.

Here are two drawings of a new figure that is different from the one shown in the first 5 drawings. Satisfy yourself that these two drawings show an object that is different and cannot be "rotated" to be identical with the object shown in the first five drawings.

Now look at this object:
1.

Two of these four drawings show the same object. Can you find those two? Put a big X across them.



If you marked the first and third drawings, you made the correct choice.

Figure 3.1.3. The example of the MRT-A test condition. The figure on the left-hand side is the target stimuli. The participant must correctly identify which other two figures are identical to that of the target.

4.) PicSOr test is a computerised perceptual-motor test (Gallagher et al., 2003), designed to simulate cognitive conditions encountered in laparoscopy. The task involves the participant manoeuvring a spinning arrowhead on a geometric object until they believe the arrowhead is perpendicular to the surface of the geometric object surface, as is illustrated in figure 3.1.4 below. The task consists of 35 items and has no official time limit. The participants were, however, told to complete the test as quickly as possible.

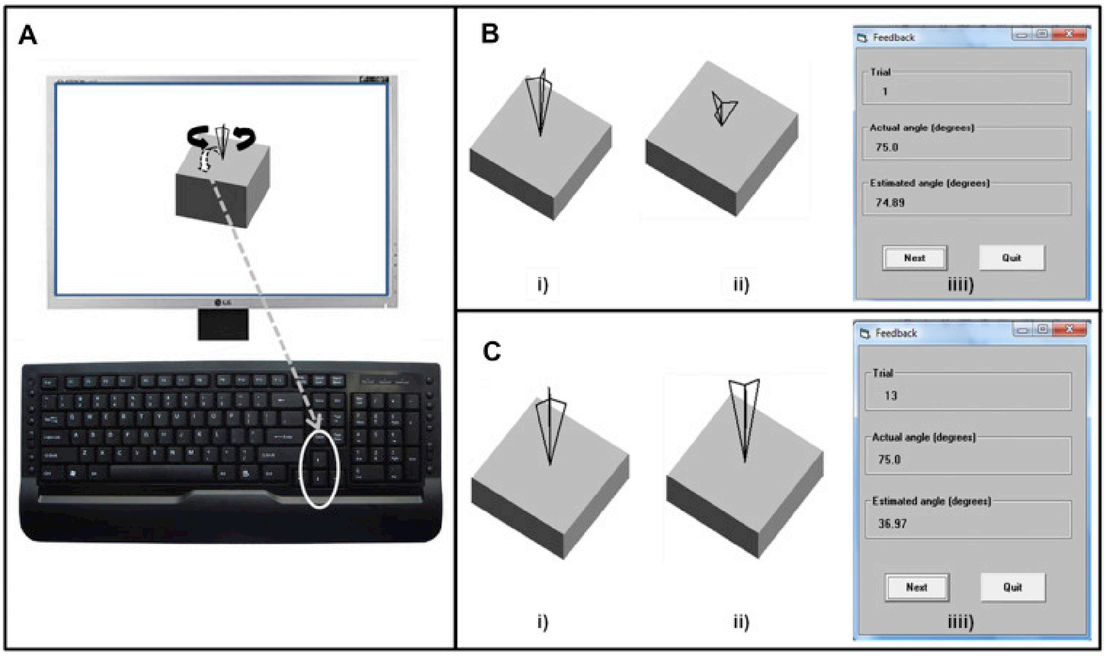


Figure 3.1.4. An example of the PicSOr arrowhead test condition. The participants must navigate the up/down keys on the keyboard to the position in which they believe that the error is entirely perpendicular to the surface of the square. The figure was taken from the original manuscript by Gallager et al. (2003).

1.2.1 Aptitude testing conditions

All 62 subjects were individually tested on the four aptitude measures. The surgeons completed the series of batteries at their respective clinics and the control participants on the University of Bremen campus. The same instructional and time-constraint conditions were followed for both cohort groups. The testing sessions took approximately 40 minutes, which included time for questions, clarifications and introduction to the tests.

PTSOT	Perspective-taking and spatial orientation	The results are calculated based on the absolute angular disparity between the correct angular direction and the participants drawn direction. The total score was calculated based on the average angular deviation across all items; thus, the reported scores represent the participants' angular deviation from the correct answer. If the participant did not provide a solution or skipped over an item, a score of 90° was awarded, indicating an angular chance performance (considering angular deviation ranges from 0° to 180°). The maximum score indicating best performance is 0, with a score of 90° showing the worst performance. For the data to share the same direction as other tests, the PTSOT scores were inverted (90 – individual test score).
GVVT	Spatial visualisation	For each correct answer, a point was awarded. The score was calculated based on the formula provided by Hegarty et al., (2009): number of correct items – (number of incorrect items / 6 (to correct for guessing).
MRT-A	3-D mental rotation	The procedure and scoring followed those of Peters et al. (1995). On each item, where both figures were correctly identified, a point was given. If the participant only correctly identified one figure but not the other, no point was awarded.
PicSOr	Perceptual-motor skills	The score is calculated using Pearson's correlation, which calculates the correlation between the actual angle of the arrowhead and the subjects estimated and positioned arrowhead. The score closet to 1 represents the best score and score closet to 0 poor performance.

1.5. Data analysis

The assumption of normality was first evaluated for all four aptitude measures. A Shapiro Wilk test (all $p < 0.03$) confirmed all four aptitude tests (PTSOT = $p < 0.01$, GVVT = $p < 0.01$, MRT-A = $p < 0.01$, PicSOr = $p < 0.02$) failed the assumption of normality. Log-transformation did not normalise the skewed distribution, therefore, raw data was used in the analyses. Descriptive statistics will be reported using median and interquartile range (IQR). To explore the component structure of visuospatial ability, both the inter-item correlation and a a confirmatory factor analysis (CFA) were conducted. The inter-item correlation using Spearman correlation was computed to assess the internal consistency among the four tests. A CFA using the structural equation modelling (SEM) lavaan package in R statistical programming language was computed to establish the structural validity of the four scales. That is, how well do all aptitude tests measure the one underlying construct – visuospatial ability. To explore whether laparoscopic surgeons possess better visuospatial skills compared to medical laypeople and whether visuospatial abilities can distinguish an expert laparoscopic surgeon from residency surgeons and control subjects, a Mann-Whitney *U* test and the Kruskal Wallis *H* Test were computed. Eta square effects sizes were calculated for both tests using an online calculator (psychometric.de) and were interpreted following Cohen (1988) criterion: 0.000 - 0.003 *no effect*, 0.010 – 0.039 *small effect*, 0.040 – 0.110 *intermediate effect* and 0.140 – 0.200 *large effect*. Finally, multiple linear regression(s) were computed to explore whether surgeon's seniority level (i.e. experience level) could predict aptitude performance and whether confounding variables such as age, gender, motivation to become a surgeon carry any effect over the observed aptitude performances. Residual plots for all computed linear regression models indicated no notable deviation from normality, deeming linear regression an appropriate method for data analysis. Considering the small sample size, the confidence intervals for the linear regression and correlation coefficients were estimated using bootstrapping. The data was analysed and visualised using the R statistical programming language (version 1.3) and the IBM SPSS statistical package (version 26).

2 RESULTS

2.1 Inter-item correlation between visuospatial measures

Spearman rank correlation was used to explore the inter-item correlation between the four aptitude measures. The purpose of the analysis was to examine whether all aptitude tests measure similar, or independent, underlying visuospatial skills. As seen in the table 3.1.2, the inter-item correlation matrix shows a positive association between all items, indicating they all appear to measures similar visuospatial constructs. The strongest correlation was between GVVT and PicSOr (Rho = .60) and the weakest correlation between MRT-A and GVVT (Rho = .37),

Table 3.1.2. Spearman Correlation Matrix among visuospatial tests

	1	2	3	4
PTOST	-	.50 **	.39 **	.47 **
		[0.29, 0.66]	[0.16, 0.58]	[0.25, 0.64]
GVVT	.50 **	-	.37 **	.60 **
	[0.29, 0.66]		[0.13, 0.57]	[0.41, 0.74]
MRT-A	.39 **	.37 **	-	.42 **
	[0.16, 0.58]	[0.13, 0.57]		[0.19, 0.60]
PicSOr	.47 **	.60 **	.42 **	-
	[0.25, 0.64]	[0.41, 0.74]	[0.19, 0.60]	

Note: ** p <. 001. Values in square brackets represent the 95% median confidence value for each correlation.

2.1.1. Factorial structure of visuospatial ability

The inter-item correlation revealed all aptitude measures are significantly related to each other. As a second step, a one-factor confirmatory factor analysis (CFA) was conducted to confirm that all four aptitude tests do in fact measure one latent construct- visuospatial ability. All latent variables were standardised allowing for free estimation of all factor loading. The model fit was acceptable, with the RMSEA (root mean square error of approximation) of 0.1 and the SRMT of 0.1 (standardised root mean square error of approximation) (as suggested by Jackson, Gillaspy & Purc-Stephenson, 2009). The model value was X^2 (2) = 24.10 with a p = 0.01, indicating the data fits the model well. All factors loading were significant ($p < 0.01$), indicating all aptitude measures loaded positively onto the single latent factor (i.e. visuospatial ability). The standardized factor loadings ranged from 0.52 to 0.79, as seen in table 3.1.3. Considering all factor loadings were above 0.50 cut-off loading, as suggested by Field (2018, pp 1010-1023), no factors were deleted.

Table 3.1.3. Confirmatory factor analysis (CFA) fit measures values

Item	Standardised	*P*
PTSOT (B_PT)	0.55	0.01
GVVT (B_G)	0.75	0.01
MRT-A (B_M)	0.52	0.01
PicSOr (B_PI)	0.79	0.01

In the view of component importance, the PicSOr and GVVT (> 0.70) showed the highest loading onto the latent variable as compared to the MRT-A and PTSOT (< 0.55). Both PicSOr and GVVT explained the highest degree of shared variation in visuospatial ability, showing evidence of convergent validity. Both MRT-A and PTSOT were just above the cut-off threshold of 0.50, suggesting the components are valid construct of visuospatial ability, albeit conceptually distant from the latent factor (i.e. visuospatial ability). Yet, both MRT-A and PTSOT showed the highest error variance (i.e. the portion of variance not covaried by the latent factor) putting forward an assumption that both tests may possibly be better explained by other latent variables, or otherwise, may rely on different set of abilities as compared to GVVT and PicSOr. A path diagram illustrating the CFA measurement model is depicted in the figure 3.1.5 below.

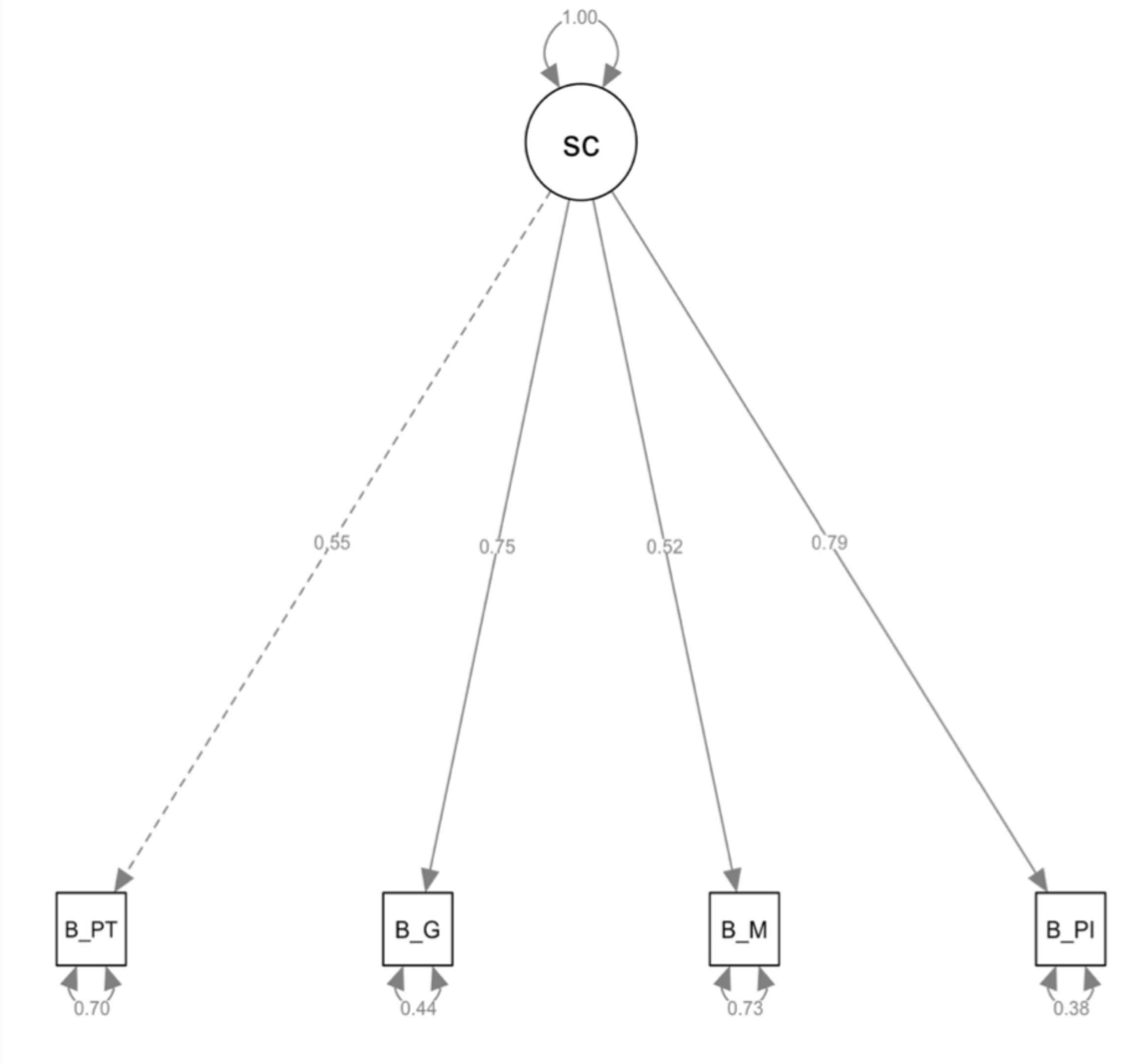


Figure 3.1.5. A path diagram of CFA representing the factor structure of the spatial cognition latent variable on the four visuospatial aptitude tests.

Note. Abbreviations: SC, spatial cognition; B_PT, baseline PTSOT; B_G, baseline GVVT, B_M, baseline MRT-A; B_PI, baseline PicSor. The dotted line represents a fixed factor, which in this case, was the first measured variable (i.e. PTSOT). Unrestricting the PTSOT variable did not result in any change in values.

Research question 1: Do laparoscopic surgeons possess a better VSA profile?

The descriptive statistics representing the median, IQR and percentiles for the performance on the four aptitude tests for both surgeons and control cohort are shown in the table 3.1.4 and 3.1.5 below. Based on the descriptive statics, surgeons show a notably better performance on the GVVT and PicSOr. Both groups show a similar level of performance on the MRT-A. Boxplots for each aptitude measure depicting score distribution per cohort are illustrated in figure 3.1.6 below.

Table 3.1.4. Median and interquartile range for aptitude scores per surgeon vs control

	Surgeon cohort n=43	Control group n=19
Tests	Median *(IQR)*	Median *(IQR)*
PTSOT	70.11 (38.64)	63.90 (34.95)
GVVT	23.5 (12.25)	11.10 (12)
MRT-A	10 (8)	11 (4)
PicSOr	.50 (0.70)	.26 (0.72)

Note. SD = standard deviation, IQR= Interquartile range

Table 3.1.5. Aptitude test scores percentiles per surgeon vs control

Group	Surgeon cohort			Control cohort		
Measure	25	50	75	25	50	75
PTSOT	42.00	70.11	82.39	39.25	63.90	74.20
GVVT	8.83	15.83	21.67	4.00	11.17	16.00
MRT-A	7.00	9.00	14.00	8.0	11.0	12.0
PicSOr	.17	.50	.87	-.03	.26	.69

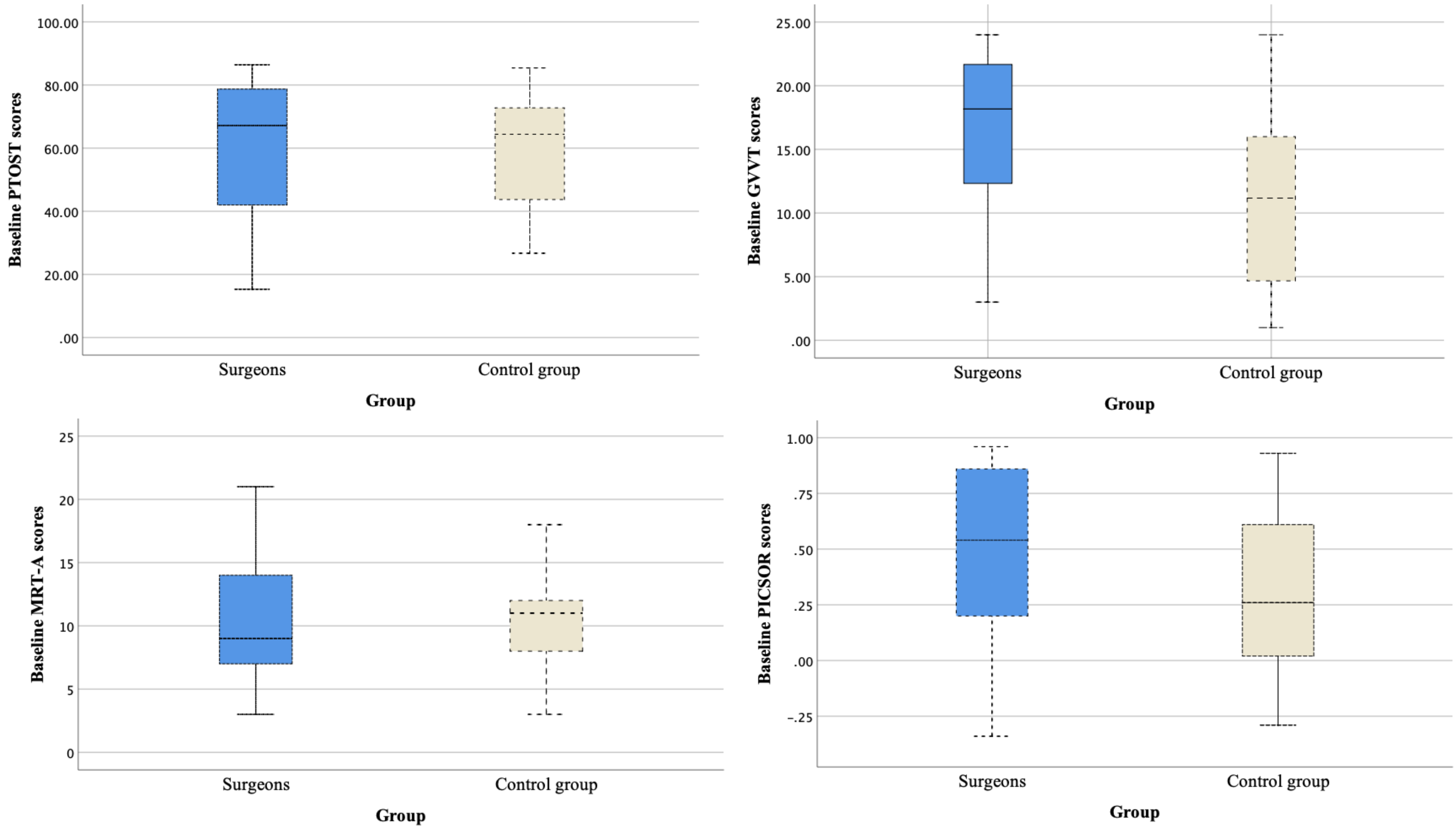


Figure 3.1.6. Boxplots depicting score distribution of the PTSOT, GVVT, MRT-A and PicSOr for surgeon and control group

A Mann-Whitney *U* test was conducted to examine performance differences between the surgeon cohort (n=43) and control group cohort (n=19) on the four baseline aptitude tests. Significant group differences with a medium effect size were found on the GVVT measure ($U = 273.0$, $p = 0.03$, η2 = 0.3), with surgeons (Mean Rank = 34.65) significantly outperforming the control group (Mean Rank = 24.37). No statistical group differences on the PTOST ($U = 328.0$, $p = 0.22$, η2 = 0.1), the MRT ($U = 291.5$, $p = .79$, η2 = 0.1) or the PicSOr *(*$U = 297.0$, $p = 0.09$, η2 = 0.3) measures were found. Yet, PicSOr does show a medium effect size. The notion that surgeons had better PicSOr performance can also be observed by looking the descriptive statistics. Lack of statistical significance could be explained by the small sample size of this study.

Research question 2: Can VSA distinguish between expert surgeons, residency surgeons and laypeople?

The descriptive statistics for summarising aptitude performance scores for residency surgeons, expert surgeons and control subjects are illustrated in the table below 3.1.6. Based on descriptive statistics, expert surgeons showed a much better performance on the GVVT (median= 20.25) compared to residents (median= 15.65) and control subjects (median= 11.17). Expert surgeons also showed a slightly better performance on the PTSOT (median= 72.52) compared to control group (median = 64.40). The MRT-A showed no obvious performance differences between the cohorts, with all scores ranging between 9.00 and 11.50. On the PicSOr test, residents performed better than expert surgeons and control group alike (residents= 0.55 vs. expert surgeons= 0.45 vs. control = 0.26).

Table 3.1.6. Median and interquartile range for aptitude scores per resident vs senior vs control

	Residency surgeons n=26	Experts n=17	Control group n=19
Tests	Median *(IQR)*	Median *(IQR)*	Median *(IQR)*
PTSOT	70.00 (31.95)	74.54 (48.13)	64.40 (34.95)
GVVT	15.65 (11.08)	20.25 (17.83)	11.17 (12)
MRT-A	11.50 (7)	9.00 (8)	11.00 (4)
PicSOr	.55 (0.76)	.45 (0.67)	.26 (.72)

The aptitude scores represented as a function of percentiles confirmed the presence of a ceiling effect for GVVT test in the expert surgeon's condition *, with all showing performance around the maximum available score of 24, as is shown in table 3.1.7. The boxplots illustrating the distribution of aptitude scores across all cohort groups are illustrated in figure 3.1.6 below.

Table 3.1.7. Aptitude test scores percentiles per resident vs senior vs control group

Group	Residency surgeons		Senior surgeons		Control group	
Measure	25	75	25	75	25	75
PTSOT	46.05	78.00	36.52	84.27	42.40	74.20
GVVT	8.54	19.62	17.67	**23.50***	4.0	12.00
MRT-A	7.0	14.25	7.5	15.00	8.0	12.00
PicSOr	.11	.86	.19	.79	-.03	.69

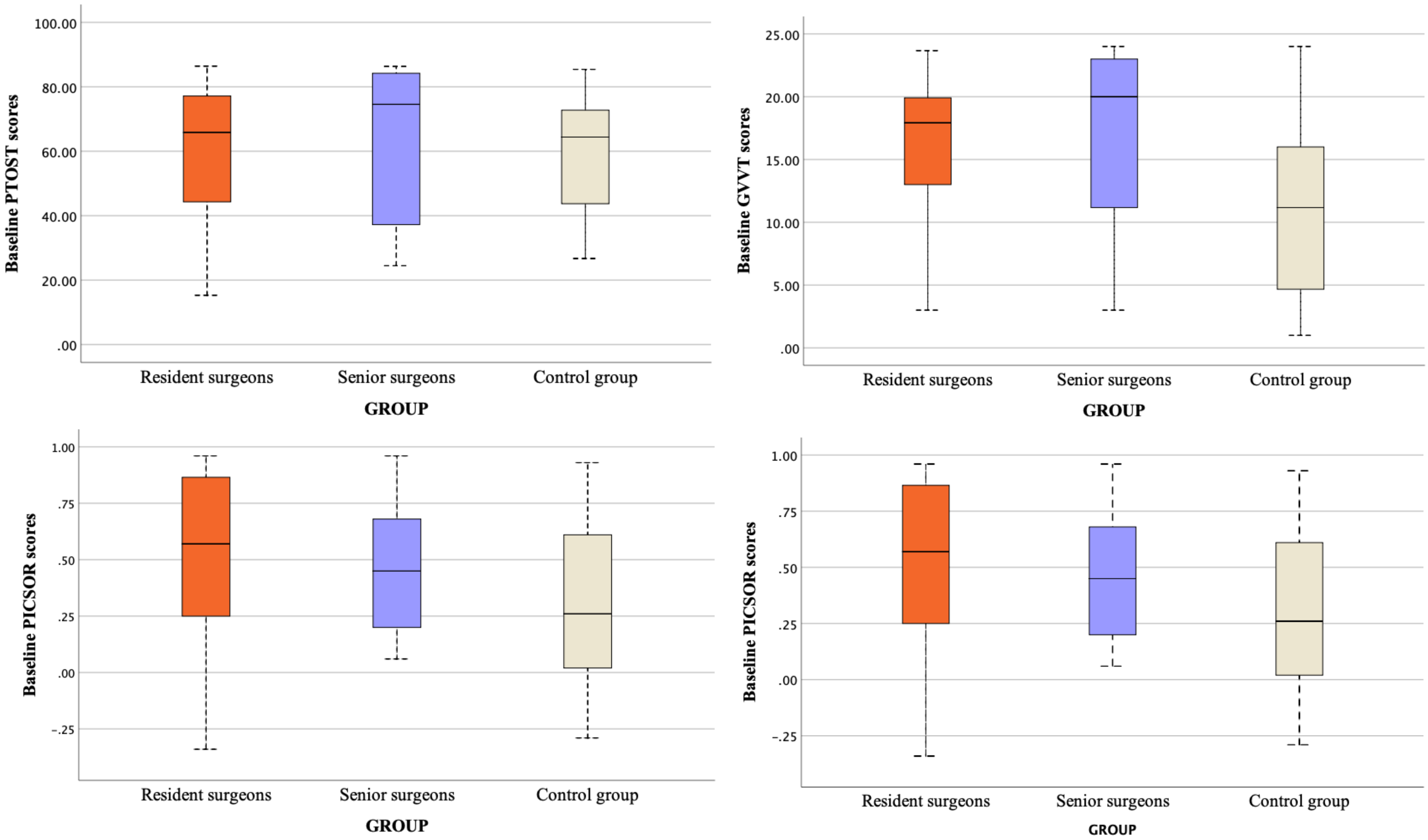


Figure 3.1.6. Boxplots depicting score distribution for all four aptitude measures across all three cohort group

A Kruskal Wallis Test explored performance differences between the expert surgeons, resident surgeons and control group across all aptitude tests. No significant group differences on any of the aptitude test across the three cohort groups were observed, as illustrated in the table 3.1.8 below. However, the GVVT did show a clear trend towards significance (p = 0.06) and an intermedium effect size (η2 = 0.05). This indicates a probability that the effect of the GVVT in distinguishing between the three cohort groups could exists, but is perhaps concealed by the low statistical power and small sample size. Looking at H values, it can be clearly observed that expert surgeons group rank is notably higher to the group ranks of control subjects or arguably residency surgeons. Other aptitude tests showed only a small effect, suggesting trivial differences.

Table 3.1.8. Kruskal Wallis H-test results of aptitude scores across three groups

Measure	Group	N	Rank	H	X^2	p	η2
PTSOT	Residents	26	32.77	0.95	1.99	.37	0.02
	Experts	17	33.29				
	Control group	19	28.16				
GVVT	Residents	26	30.48	4.75	3.72	.06	0.05
	Experts	17	37.62				
	Control group	19	24.68				
MRT-A	Residents	26	33.00	0.32	1.61	.45	0.03
	Experts	17	30.21				
	Control group	19	30.61				
PicSOr	Residents	26	33.75	2.76	4.02	.13	0.01
	Experts	17	34.44				
	Control group	19	25.75				

Note. p <.05 level of significance. *Abbreviations:* N = number of participants, H = Kruskal Wallis value, X^2 = Chi-square value, p = p-value, η^2 = Eta squared effect size

Research question 3: Can laparoscopic experience predict visuospatial performance?

Multiple linear regression was used to test whether years of laparoscopic experience could predict the surgeon's performance on the four aptitude tests. Surgeons years of laparoscopic experience were used as the predictor to operationalise laparoscopic expertise. Years of laparoscopic practice ranged from 0 years to 30 years. Residency surgeons reported having a median 4 years of laparoscopic experience (range = 2), specialist surgeons a median of 9 years (range = 2), consultant surgeons a median of 12 years (range= 10) and clinical directors a median of 30 years (range = 15).

The results revealed that years of laparoscopic experience was a strong predictor of surgeon's performance on the GVVT test, explaining 70% of performance variance (R^2= 0.70, F (1,60) = 6.788, *p*= 0.01). The participants GVVT score increased by 0.34 points for each year of laparoscopic experience (Beta= 0.34, SE= 0.128, 0.01), 95% CI [0.8, 0.29]. There was, however, no sufficient evidence to suggest that years of laparoscopic experience can predict performance on PTSOT (Beta= -0.16, SE= 0.05, *p*= 0 .48) 95% CI [-0.06, 0.12], MRT-A (Beta= -0.25, SE= 0.24 *p*= 0.40), 95% CI [-0.67, 0.27] and PicSOr (Beta= 3.40, SE= 2.88, *p*= 0.24), 95% CI [-2.34, 2.18]. Considering the beta value for PicSOr falls outside the 95% confidence interval, it can be concluded that the probability the value represents the true value is less than 5%. In other words, the regression value of the PicSOr is unlikely represent a true value.

2.2 Impact of confounding factors on the aptitude performance

Cognitive performance is known to vary between individuals due to confounding factors such as age, gender and experience with a musical instrument and videogames. Particularly in surgeons, it has been previously speculated by Keehner et al. (2006) that surgeons may pre-select themselves to the field based on their innate visuospatial abilities. Additionally, as was revealed in study one, females are the next generation of surgeons, and as described in study two, visuospatial ability is an important core attribute of laparoscopic competence.

Exploring whether gender bears any impact over visuospatial performance is therefore an important step towards better understanding the implications the demographic shift in Germany may bear on laparoscopic performance. A multiple linear regression was computed to address these propositions. In the first model, the effect of gender, age and experience with musical instruments and videogames on visuospatial performance across all subjects were explored. In the second model, the predictor of group was included to explore whether the effects differ between surgeons and control group. In the third model, to test the hypothesis proposed by Keehner et al. (2006), the predictive nature of surgery being ones dream profession on surgeon's visuospatial performance was explored. For categorical values, dummy variables were created: gender (0. Females, 1. Male), experience with music instruments (0. Yes, 1. No), experience with video games (0. Yes, 1. No). The descriptive statistics for the five factors investigated across both the surgeon and control group are demonstrated in table 3.1.9.

Table 3.1.9. Descriptive statistics for factors investigated across surgeons and control

	Surgeon cohort N= 43	Control group N= 19
	Frequency	Frequency
Gender	15 females (34.9%) 28 males (65.1 %)	6 (31.6 %) females 13 (68.42 %) males
Age	Median= 34	Median= 22
Music experience	29 (67.4 %) Yes 14 (32.6 %) No	13 (68.4 %) Yes 6 (31.6 %) No
Video experience	19 (44.2 %) Yes 24 (55.8 %) No	14 (73.7%) Yes 5 (26.3 %) No
Dream to become a surgeon	26 (60.5%) Yes 17 (39.5%) No	

First, a multiple linear regression was computed across all 62 participants on predictors of gender, age, music and video experience on the PTSOT performance. The results showed that 31 % of the performance variance could be explained by the four predictor variables, however the model was not a significant predictor of PTSOT performance (R^2= .31, F (4, 21) = 2.39, *p*= 0.08). All individual predictors did not significantly contribute to the model; gender (B = 13.28, *p* = 0.06), age (B= 0.78, *p* = 0.10), musical experience (B= 0.09, *p*= 0.99) and videogame experience (B= 6.75, p = 0.35), although the effect of gender was trending near significance. Second, the above-stated regression model was re-run across both groups. For the surgeon group the model explained 56% of performance variation (R^2= 0.56, F (4,21) = 2.44, *p*= 0.08) and 31% in the control group variation (R^2= 0.31, F (4, 14) = 0.38, *p*= 0.82), however, both models did not significantly predict PTSOT performance in both groups. Surgeons 'dream' to become a surgeon was also not a significant predictor of PTSOT performance (R^2= 0.00, F (1, 41) = 0.01, *p*= 0.933),

For the GVVT, the predictors explained 21 % of the performance variance but were not significant predictors of GVVT performance (R^2 = 0.21, F (4, 21) = 1.44, *p* = 0.26). All individual predictors did not significantly contribute to the model: gender (B= 2.99, *p* = 0.22), age (B= -0.11, *p* = 0.73), musical experience (B = 5.24, p = 0.09) and video experience (B= 0.70, *p* = 0.79). Comparing the regression models across both groups, the four predictors explained 22% of performance variance (R^2= 0.22, F (4,21) = 1.44, *p*= 0.26) in the surgeons' group but were not significant predictors of GVVT performance. In the control group, however, the four predictors explained 76% of performance variations and were found to be significant predictors of GVVT performance (R^2= 0.76, F (4, 14) = 11.04, *p*= 0.00). The variables of gender (B= -13.42, *p*= 0.01) and age (B= -1.14, *p* = 0.01) were significant predictors of the GVVT performance in the control group. In other words, the results revealed that in the control group, females had better performance on the measure and an increase in age was significantly associated with a decrease in GVVT score. Surgeons 'dream' to become a surgeon was not a significant predictor of GVVT performance (R^2= 0.01, F (1,42) = 0. 17, *p* =. 69)

For the MRT-A, the predictors explained only 3% of the performance variance and were not significant predictors of performance (R^2= 0.03, F (4, 21) = 0. 17, *p* =0.95). None of the individual predictors showed any significant contribution to the model: gender (B= 1.16, *p* = 0.61), age (B= - 0.01, *p* = 0.98), musical experience (B= -0.11, *p* = 0.96) and video game experience (B= -1.59, *p* = 0.50). Comparing the models between the two groups revealed the four variables were not a significant predictor of MRT-A performance. The four variables explained only 3% of surgeon's variation in performance (R^2= 0.03, F (4, 21) = 0.17, *p* =0.95) and 39% of variation in the control groups (R^2= 0.39, F (4, 14) = 2.22, *p* =.0.12). None of the individual variables contributed towards surgeon's performance, however in the control group, age (B= -0.57, *p*= 0.02) was a significant contributor to the model. In other words, as age increased the MRT-A performance decreased among the control subjects. Surgeons 'dream' to become a surgeon was also not a significant predictor of MRT-A performance (R^2= 0.04, F (1,41) = 1.53, *p* = 0.22)

For the PicSOr test, the predictors explained only 11% of performance variations and were not significant predictors of performance (R^2= 0.11, F (4, 21) = 0.63, *p*= 0.65). Similarly, none of the individual predictors significantly contributed to the model: gender (B= -0.07, *p* = 0.67), age (B= -0.01, *p*= 0.59), musical experience (B= 0.20, *p*= 0.27) and video game experience (B= 0.18, p = 0.32). The inclusion of the group variable offered no further explanation of the variations in performance; surgeons' group (R^2= 0.11, F (4, 21) = 0.63, *p*= 0.65) and control group (R^2= 0.11, F (4, 14) = 0.44, *p*= 0.78). As with other analyses, the surgeons dream to become a surgeon did not predict the performance on the PicSOr measure (R^2= 0.00, F (1,41) = 0.18, *p* = 0.67).

3 Discussion

The results of this investigation contribute new insight implicating spatial visualisation as a notable ability associated with laparoscopic expertise. Additionally, new understanding on the component structure of visuospatial ability is contributed. First, the results revealed that across all visuospatial measures, laparoscopic surgeons significantly outperformed the control subjects on the GVVT test measuring spatial visualisation ability only. These findings are in line with the results reported by Risucci (2002), who similarly found surgeons to outperform the general population on spatial visualisation ability. Additionally, these results give further support to the speculations made in study two, suggesting that spatial visualisation may not only be an important component of competence but expertise as well. Yet, when exploring whether visuospatial ability can distinguish between expert surgeons, residency surgeons and control group, no statistical group differences in performance on any of the aptitude measures was observed. The GVVT did, however, show a clear trend towards significance (p= 0.06) with an intermedium effect size ($\eta 2$= 0.05) in favour of expert surgeons. Considering other results in this investigation, it seems probable that these results merely reflect the small and unequal sample size in groups and consequently low statistical power. This assumption is based on the clear pattern observed across the findings in this investigation, all implicating spatial visualisation as a notable characteristic of laparoscopic expertise. First, expert surgeons did show an overall better performance on the test as compared to residency surgeons and control subjects and did consistently perform around the maximum score. Second, the results showed that years of laparoscopic experience was a significant predictor of GVVT performance, indicating that spatial visualisation ability does seem to increase with laparoscopic expertise. Third, no confounding factors such as gender, age, musical and videogame experience or preselection to surgery based on innate abilities predicted surgeon's performance on the GVVT. Taken together, the results of this current investigation put forward a convincing hypothesis that spatial visualisation is characteristic of laparoscopic expertise which improves in the context of laparoscopic practice. Similarly, these results also warrant the argument that the failure in detecting group differences on the GVVT measure was most likely due to the small and unequal sample size in groups, as opposite of the lack of true effect.

Spatial visualisation refers to processing, transformation and manipulation of two-dimensional and three-dimensional objects that may be hidden or partially occluded (Linn & Peterson, 1985). The ability allows one to process visual information, construct mental models, infer spatial relations between objects or organisms in visual view and perform complex mental transformation (e.g. two-dimensional view into three-dimensional representations) (Kozhevnikov, Motes, Rasch & Blajenkova, 2006). The GVVT test requires the subject to make sense of two-dimensional depictions of three-dimensional objects and make mental inferences on how the object make look like from various viewpoints. Such nature of the task corresponds conceptually well with the characteristics of laparoscopy. First, the surgeons must perceive the two-dimensional image of anatomy displayed on the monitor and mentally "re-think" that image into its three-dimensional representation. Second, based on that mental representation of anatomy, the surgeon must envision that anatomical representation from different viewpoints with respect to spatial relations of other anatomical landmarks. Third, they then have to maintain that mental representation of anatomy to guide their actions. Such visuospatial information processing is important considering that laparoscopic surgeons cannot manipulate or move the organs to identify pathology that may lie behind an obstructed view (i.e. gall bladder behind the liver), rather they must envision the characteristics of the structure from a certain view in which its seen (i.e. envision the position of the gallbladder from the viewed position of the liver). The surgeons' experience in estimating and judging projection planes in the laparoscopic screen and reasoning with two-dimensional representations of three-dimensional anatomy nicely explains why laparoscopic surgeons possess better spatial visualisation abilities to laypeople.

The results of this current investigation failed to find evidence to suggest that laparoscopic surgeons possess better spatial orientation skills (PTOST) and mental rotation skills (MRT-A) compared to medical laypeople. No statistically significant differences between surgeons and control subjects on PicSOr were similarly observed. Yet, a medium effect size was found and surgeons were shown to have a higher median score on the PicSOr (median = 0.50) than control subjects (median= 0.26). These results suggest that these group differences could potentially carry some practical significance but were clouded by the study's small sample size. Referring back to mental rotation, the results of this investigation challenge our current understanding on the role of visuospatial ability in laparoscopy. Existing literature has consistently implicated mental rotation as a significant predictor of simulated (i.e. virtual reality) laparoscopic performance. These findings suggested that mental rotation is an important component of laparoscopy, forming an assumption that if these skills are exercised on the daily basis, laparoscopic surgeons should possess better mental rotation abilities. The results of this investigation finding surgeons having no performance advantages on the measure challenges this assumption. As means of comparison, let's consider the performance on mental rotation across different professional groups. The university students commonly score around 10 points out of 24 (Caissie, Vigneau & Bors, 2009), the aviation security screeners score around 11.26 points (Krüger & Suchan, 2016), medical students commonly score around 13.9 points (Shafqat, Ferguson, Thanawala, Bedford, Hardman & McCahon, 2015) and senior minimally invasive orthopedic surgeons score around 14.20 points out of 24 (Vajsbaher, Schultheis, Sa-ngasoongsong, Watcharopas, Su Yin & Haddaway, 2020). The performance on mental rotation among laparoscopic surgeons is therefore within the same general range as those of university students. Interestingly, however, laparoscopic surgeons showed lower performance on the mental rotation tests as did the arthroscopic surgeons. Laparoscopy and arthroscopy are both minimally invasive surgical technique. The only difference between them lies in the targeted anatomy. Whereas laparoscopy tackles diseases in the abdominal and pelvic cavity, the arthroscopy tackles issues in the restricted joint cavities. See illustration 3.1.7 for graphical overview of the fundamental differences between the two techniques. These critical differences in operative environments (i.e. restricted vs. open) could perhaps explain why minimally invasive orthopaedic surgeons show better performance on mental rotation test than do laparoscopic surgeons.

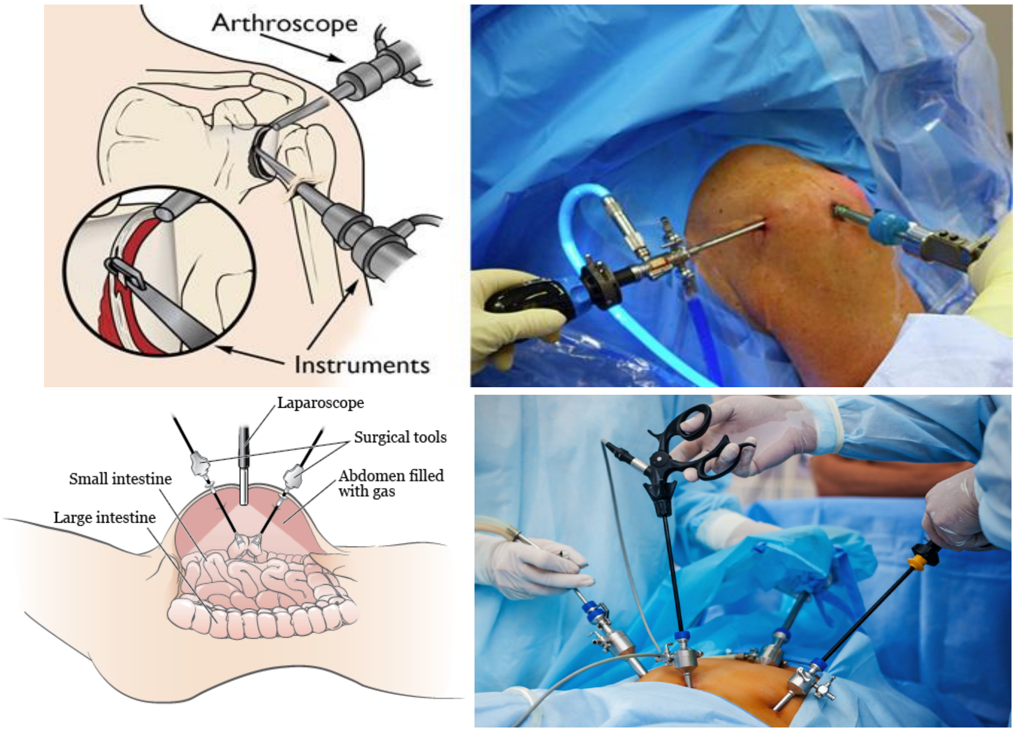


Figure 3.1.7. Graphical illustration of the fundamental differences between the arthroscopic surgery (first row) and laparoscopic surgery (second row).

A study by Kozhevnikov, Hegarty & Mayer (2002) has shown that whereas good mental rotators construct schematic spatial representations of figures without any visual details, the poor rotators focus more cognitive effort on visually detailing the representations of figures. This could offer further insight and point for speculation into the surgeons' poor performance on mental rotation. During the aptitude testing sessions, it became evident that the large majority of surgeons did not follow the instructions to visualise and rotate the figures mentally. It was commonly observed that surgeons engaged in the strategy of comparing and contrasting the shapes and characteristics of the figures. Some were even observed counting the squares in the figures as a means of solving the task. These have already been identified as poor strategies for solving mental rotation tasks (Geiser, Lehmann, & Eid, 2008; Robertson & Palmer, 1983). When surgeons were informally asked about their experience with the test, an overwhelming number of them reported not having to mentally rotate the figure. These reports suggest that laparoscopic surgeons employ a viewpoint-independent strategy in solving mental rotation tasks (Khooshabeh, Hegarty & Shipley, 2013). That is, they seemingly focus on visually representing the relations between specific characteristics of the figures, which are then compared to determine whether a match has been found – without mentally rotating those visual representations. One can therefore speculate on the basis of these results that laparoscopic surgeons are experts in visually representing two-dimensional into their three-dimensional shape and inferring viewpoints based on that visual representation but not in mentally rotating three-dimensional representations of objects. This offers an explanation as to why surgeons show good performance on the spatial visualisation but performance on poor mental rotation. Yet, although this investigation found evidence of poor performance on the measure, the question as to whether the ability shows any associations with intraoperative performance remains to be determined. This will be explored in the scope of investigation two.

The results of this study also contributed new insight to basic spatial cognition research concerning factors that influence visuospatial performance and the component structure of visuospatial ability. Performance on spatial cognition tests is known vary across individuals due to common denominators such as gender, age, musical experience and videogame experience (Hegarty & Waller, 2005). Controlling for the effect of these confounding variables was therefore important to better understand whether any unwanted noise (i.e. individual differences) was causing variations in the aptitude performance. The results revealed that the common denominators known to impact spatial cognitive performance (stated above) did not predict surgeons aptitude performance on any measure. That is, individual differences explored in the scope of this investigation showed no mediating influence over surgeons' visuospatial performance. Exploring the effect of gender on surgeons' aptitude performance was of particular importance considering the results of study one, which found females to be the next generation of laparoscopic surgeons. The finding that gender carries no confounding effect over the visuospatial performance of surgeons is therefore an important first indicator suggesting that females are of no spatial cognitive disadvantage to their male counterparts. Yet, the question as to whether gender differences mediate intraoperative performance outcomes will be determined in the scope of the longitudinal study. The variable of age is also a known confounding denominator influencing spatial cognitive performance. Research has found evidence to suggest that performance on spatial cognitive measures decreases with age, even among individuals who exercise the ability as part of their professional role on a daily basis (Techentin, Voyer & Voyer, 2014). Yet, age had no effect over the aptitude performance of laparoscopic surgeons in this investigation, putting forward a suggestion that some aspects of surgical practice may be preserving these age-related declines in spatial ability. Additionally, it has been previously speculated that individual differences in spatial ability can be eliminated by playing video games or playing a musical instrument (Feng, Spence & Pratt, 2016). This investigation found no evidence to suggest that video games, nor musical experience carried any effect over the surgeon's aptitude performance. Similarly, no evidence of laparoscopic surgeons preselecting themselves to surgery based on their innate spatial abilities were observed in the scope of this investigation, a hypothesis which was previously proposed by Keehner et al. (2006). These results put forward a proposition that perhaps the shared professional characteristics (i.e. being a laparoscopic surgeon) may have attenuated individual differences in spatial cognition. This proposition could also offer an explanation as why these confounding variables showed an effect over control subjects aptitude performance but not the performance of surgeons. In the control group, gender and age explained 73% of performance variation on spatial visualisation test (i.e. GVVT) Females had a significant disadvantage on the measure whereas an increase in age was associated with a decrease in GVVT score. In respect to gender differences, it must be noted that the predominant number of females in the control group were psychology undergraduates or postgraduate students. The male subjects were either computer science students or public health students. These gender differences could therefore be explained by considering educational characteristics of the subjects, considering videogames or musical instruments did not carry any effect. Yet, the variable of age was found to carry a significant effect over the aptitude performance of control subjects, findings which are in line with studies who found a similar effect in the general population (Techentin et al. 2014). As previously argued, these results do suggest that some aspects of surgical practice could be attenuating individual differences of surgeons.

The results of this current investigation also contributed new insight into the component structure of visuospatial ability, in particular on the topic of spatial visualisation and mental rotation ability. There has been a longstanding debate in the spatial cognition research on whether mental rotation and spatial visualisation are a unitary ability or distinct entities. Whereas some studies found strong intercorrelation between the two abilities suggesting a unitary structure (Carroll, 1993), others found only a weak intercorrelation suggesting they are distinct entities (Lohman, 1988). The results of the confirmatory factor analysis (CFA) revealed that all four visuospatial abilities were closely related to the latent factor of visuospatial ability. However, spatial visualisation and mental rotation were found to be functionally distant in relation, connected only through a weak inter-correlation ($r = 0.39$). These results give support to the hypothesis proposed by Hegarty & Waller (2004), that spatial visualisation can exist without mental rotation. One can speculate that the weak association connecting both abilities merely reflects the underlying network of processes they both share. Conceptually, both abilities require the individual to (1) perceptually encode stimuli, (2) identify stimuli's structure (3), estimate parity and (4) response and execution. Where the two abilities conceptually differ is in actual mental rotation of three-dimensional representations. Based on the findings of this current investigating, it appears that the ability to mentally represent two-dimensional representations of three-dimensional objects and *imagine* the object from various viewpoints is a distant cousin to the ability to mentally hold and rotate three-dimensional representations of objects. This offers an explanation as to why laparoscopic surgeons possess superior spatial visualisation abilities but mediocre mental rotation abilities at best.

This investigation shed new insight into the visuospatial cognitive profiles of laparoscopic surgeons across all expertise levels. The results have highlighted that spatial visualisation does appear to be associated with laparoscopic experience. What now remains to be determined is how, and which, visuospatial abilities bear influence over actual intraoperative laparoscopic performance of residency surgeons currently in training.

INVESTIGATION 2. How does visuospatial ability influence laparoscopic intraoperative performance of residency surgeons?

Investigation one revealed new insights into the visuospatial profiles of laparoscopic surgeons across all levels of expertise. In this current investigation, the associations between visuospatial abilities and intraoperative laparoscopic performance of *residency surgeons* of all training years will be explored. With its empirical effort, it aims to address which visuospatial abilities are related to laparoscopic intraoperative performance outcomes and to what extent. The current investigation explores the baseline characteristics and associations related to the participation status of the longitudinal study. As such, the results aim to provide a first insight into the baseline relationship between visuospatial process and laparoscopic performance of residency surgeons, upon which the results of the longitudinal study will build on.

1 Method

1.1 Participants

Baseline measurements of 21 general and visceral residency surgeons in laparoscopic training were analysed in the scope of this investigation. The sample includes 10 junior residents in their 3-4th training year (47.6%) and 11 senior residents in their final 5-6th year (52.4%), of which 11 are females (52.2.1%) and 10 are males (47.8%). Average age in the sample was 33 years (SD = 3.91, range= 27-47). The average number of overall laparoscopic procedures performed by residents as either an assistant or main operator was 580 cases (SD = 851.36, range = 50-1.000). Junior residents reported completing an average of 68 laparoscopic cases (SD= 86.46, range = 10 - 350) and senior surgeons an average of 289 laparoscopic cases (SD= 310.20, range= 3- 250). Five residency surgeons from investigation one (n= 26) were not included into this baseline investigation as they haven't yet begun their laparoscopic training at the time of data collection.

1.2 Visuospatial aptitude tests

The aptitude data from the investigation one were used in this current investigation (see page 90 for descriptive ovrview). The four visuospatial aptitude tests and their scoring and testing conditions are described in the investigation one method section (see pages 77-82).

1.3 Intraoperative assessment

The intraoperative laparoscopic performance of residency surgeons was assessed by the supervising senior surgeons using the Global Operative Assessment of Laparoscopic Skills (GOALS). The measure comprises of a 5-item global rating scale evaluating depth perception, bimanual dexterity, efficiency, tissue handling and autonomy. Each item was scored on a 5-point interval scale: 1 (poor performance), 3 (good performance), 5 (great performance). The total score represents a sum of all intraoperative items and is calculated out of 25. The GOALS assessment tool has been empirically validated in a randomised blind longitudinal trail, as found to be a reliable measure with good construct validity in assessing resident surgeon's intraoperative technical performance in laparoscopy (Kramp, van Det, Hoff, Lamme, Veeger & Pierie, 2016; Vassiliou, Feldman, Andrew, Bergman, Leffondre, Stanbridge & Fried, 2005).

Item 1: Depth perception

This item assesses the surgeon's compensatory system to reason with three-dimensional anatomy depicted in a two-dimensional projection. Due to the monocular optical system, depths cues are diminished. This item measures the surgeon's ability to execute an appropriate action in the absence of depth information. Depth perception is associated with achieving the correct plane of the instrument, which includes laparoscopic-specific examples such as activating bipolar cautery before the contract with the tissue. A poor score would indicate an incorrect estimate of the spatial relation between the instrument and anatomical structures leading to tissue damage.

Item 2: Bimanual dexterity

This item assesses the surgeon's ability to efficiently and smoothly manoeuvre and coordinate both instruments ambidextrously. Excellent bimanual dexterity is demonstrated through a targeted and purposeful ambidextrous movement of the instruments executed with equal precision. Poor performance is demonstrated through poor ambidextrous coordination and reliance on the dominant hand in handling the instruments.

Item 3: Efficiency

This item assesses the surgeon's capability of executing a task in a confident, efficient and safe manner. Efficient performance is observed when one maintains a consistent view and focus of the operative field and executes actions safely and confidently. Poor efficiency is observed with when one struggles to maintain focus and the overview of the critical aspects of the operative field and makes many tentative and uncertain movements with no underlying purpose.

Item 4: Tissue handling

This item assesses the surgeon's ability to handle tissue with appropriate traction and usage of energy sources[4] without injury to adjected structures. Excellent performance indicates the instruments were used with great caution and quality of the tissue is maintained. Poor performance indicates rough handling of the tissue through excessive traction, which results in tissue tears and injuries to the adjacent structures.

Item 5. Autonomy

This item assesses residents' operative autonomy, that is, how well they can complete the operation independently without little to no guidance from the supervising surgeon. This item essentially measures surgeons' competence in the

[4] Laparoscopic surgery relies on electrosurgical cutlery, whereby high-frequency currents are used to achieve the desired thermal tissue effect. The energy modalities include monopolar and bipolar approaches. Unsafe or undirected usage of electrosurgical cutleries is a common culprit for irreparable tissue damage.

laparoscopic procedure. Excellent performance is observed with an independent performance of the entire procedure without any assistance. Poor performance is observed when one is unable to complete the entire procedure, even when verbal guidance is provided and the case is deemed as "straightforward". Poor performance is also characterised by any situation in which the resident demonstrates unsafe performance.

1.3.1. Adaptation and translation of the GOALS intraoperative tool

Four additional items were added to the GOALS assessment tool: (1) name of the clinic, (2) a three-point operative difficulty rating scale (i.e. easy, medium, hard), (3) a five-point ASA-scale patient risk assessment (see 1.4.1 below) and (4) an indication of conversion measured on a dichotomous scale[5]. These items were added to gain a better overview of the data collected and the surgical case at hand. The GOALS assessment is currently only available in English. To facilitate the native language of the senior surgeons responsible for the assessments, the tool was professionally translated by medical translation company medDOC (Bremen, Germany) to German using a back-translation approach. The English version of the assessment tool was first translated into German by two independent translators in the company, with a final quality inspection by a senior employee. The translated version was then back-translated by a bilingual senior visceral surgeon, who verified that the internal quality of the measure was retained. The final translated version of the tool was inspected for quality by two senior visceral surgeons (M.M & N.F) and a senior gastroenterologist. The intraoperative assessment tool used in this study can be found in the appendix 7.

1.4 The ASA (American Society of Anaesthesiologists) classification system

The ASA classification system is a risk assessment scale evaluating the patient's pre-anaesthetic medical co-morbidities. In layman terms, it assesses the patient's

[5] An indicator whether the operation had to be converted from the laparoscopic technique to open surgery.

physical wellbeing and fitness before surgery that could be indicative of the difficulty of the operative case at hand. In the scope of this doctoral thesis, the ASA risk assessment scale was used as yet another indication of the complexity of the surgical case. The description of each ASA item is provided in the table 3.2.1 below.

Table 3.2.1. Overview of the ASA risk assessment classification

ASA rating	**Description**	**Morality risk**
1	Normal healthy patient (e.g. healthy BMI, non-smoker or drinker)	0.05%
2	Mild to moderate systematic disease (e.g. obesity, smoker & drinker)	0.4%
3	Severe systematic disease (e.g. morbid obesity or alcohol/drug abuse)	4.5%
4	Severe systematic disease that is a threat to life (e.g. stroke)	25%
5	Moribund patient not expected to survive without surgery (e.g. life-threatening emergency)	50%

1.5. Intraoperative data collection

The intraoperative data collection occurred in close collaboration with both participating clinics. Operative rosters in each clinic were monitored on the daily basis by either the clinics research team or the secretarial office. Residency surgeons scheduled to operate on a laparoscopic case as the main surgical operator or a first assistant were identified and the intraoperative assessment tool handed over to the supervising senior surgeons scheduled on the case. After the procedure, the senior surgeons submitted the completed assessment tool to a safe and secure location in the clinic or to the member of the clinics research or secretarial team.

1.6. Data analysis

The Shapiro-Wilk normality test revealed all five intraoperative items measured by GOALS failed the assumption of normal distribution (all $p < 0.01$). The four visuospatial aptitude tests were similarly found to deviate from the normal distribution (see page 83). The central tendency will be described using frequencies, median and the IQR (i.e. interquartile range). First, the internal consistency (i.e. reliability) of the GOALS assessment tool using Cronbach's alpha was determined. This analysis aimed to explore the degree to which all individual items actually measure one underlying construct – laparoscopic technical performance. Second, associations between visuospatial abilities and intraoperative items on the individual-level and the aggregated level were explored. First, Kendall Tau-b was used to explore the associations at the individual-level, as the approach works best with correlating continuous variables (i.e. aptitude scores) with ranked variables (i.e. GOALS scores). Tau is less sensitive to error and discrepancies in the data, offering a more accurate alpha interpretation in a small sample (Yue & Pilon, 2004). Second, Spearman's correlation was used to explore the correlation between visuospatial abilities and intraoperative scores aggregated around the surgeon's experience level in laparoscopy. The aim of this additional analysis was to explore whether the relationship between the two variables changes when the experience level in laparoscopy is considered. Considering the small sample size in this investigation, the alpha for multiple comparisons were not corrected for. As was already observed in the investigation one, the data in this study is prone to type II error. To achieve a more careful balance between type I and type II error, a bias-corrected and accelerated bootstrapped 95% confidence intervals and critical values for both Tau and Rho will be reported. Both the statistical significance and practical significance will be discussed when interpreting the results. Finally, a linear regression was computed to explore sub-group differences between visuospatial abilities and intraoperative items and explore the effect of gender on intraoperative performance. Residual plots for all regression models showed no notable deviation from normal distribution. For all regression results the Cohen's f^2 (Cohen, 1988) effect size was computed.

2 Results

2.1. *Cronbach's alpha test of reliability*

The intraoperative data used in this study is based on a single administration of the GOALS assessment tool. Cronbach's alpha was computed to determine the reliability of the tool, finding it to be a highly reliable measures of laparoscopic technical performance, with the Cronbach's alpha of 0.85.

2.2. *Summary of baseline intraoperative scores*

The median score across all residency surgeons and intraoperative scores was 3 (out of 5), which describes 'good performance'. The average intraoperative total score was 16 out of 25. The descriptive statistics summarising the baseline intraoperative scores across all residency surgeons can be seen in table 3.2.2.

Table 3.2.2. Descriptive summary of the baseline intraoperative scores

N=21	**Depth perception**	**Bimanual dexterity**	**Efficiency**	**Tissue handling**	**Autonomy**	**Total score**
Median (IQR)	3.0 (1.0)	3.0 (0.5)	3.0 (1.0)	3.0 (1.0)	3.0 (1.9)	16.0 (4.0)
Min	2.0	1.0	1.0	2.0	1.0	9.0
Max	5.0	5.0	5.0	5.0	4.0	23.0

2.3. Summary of the laparoscopic procedures

Cholecystectomy was the most frequent laparoscopic procedure operated by the residency surgeons (47.8%), followed by laparoscopic hernia repair techniques (30.4%) and appendectomy and exploratory laparoscopy (21.7%) The average ASA risk assessment score of the patient operated by the resident was 2 (SD = 0.81). The average difficulty rating of a laparoscopic case was "medium" (57.1%). All procedures were elective with no reported conversion. The frequency distribution summary for all laparoscopic procedures captured at the baseline level are illustrated in the table 3.2.3 below.

Table 3.2.3. Frequency distribution of the number of laparoscopic procedures captured at baseline

Laparoscopic procedures	***N* residents per procedure (%)**
Cholecystectomy (CHE)	**9 (42.9%)**
Hernia Repair (HR)	**7 (33.3%)**
Intraperitoneal Onlay Mesh (IPOM)	4 (57.1%)
Total extraperitoneal (TEP)	3 (42.9%)
Appendicitis (APP)	**5 (23.8%)**
Appendectomy (APP)	2 (40%)
Explorative/Diagnostic (EX/DI)	3 (60%)

2.4 Association(s) between visuospatial processes and laparoscopic baseline performance

Kendall Tau correlation coefficient was computed across all residency surgeons at the individual-level to explore the association(s) between the surgeons' baseline visuospatial scores and scores across all six intraoperative items. The aim of this analysis was to determine whether higher visuospatial scores are associated with higher intraoperative scores. The results revealed a positive association between GVVT ($R_t = 0.33$, $p < 0.01$), MRT-A ($R_t = 0.38$, $p < 0.01$), and PicSOr ($R_t = 0.42$, $p < 0.01$) on intraoperative measure of autonomy, suggesting that individual with higher visuospatial abilities did tend to score higher on autonomy. The GVVT explained 12 % ($R^2 = 0.12$) of variation in operative autonomy scores, the MRT-A explained 14 % ($R^2 = 0.14$) of variation and the PicSOr explained 18 %. ($R^2 = 0.18$) of variation in autonomy scores at the individual-level. See table 3.2.4 for the correlation matrix.

Table 3.2.4. Tau correlations exploring the relationship between aptitude scores and intraoperative assessment matrices

Aptitude tests	**PTSOT**	**GVVT**	**MRT-A**	**PicSOr**
GOALS items	R_t	R_t	R_t	R_t
Depth perception	-0.13 [-0.54, 0.28]	-0.08 [-0.54, 0.39]	0.10 [-0.28, 0.33]	0.15 [-0.25, 0.58]
Bimanual dexterity	-0.04 [-0.45, 0.37]	0.26 [-0.26, 0.37]	0.25 [-0.11, 0.56]	0.04 [-0.39, 0.33]
Efficiency	-0.07 [-0.53, 0.38]	0.15 [-0.23, 0.50]	0.26 [-0.10, 0.58]	0.14 [-0.32, 0.55]
Tissue handling	-0.26 [-0.67, -0.09]	-0.21 [-0.56, 0.15]	0.02 [-0.43, 0.47]	-0.14 [-0.47, 0.21]
Autonomy	-0.03 [-0.48, 0.37]	**0.33*** [0.01, 0.69]	**0.38*** [0.02, 0.73]	**0.42*** [0.04, 0.72]
Total score	-0.04 [-0.45, 0.38]	0.07 [-0.33, 0.47]	0.24 [-0.18, 0.60]	0.16 [-0.25, 0.56]

Note: ***** Significant at p < 0.01, brackets illustrate bias-corrected bootstrapped 95% confidence intervals for Tau values.

Considering the small sample size in this study (n= 21), the two-tailed Tau values were compared to Kendall's critical values table, to test the probability of these associations occurring by chance. For the sample size of 21 and alpha value 0.05, the Kendall's Tau critical value is 0.30. The Tau values for GVVT, MRT-A and PicSOr, are all above the critical value. The critical Tau values for alpha 0.01 is 0.37, suggesting only the MRT-A and PicSOr would reach significance at $p < 0.01$. Based on the 95% confidence interval, all significant associations showed a positive trend with no inclusion of the null (i.e. 0 value) in the intervals. Both values indicate statistical and practical significance. Yet, the confidence intervals for all associations are very wide, indicating we have little knowledge about the magnitude of the effect. Again, this can be largely attributed to the small sample size of this study. In respect to practical importance, the coefficient of determination was calculated to assess the effect size of these significant correlations.

2.5. Association between visuospatial ability and intraoperative performance at the experience level

Following on individual-level correlation, it was of interest to explore whether the relationship between visuospatial abilities and intraoperative performance changes when considering the experience levels in laparoscopy. This analysis follows up on the results from the investigation one, which hinted towards the notion that some aptitude measures (i.e. spatial visualisation in particular) could be closely associated with the experience level of the surgeon. Laparoscopic experience was operationalised by the number of laparoscopic cases performed by the resident at the baseline level. Both visuospatial scores and intraoperative items were aggregated around the average and grouped around the four experience-level categories: (1) 0-50, (2) 50-100, (3) 100-350 and (4) 450-500. See table 3.2.5 for the descriptive overview of the experience groups. The results now reflect an average level for each visuospatial test and intraoperative scores for each aggregated experience group. Such an approach was deemed more suitable to avoid computing correlation coefficient across 10 variables on a small and unequal sample size of the residency sub-groups (i.e. junior vs senior residents).

Table 3.2.5. Frequency distribution of the number of laparoscopic cases completed

Number of laparoscopic cases	Frequency
0-50	9 (42.9%)
50-100	7 (33.3%)
100-350	2 (9.5%)
350-500	3 (14.3%)

Spearman correlation was computed between visuospatial scores and intraoperative scores aggregated around the average experience-group. The results confirmed the pattern of associations captured at the individual-level (section 2.4), revealing a strong positive relationship between spatial visualisation (GVVT) (Rho= 0.62, $p < 0.01$) and operative autonomy alongside a moderate positive association with mental rotation (MRT-A) (Rho= 0.44, $p = 0.04$) and perceptual-motor skills (PicSOr) (Rho= 0.58, $p < 0.01$) on operative autonomy.

Based on the critical values for Spearman correlation on n = 21 and alpha 0.05 the Rho is 0.37, which all correlations reach. Yet, based on the critical value for alpha 0.01, the Rho is 0.51, which only the GVVT and PicSOr reached. Taking into the account confidence intervals, all three significant correlations confirm a positive and significant associations. Yet, due to the small sample in this study, the intervals are wide and the true magnitude of the effect remains uncertain. See table 14 for all correlation values. Comparing the correlations at the experience-level to those captured at the individual-level, the GVVT now shows the strongest relationship with operative autonomy as compared to the MRT-A and PicSOr, whereas the MRT-A now shows the weakest relationship with operative autonomy as it did at the individual level. The GVVT now explains 38.4% (R^2 = 0.384) of variation in autonomy scores, the MRT-A explains 19.4% (R^2 = 0.193) of variation and the PicSOr explains 33.6% (R^2 = 0.336) of variation in autonomy scores at the experience-level. See table 3.2.6 for the correlation matrix.

Table 3.2.6. Spearman correlation on visuospatial and intraoperative scores at experience-level

Aptitude tests	**PTSOT**	**GVVT**	**MRT-A**	**PicSOr**
GOALS items	Rho	Rho	Rho	Rho
Depth perception	-0.05 [-0.49 0.46]	0.04 [-0.51, 0.69]	-0.09 [-0.56, 0.56]	0.19 [-0.40, 0.74]
Bimanual dexterity	0.36 [-0.17, 0.75]	0.38 [-0.11, 0.79]	0.39 [-0.05, 0.66]	0.29 [-0.27, 0.83]
Efficiency	0.28 [-0.18, 0.68]	0.47 [-0.03, 0.86]	0.30 [-0.14, 0.59]	0.43 [-0.32, 0.94]
Tissue handling	0.00 [-0.40, -0.41]	-0.04 [-0.56, 0.40]	-0.09 [-0.52, 0.39]	-0.22 [-0.63, 0.23]
Autonomy	0.25 [-0.27, 0.68]	**0.62*** [0.15, 0.89]	**0.44**** [0.03, 0.79]	**0.58**** [0.22, 0.82]
Total score	0.09 [-0.36, 0.52]	0.35 [-0.12, 0.79]	0.15 [-0.25, 0.56]	0.25 [-0.26, 0.72]

Note: * significant at p < 0.5, ** significant at p < 0.1, brackets illustrate bias-corrected bootstrapped 95% confidence intervals for Rho values.

2.6. The impact of confounding factors on intraoperative performance

Investigation one explored possible common dominators known to bear influence over visuospatial performance. In this investigation, the effects of speculated confounding factors previously found to bear impact over intraoperative laparoscopic performance were explored. These include gender (White & Welch, 2012), the patient's ASA risk factors (Hackett, De Oliveira, Jain & Kim, 2015) and the difficulty of the operative case (Curtis, Thomas, Denninson, Ockrim, Conti, Dalton, Allison & Francis, 2019). A multiple linear regression for each one of the five intraoperative items were computed to explore whether the three variables can predict residents' intraoperative technical performance. Descriptive statistics for each confounding factor across all residency surgeons are illustrated in table 3.2.7.

Table 3.2.7. Descriptive statistics for each confounding factor

Variable	Frequency
Gender	11 (52.4%) females
	10 (47.6%) males
ASA-scale	6 (28.6%) ASA 1
	11(52.4%) ASA 2
	4 (19.0%) ASA 3
Difficulty of the case	Median= 3

A multiple regression revealed that none of the three speculated confounding variables were a significant predictor of residency surgeons' intraoperative technical performance.

For depth perception, the three factors explained 9% of performance variation (R^2=0.09, F (3, 17) = 0.58, p = 0.64, f^2 = 0.10). The individual predictors of gender (B= -0.20, p = 0.45), ASA-scale (B= -.03, p = 0.91) and case difficulty (B= 0.28, p = 0.25) did not significantly contribute to the model. For bimanual dexterity, the four predictors explained only 7% of performance variance on the item (R^2 = 0.07, F (3, 17) = 0.45, p = 0.72, f^2 =0.01). The individual predictors did not significantly contribute to the model: gender (B= -0.32, p = 0.45), ASA-scale (B= -0.23, p = 0.45) and case difficulty (B= 0.02, p = 0.42) did not significantly contribute to the model. For the efficiency item, the four predictors explained 22% of the performance variation (R^2= 0.22, F (3, 17) = 1.63, p = 0.22, f^2 = 0.28). The medium effect size indicates that the relationship may not be trivial and could have been occluded by the small sample size. The individual predictors did not significantly contribute to the model: gender (B= -0.38, p = 0.39), ASA-scale (B= -0.17, p = 0.68) and case difficulty (B= .00, p = 0.37) did not significantly contribute to the model. For the tissue handling item, the predictors explained 12% of the performance variation (R^2= 0.12, F (3, 17) = 0.76, p = 0.53, f^2 = 0.14), but were not significant contributors to the model: gender (B= -0.15, p = 0.74), ASA-scale (B= -0.21, p = 0.50) and case difficulty (B= 0.04, p = 0.19). For autonomy item, the predictors explained only 5% of the performance variations (R^2= 0.05, F (3, 17) = 0.28, p = 0.84, f^2 = 0.05) and did not significantly contribute to the model: gender (B= 0.29, p = 0.55), ASA-scale (B= -0.12, p = 0.73) and case difficulty (B= 0.00, p = 0.79).

3 Discussion

The results of this investigation reveal a positive association between visuospatial ability and operative autonomy only. That is, residents with higher spatial visualisation, mental rotation and perceptual-motor abilities ranked higher on the measure of operative autonomy. A clear positive relationship between visuospatial ability and measures of safe and independent laparoscopic performance was, therefore, established. These findings are practically meaningful. In light of the known complexities associated with laparoscopy, operative autonomy assesses the degree to which surgeons can integrate all the necessary skills and abilities needed to execute the procedure without little to no guidance. The postulation that these abilities include comprehension and reasoning with two-dimensional representations of three-dimensional anatomy, mental manipulation of these representations and instrument-based actions, is therefore warranted. Without the ability to reason with the two-dimensional laparoscopic view and execute motor responses based on the perceptual cues, one would arguably struggle with performing laparoscopy. Such a struggle would be reflected in the resident's inability to execute tasks, resulting in more verbal guidance from the supervising surgeons and consequently lower operative autonomy scores. These captured associations therefore nicely reflect how different visuospatial skills all relate to one single behavioural outcome of laparoscopic performance.

Yet, an interesting change in the associations was observed when comparing the strength of the relationship with autonomy at the individual-level and the experience-level. At the individual level, perceptual motor skills and mental rotation skills, respectively, showed stronger association with autonomy compared to spatial visualisation. However, the effects on operative autonomy were generally weak (ranging from 0.33 to 0.42), with PicSOr sharing 17.6% of variance with autonomy, the MRT-A shared 14.4% and the GVVT shared only 10.9% of variation in autonomy scores. At the experience level, however, spatial visualisation and perceptual-motor skills showed the strongest relationship with autonomy as compared to mental rotation. The strength of associations across all three aptitudes increased in strength (range from 0.44 to 0.62) with the GVVT now sharing 38.4% of variance with autonomy, the MRT-A shared 19.4% and PicSOr shared 33.6% of variance. These differences in correlation effects can be interpreted by two statistical components: (1) degree of individual variation and (2) degree of interdependence (see Ostroff, 1993 for a detailed discussion on comparing individual-level and aggregated correlations). When variables are aggregated, the individual differences (the 'noise') within those variables are reduced. Thus, by eliminating individual variations in scores, a clearer picture of the micro-relationship between average visuospatial ability and average laparoscopic performance at the experience group level emerges. The most notable change in the strength of the relationship between individual-level and experience-level was observed on spatial visualisation. At the individual-level, the GVVT explained only 10.9% of variation in the autonomy scores. Yet, at the experience-level, it explained 38.4% of variation. These results provide an interesting indication that the relationship between GVVT and autonomy shows some degree of interdependence on experience. These results are in line with the emerging trend in the results of this doctoral thesis, all implicating spatial visualisation as an important component of competence (i.e. study two) and expertise (i.e.

investigation two). As discussed by Ostroff (1993), a correlation which increases in strength at the aggregated level (i.e. experience in this investigation) captures the interdependence between the two variables within that aggregation group. In other words, the results suggest that the relationship with spatial visualisation at the baseline level is stronger at the experience group level than at individual level. This could be due to significant individual variations at the individual-level that supressed the effect of the relationship. In respect to the MRT-A and PicSOr, the relationship with operative autonomy similarly strengthened at the experience group level. Yet, unlike with spatial visualisation, these increases were small. The effect of the MRT-A increased only slightly (i.e. from 0.38 to 0.44), suggesting the relationship to be homologous at both levels. In other words, mental rotation was similarly related to operative autonomy at both the individual level and the experience group level. Perceptual-motor skills as measured by PicSOr, on the other hand, did show a more notable increase in the association with autonomy at the experience level (e.g. from 0.42 to 0.58). These results suggest that considering experience levels of the residency surgeons does lead to a strengthened relationship between perceptual-motor skills and autonomy, albeit not as significant as observed for spatial visualisation. Together, these findings confirm that spatial visualisation, mental rotation and perceptual-motor skills are notably related to operative autonomy at both the individual and experience levels. Yet, based on the observed changes in the magnitude of the effect at the experience level, there is reason to believe that the hypothesis that spatial visualisation is experience dependent, or in another words, that the effect of spatial visualisation increases with experience, does hold merit. Such a hypothesis would be in line with the findings of the investigation one, which found years of laparoscopic experience to predict surgeon's performance on the spatial visualisation test.

In respect to confounding factors, variables such as gender, patients ASA risk scale or case difficulty did not significantly predict laparoscopic technical performance of residency surgeons. These results carry important insight for surgical education. In respect to gender, the results revealed no significant effect over the surgeons' technical laparoscopic performance. Taking the results of investigation one into consideration, these findings provide sufficient evidence to suggest that females are at no significant performance disadvantage on any of the two measures. Additionally, the complexity of the case similarly carried no significant effect over laparoscopic performance. In respect to operative autonomy, some further interesting trend in confounding influences were observed. As means of comparison, the variables of gender, ASA-scale and case difficulty explained only 5% of variation in operative autonomy scores. Yet, visuospatial abilities explained 20% to 38% of score variation. This is an interesting indication that visuospatial abilities may play a more notable role in influencing operative autonomy outcomes than do previously speculated surgery-based indicators.

This investigation was able to gather interesting new insight suggesting that visuospatial ability is positively associated with autonomous performance. Yet, it must be noted that residency surgeons did not show better performance on the MRT-A and PicSOr as compared to expert surgeons or control subjects. The true practical implications of these correlations on operative autonomy therefore remain uncertain. Yet, the results from the longitudinal study could offer some further insight.

General discussion

To date, empirical research has mainly investigated the role of visuospatial ability in laparoscopic performance using simulated tools on medical laypeople or residency surgeons with little experience. As a result, insight into whether laparoscopic surgeons of varying experience levels actually possess good visuospatial abilities was lacking. Suck lack of data was most apparent among expert laparoscopic surgeons, who remain underrepresented in empirical investigations. Additionally, insight into whether visuospatial abilities bear any influence over actual intraoperative laparoscopic performance of residency surgeons of all training years and experience levels was also lacking. This current study sought to address this gap in the literature. In investigation one, visuospatial cognitive profiles of laparoscopic surgeons of all experience levels were explored and quantitively compared to determine whether, and which, visuospatial abilities categorise laparoscopic surgeons. In investigation two, the relationship between visuospatial abilities and intraoperative technical performance of residency surgeons were explored. The general findings of this study suggest that visuospatial ability is related to laparoscopic expertise and is positively associated with laparoscopic intraoperative performance.

The results from investigation one reveal that laparoscopic surgeons do possess significantly better spatial visualisation ability as compared to medical laypeople. That is, their notable strength lies in imagining how a three-dimensional object depicted in a two-dimensional plane may look like from various viewpoints. Considering that these abilities are characteristics of laparoscopy, it can be concluded that the GVVT does appear to be a reliable measure for capturing laparoscopy-specific attributes. Spatial visualisation ability was also the only ability that was predicted by laparoscopic expertise. The results reveal that an increase in laparoscopic experience was positively related to an increase in GVVT performance. This puts forward a convincing hypothesis that spatial visualisation ability may improve in context of laparoscopic training or vice versa. Such a hypothesis would be in line with the existing empirical insight suggesting that spatial abilities are malleable and do improve in the context of training (Keehner et al., 2004; Newcombe, Mathason & Terlecki, 2002; Ulman & Sorby, 1995). In addition, the results of this study also contribute new insight into the previous speculations that surgeons may pre-select themselves to the field of surgery based on their innate spatial abilities (Keehner et al., 2006), a speculation not supported by the findings of this study.

Although only spatial visualisation predicted experience levels of laparoscopic surgeons, the results of the investigation two revealed a positive association between numerous visuospatial abilities and operative autonomy. These findings reveal two important clues about the role of visuospatial ability in laparoscopy. First, it shows that visuospatial ability is positively associated with residents' ability to demonstrate good and safe laparoscopic performance with little supervision. The emphasis here is on 'good' and not 'excellent'. Second, it reveals that such performance is related to spatial visualisation, mental rotation and perceptual-motor skills. That is, resident surgeons with better visuospatial abilities were also ranked higher on the operative autonomy measure. These findings are novel as they are the first to demonstrate the seeming interplay between various visuospatial processes in enabling a single laparoscopic task behaviour. Operative autonomy is a very broad categorisation for assessing one single component of laparoscopic performance. Assessing how safely and independently one performed the procedure encapsulates various skills and abilities that enable the surgeon to demonstrate such behaviour. The finding that different visuospatial abilities were positively related to that one behavioural component is therefore highly conceivable.

The most interesting finding arose when comparing the relationship between visuospatial abilities and laparoscopic performance at the individual-level and experience group-based level. The results highlighted that spatial visualisation, mental rotation and perceptual-motor skills all showed a positive correlation with operative autonomy at both levels. Yet, the strength of these correlations changed when considering the average laparoscopic experience of the residency surgeons. At the individual-level, all three aptitudes showed a weak to moderate correlation with autonomy. The strongest correlation among visuospatial abilities was observed between PicSOr (i.e. perceptual-motor), MRT-A (i.e. mental rotation) and the weakest with GVVT (i.e. spatial visualisation). However, at the experience group level, a moderate to strong correlation with autonomy was observed. Spatial visualisation showed the strongest correlation whereas perceptual-motor skills and mental rotation showed a moderate correlation. In other words, spatial visualisation showed the most notable change in magnitude between the two investigated levels. These changes in the correlational magnitude at the experience level could be an indication that the influence of visuospatial abilities changes with experience. Or, it could simply be a by-product of the aggregation, as correlations between aggregated variables are known to inflate the effect size of the coefficient (Ostroff, 1993). However, these observed changes in the magnitude at the experience level, particularly for spatial visualisation, do fit into the overall picture which has been systemically emerging throughout this doctoral thesis.

Correlation does not imply causation, yet, the trend implication spatial visualisation as a notable ability underlying laparoscopic competence and expertise is convincing. The results from investigation one have shown that spatial visualisation can distinguish laparoscopic surgeons from medical laypeople. Additionally, years of laparoscopic experience (i.e. expertise) was also found to be a significant predictor of performance on the spatial visualisation test. The results from study two have also highlighted spatial visualisation as an important component of laparoscopic competence and the results of study one found residency surgeons with little laparoscopic experience reporting aspects of spatial visualisation to be particularly challenging when operating with laparoscopy. In other words, all results appear to suggest that spatial visualisation is closely related to laparoscopic experience. Thus, by eliminating individual variations through aggregation, it is entirely possible that these correlations at the experience level captured the interdependence of spatial visualisation on laparoscopic experience. The true significance of this hypothesis will become evident in the scope of the longitudinal study.

In respect to perceptual-motor (i.e. PicSOr) and mental rotation skills (i.e. MRT-A), the strength of the relationships showed only a slight increased at the experience group level. Based on the findings of investigation one, residency surgeons did perform slightly better on the PicSOr than did expert surgeons or medical laypeople, albeit the difference not being statistically significant. Yet, it could offer some further insight into the observed correlation between PicSOr and autonomy. In respect to mental rotation, the relationship showed only a slight increase at the experience level. The homogeneous level of performance observed at the individual and experience level is an indication that the experience level of the resident does not change the magnitude of the relationship. This is in line with the results from the investigation one, which showed no performance differences on the measure between laparoscopic surgeons of varying experience levels. Yet, these results highlight an important aspect that should be taken into the consideration by researchers working on the topic. Surgeons in this study showed an arguably low performance on the measure, yet, the ability still showed a positive association with laparoscopic performance. These results clearly highlight that a correlation between the two variables can co-exist even when the performance on one of the measures is clinically subpar. Future researchers on the topic are highly encouraged to always accompany their correlation analyses with a descriptive overview of the aptitude performance scores of their participants. As this is not yet a common practice in the existing literature, our current understanding of the true practical implications of the reported correlations is limited. The extent to which mental rotation continues to influence laparoscopic performance of residency surgeons will be determined in the scope of the longitudinal study.

Limitations

When interpreting the findings of this study, some limitations must be considered. First, the sample size in both studies is arguably small, which has resulted in low statistical power. Unfortunately, due to the exploratory and purposive sampling nature of this study, increasing the sample size was not a possibility. To compensate for such limitations, all statistical analyses were performed using methods known to retain power in small samples. The type and number of analyses conducted on the sample was carefully considered. The data was described predominantly using descriptive and non-parametric statistics. All statistical outputs were always accompanied by measures of uncertainties (i.e. confidence intervals), effect size measures and critical value comparisons. Second, the residents' intraoperative performance was subjectively assessed by the supervising senior surgeons. I acknowledge that the observer bias couldn't have been eliminated. Two primary reasons drove the decision to use subjective assessments as part of this study. First, using subjective measures was favoured considering the pressing ethical considerations and logistical restrictions in conducting studies in operative theaters on live patients. Second, the philosophy underpinning this doctorate is based on investigating visuospatial processes driving laparoscopic skill acquisition in their naturalistic settings. Allowing senior surgeons to make judgements about the residents' performance fits such an approach, as this is a common practice in the surgical residency programs.

Conclusion

The findings of this current study contribute important new insight to surgical education showing that spatial visualisation shows the most promising trend in categorising laparoscopic surgeons of varying experience levels, predicting laparoscopic expertise and influencing intraoperative performance. Yet, in the light of the current empirical uncertainties as to which specific abilities play an important role in promoting laparoscopic performance, spatial visualisation does appear to be a significant candidate. The results also contribute a broader new insight to the field of spatial cognition, suggesting that mental rotation and spatial visualisation may be conceptually distant abilities. What now remains to be determined is how these visuospatial abilities develop and influence laparoscopic skill learning over the 27-month period.

STUDY 4

How do visuospatial abilities develop and influence laparoscopic skill learning: A longitudinal study

This longitudinal study explores how visuospatial abilities develop and influence laparoscopic skills learning over a 27-month residency training period.

1 Introduction

In the scope of this doctoral thesis a clear trend has been emerging implicating visuospatial ability as an important component underlying laparoscopic competence and expertise. The findings from study three lend further support to the observed trend by revealing that visuospatial ability can distinguish between laparoscopic surgeons and medical laypeople, can be predicted by laparoscopic experience and is positively associated with resident surgeons' intraoperative performance. Yet, the results from study three have highlighted an interesting dichotomy between abilities that characterise laparoscopic surgeons and abilities that influence laparoscopic performance. This raised the hypothesis that visuospatial abilities may play a differential role and influence over laparoscopic performance as experience in the technique is gained.

To date, there have been only a few attempts at exploring the role of visuospatial ability in the context of laparoscopic training over an extended time period (Harrington et al., 2018; Hedman, 2006; Keehner et al., 2006; Luursema et al., 2012; Stefanidis, Korndorffer, Black, Dunne, Sierra, Touchard et al., 2006). Yet, these studies reported largely divergent findings, raising ambiguity as to the true extent of influence that visuospatial ability bears over laparoscopic skill learning. As of now, our current understanding on the topic is based on two key findings reported in the existing literature: (1) visuospatial ability diminishes in importance as experience is gained, and (2) visuospatial ability remains important even when competence is gained. That is, some researchers found visuospatial ability to positively influence laparoscopic performance during the skill acquisition phase (Harrington et al., 2018; Keehner et al., 2006; Stefanidis et al., 2006) whereas others reported the influence of visuospatial ability to diminish during training (Hedman et al., 2006; Lurrsema et al., 2012). In other words, how visuospatial abilities develop and influence the acquisition of laparoscopic technical skills remains unclear. This uncertainty is further amplified by the lack of data collected on actual laparoscopic surgeons inside the operating theater.

This current longitudinal study seeks to break new grounds by exploring how visuospatial abilities *develop* and *influence* intraoperative laparoscopic skill learning of actual residency surgeons over a 27-month training period. With its empirical efforts, it seeks to gain deeper understanding on how visuospatial abilities influence skills learning and shape competence in the technique in the scope of actual surgical residency training. Such new gained insight carries the potential to inform spatial cognition researchers on the malleability of spatial cognition and provide surgical educators with new understanding of how laparoscopic skills are acquired during surgical residency and their implications for training the new generation of surgeons.

2 METHOD

1. Participants

This present pair-matched longitudinal study evaluated 36 subjects throughout the 27-month period, starting in January 2018 and ending in March 2020. The cohort includes 18 residency surgeons and 18 control group subjects. The surgeon cohort are residency surgeons currently training in general and visceral surgery at Klinikum Bremen-Mitte and Pius Hospital Oldenburg. The sample includes 10 (55.5%) junior residents (in 3-4 residency year) and eight (44.5%) senior surgeons (in final 5-6 residency year). Within the sample are six females and 12 males, with the average age of 34 (*SD* = 2.28, *range*= 30-47). The average number of laparoscopic cases completed by the residency surgeons as the **main operator** was 179 cases (*SD*= 103.4, *range* = 30 - 656). The control group participants are medical laypeople recruited from the University of Bremen and the general population. The cohort includes 12 females (66.6%) and six males (33.4%) with the average age of 24.6 (*SD* = 4.38, *range* = 21-37). Further details of the subject's characteristics and matched pair design see study three, pages 75-76. The overview of the pair-matched data can be found in the appendix 5.

1.1. Missing Data

At the baseline, an overall of 40 participants were tested: 21 residency surgeons and 19 control subjects (see study three, investigation two, page 103). However, it was prior knowledge that three residency surgeons (1 junior resident and 2 senior residents) and one control subject will not be participating in the longitudinal study due to the re-shift in the surgical department and other personal reasons. Their data was included in study three (i.e. baseline exploration) but was excluded in this current longitudinal study. Thus, only 36 subjects officially participated in this study. From these 36 subjects, data from 10 residency surgeons were further lost over the 27-month period. At the 6th month period, four resident surgeons (25%) dropped out of the study: three surgeons finished their residencies and one resident surgeon left the clinic. Between the 6th and 24th month period, six residency surgeons and one control subjects were lost. In the residency group, four finished their training and two were rotated around surgical departments in another hospital in Germany. Data from one control subject was lost due to relocation to another country. The most significant loss of data occurred between month 24-26 as a direct consequence of the COVID-19 related lockdown and cancellation of elective surgeons across Germany. Due to the health measures imposed at that time, data from only four resident surgeons and 16 control group subjects was collected between January 2020 and March 2020. The overview of the sample size per group and each re-testing time condition over the 27-month period can be seen in table 4.1.

Table 4.1. Overview of the sample size per cohort group and each testing condition

	Resident surgeons	Control subjects
Baseline	18 (100%)	18 (100%)
6-month	14 (-22.2%)	18 (100%)
12-month	10 (-44.4%)	18 (100%)
18-month	8 (-55.5%)	17 (-5.5%)
24-month	8 (-55.5%)	17 (-5.5%)
27-month	4 (-77.7%)	16 (-11.1%)

2. Aptitude and Intraoperative Measures

The four aptitude measures (i.e. PTSOT, GVVT, MRT-A and PicSOr) and the intraoperative assessment tool (i.e. GOALS) used in this study are described in detail in study three, investigation one, pages 77-82. The information about the intraoperative assessment tool and its administration procedure is described in study three, investigation two, pages 105-108. Aptitude tests were administrated after every 10^{th} laparoscopic procedure the resident surgeon completed as the main operator. This occurred roughly every six months. This specific timeline was chosen in an attempt to reduce the learning effect that accompanies repeated exposure to psychometric tests and reduce the burden of research participation of surgeons. Considering the pair-matched design of this study, the control subjects were tested at the same time intervals as their surgeon pair.

3. Statistical analysis

Visuospatial scores and intraoperative scores failed the assumption of normality (all $p < 0.03$). Across all measures, only the intraoperative total score was normally distributed ($p = 0.08$). For these purposes, data will be described using median and interquartile range (IQR). The internal validity and reliability of visuospatial scores and intraoperative performance scores was tested. The aim was to determine whether all repeated measures captured in this study produced consistent and stable results throughout the 27-month period. For these purposes a test-retest reliability was computed for visuospatial scores (i.e. self-administered tests) and the inter-rater reliability (i.e. test based on the subjective opinion of numerous senior surgeons) for the intraoperative scores. The interclass correlation coefficient (ICC) was computed for both methods. The strength of relationships for ICC coefficients was classified as: $0.3 \leq r < 0.5$ was 'poor', $0.5 \leq r < 0.75$ was 'moderate', $0.75 \leq r < 0.9$ was 'good' and $0.9 \leq r < 1.0$ was 'excellent' (Koo & Li, 2016). In line with the proposed aim of this longitudinal study, two main statistical analyses were performed: (1) multilevel mixed-effect modelling to explore the development of visuospatial and intraoperative skills over time and (3) repeated-measures correlations to explore the influence of visuospatial abilities on intraoperative skill learning over time.

First, the developmental trajectories of visuospatial abilities and intraoperative laparoscopic performance over the 27-month period was analysed using longitudinal linear mixed-effect growth curve modelling approach (LMM). The LMM approach was deemed particularly appropriate to tackle the complexity of the data in this study for five main reasons. First, the LMM can handle non-normal distribution of the dependent variables. Second, the LMM method allows for a more flexible linear and non-linear growth curve modelling of individual trends whilst simultaneously estimating the sample average trends (Goldstein, 2010). Third, the LMM can handle complex data and is particularly suitable for unbalanced (i.e. different number of time points per participant), correlated and hierarchically clustered data (Hair & Favero, 2019) as is the case in this study. Fourth, unlike repeated measures ANOVA, the LMM can handle missing values across the entire dataset whilst maintaining its power. Finally, the LMM incorporates fixed and random effects into one model, whereby variabilities in the individual trajectories (i.e. different baseline scores) and time points (i.e. measurements taken at different time points) can be best accounted for. The longitudinal growth curve modelling using the LMM conducted in this study closely followed the approach proposed by Shek & Ma (2011).

Second, the relationship between visuospatial abilities and intraoperative performance over the 27-month period was explored using two repeated measures correlation approaches: the within-subjects correlation and between-subjects correlation. The *within-subjects correlation* was computed using a repeated measures correlation method ("rmcorr") on the R-statistical software package developed by Bakdash & Marusich (2017). This approach measures whether an increase in one variable within an individual is associated with an increase in the second variable within the subject over time. Conceptually, the rmcorr can be compared to the null mixed-effect model, calculating the common regression slope across all subjects and time conditions and the association shared among the subjects. However, unlike the mixed-effect models that estimate the variance of both fixed and random effects, the rmcorr estimates the *overall* shared within-subject variance and is not influenced by the individual slopes' heterogeneity (Bland & Altman, 1995). Unlike other longitudinal correlation approaches, the rmcorr has high statistical power in detecting effect sizes, even in smaller samples (Bakdash & Marusich, 2017). The rmcorr analyses were bootstrapped considering the non-normal distribution of the data. The *between-subjects correlation*, on the other hand, measured whether subjects with higher scores on one variable also tend to have higher scores on another. The between-subjects' correlations were computed using weighted Spearman correlation coefficient on the subjects mean scores on visuospatial abilities and aggregated scores on intraoperative items, as was proposed by Bland & Altman (1995). All statistical analyses in this study were performed using the IBM SPSS (version 26) and the R-statistical programming software (R Core Team, 2020).

3 RESULTS

3.1. Test-retest reliability and inter-rater agreement assessment

3.1.1. Test-retest reliability of visuospatial aptitude tests

The ICC at the individual-level was computed using the two-way mixed-effect analysis of variance model with interaction, to examine the absolute agreement between the single scores across all time points and subjects on each aptitude measure, as recommended by Qin, Nelson, McLeod, Eremenco & Coons (2019). The absolute agreement computation takes into the account the self-reported nature of aptitude tests and aims to test for systematic differences between the participants' scores across various time points. This has been proposed as the most suitable approach in testing for the reliability of the cognitive measures (Cooper, Gonthier, Barch, & Braver, 2017). The results revealed excellent test-retest agreement for GVVT, whose ICC was 0.91, 95% CI [0.82, 0.96], MRT-A whose ICC was 0.97 (95 % CI [0.95, 0.99]) and PicSOr, whose ICC was 0.90 (95% CI [0.80, 0.95]). The PTSOT measure showed a good test-retest agreement with an ICC of 0.77 (95% CI [0.57, 0.90]).

3.1.2. Inter-rater reliability of the GOALS intraoperative assessment

The inter-rater reliability using a two-way mixed approach was computed to test for absolute agreement between the intraoperative assessments of 14 senior surgeons on each intraoperative item across all residency surgeons. The goal of this analysis was to examine the degree of consistency in the senior surgeons' ratings of intraoperative performance. Considering the performance of each resident was evaluated by different senior surgeons in the department, the inter-rater reliability aimed to estimate the possible variations in the scoring on each of these intraoperative items. Good agreement was found between the senior surgeons' ratings on bimanual dexterity, with an ICC of 0.82 (95% CI [0.16, 0.99]. Moderate agreement was found on the ratings of depth perception, with an ICC of 0.70 (95% [-0.09, 0.98]) and autonomy with an ICC of 0.67 (95% CI [-0.4, 0.97]. However, a low agreement was found among senior surgeons on the assessment of efficiency and tissue handling, with an ICC of -0.20 (95% CI [-4.15, 0.92] and -1.30 (95% CI [11.97, 0.89], respectively. The captured disagreement between the ratings on the assessment of efficiency and tissue handling suggests that the between-subjects variance on these two items were low whereas the between-rater variance was high.

Research question 1: How do visuospatial abilities develop over time?

This research question tackles the first aim of this longitudinal study: How do visuospatial abilities develop over time? In the section 1.1, descriptive statistics summarising visuospatial test scores per each testing session over the 27-month period are presented. In the section 1.2 the results from the longitudinal linear mixed-effect growth curve modelling of visuospatial abilities over the 27-month period are provided. Finally, in the section 1.3 the confounding effect of gender on aptitude trajectories are explored to determine whether gender can predict the rate of improvement in visuospatial abilities over time.

1.1 Descriptive overview

Overall, a total of 164 visuospatial tests were collected throughout the 27 months, of which 62 aptitude measures were collected from the residency surgeons and 102 measures collected from the control group subjects. The difference in the number of collected measures per group is due to the disruption in data collection in the surgeon cohort related to the COVID-19 pandemic in the last stages of data collection. Whereas data collection was still partly possible in the control subjects, the implemented health measures at the hospitals made data collection in the surgeon cohort impossible.

In this first stage of data analysis, the visuospatial development (i.e. trajectory) across all 36 subjects was explored. Based on the descriptive statistical, all subjects showed an improvement in visuospatial test scores over the 27 months. The MRT-A and PicSOr showed the faster rate of improvement from the baseline, increasing up to 49.2% and 32.8, respectively. The GVVT showed a more stable improvement, increasing up to 25.4% from the baseline. The PTSOT, on the other hand, showed the smallest rate of improvement as compared to other aptitudes, increasing around 12.5% from the baseline. The descriptive statistics representing the median score across all subjects and aptitude tests, at each time condition, are illustrated in table 4.2 below. The rate of change is described as the percentage of score change between the mean baseline score and the score at each time condition.

Table 4.2. Descriptive summary of the visuospatial scores across all subjects and time conditions

		PTSOT	GVVT	MRT-A	PicSOr
	n	Median (IQR)	Median (IQR)	Median (IQR)	Median (IQR)
Baseline	36	67.54 (31.89)	14.67 (12.26)	11.00 (5.75)	.47 (0.65)
6th month	32	73.95 (19.21)	18.17 (8.19)	14.00 (7.0)	.36 (.63)
% score change from baseline		+ 9.5 %	+ 23.9 %	+ 27.3 %	- 23.4 %
12th month	27	72.00 (9.33)	20.50 (9.33)	15.00 (6.00)	.47 (.50)
% score change from baseline		+ 6.6 %	+ 39.7 %	+ 36.4 %	0%
18th month	25	79.40 (17.11)	20.50 (6.99)	17.00 (7.50)	.70 (.64)
% score change from baseline		+ 17.6%	+23.7 %	+ 54.6%	+ 48.9 %
24th month	24	78.41 (22.34)	21.09 (6.99)	17.50 (7.25)	.68 (.72)
% score change from baseline		+ 16.1 %	+ 43.8 %	+ 59.1 %	+ 44.7 %
27th month	20	76.00 (18.42)	20.50 (8.0)	18.50 (6.75)	.91 (.68)
% score change from baseline		+ 12.5 %	+ 39.7 %	+ 68.2 %	+ 93.6 %
Average change score (%)		+ 12. 5 %	+ 25.4 %	+ 49.2 %	+ 32. 8 %

1.2 Longitudinal Linear Mixed-Effect Modelling

Three growth curve models were computed using linear mixed-effect modelling to examine the development (i.e. growth) of visuospatial abilities over 27 months. Model 1 is an *unconditional (i.e. "null") mean model* with no predictors and no regard for time. The purpose of the unconditional model is to assess the amount of within and between-subject variations in the aptitude scores and determine the grand mean (i.e. pool mean) across all subjects. The insight of the variations in the scores informs decision-making process as to which predictors should be included to the subsequent models and allows for the comparison of the variations across different models with different predictors. Model 2 is an *unconditional growth curve model* examining individual variations of the growth rates with time as the level 1 predictor. As opposite of the unconditional mean model which only assesses variation across individual, the unconditional baseline model also examines individual changes over time. If no intraindividual variation is captured, no subsequent modelling would be performed. Model 3 is *a conditional multivariate growth model* which uses group as the predictor to determine whether group characteristics (i.e. resident surgeons or control subjects) can predict individual growth changes over time. In other words, this particular model will inform us of the differences in visuospatial trajectories between resident surgeons and control subjects over time. All models performed in this study were examined for assumptions using residual plotting, none showing any notable deviation from homoscedasticity. The assumptions for mixed effect linear modelling was therefore met. Considering time points and baseline score differs among the subjects, variable of time and variable of subjects (i.e. subjects ID) will be treated as random effects in all performed models, to better control for such variation.

Model 1. Unconditional mean model to explore the degree of interindividual differences in aptitude test performances

Four individual unconditional growth models were computed for each aptitude measure across all subjects. The intraclass correlation coefficient (ICC) was calculated to quantify the total between-subject variance in aptitude performances. A maximum likelihood (ML) approach was used to estimate the model with the scaled identify [6] set as the covariance structure. The ICC's for each aptitude measure is displayed in table 4.3 below [7]. The grand mean score on the

[6] The scaled identity covariance structure has constant variance and assumes no correlation between any elements.

[7] Calculation based on the following formula: [(model 1 value – model 2 value) / model 1]

PTSOT measure was 68.72 (*SE*= 2.02). The between-subject variance (i.e. intercept) across the subjects was 98.5 (*SE*= 35.6), whereas the within-subjects performance variations (i.e. residuals) was 183.4 points (*SE*= 22.98). The ICC for PTSOT suggests that 35% of the total outcome variations in PTSOT performance are related to the differences between-subjects. The grand mean score on the GVVT was 16.8 (*SE*= 0.87). The between-subjects' variations in GVVT was 23.0 (*SE*= 6.6), and within-subjects' variation being 15.2 (*SE*= 1.9). The ICC suggests that 60% of the total variation in performance can be attributed to the differences between subjects. The grand mean score for the MRT-A was 13.8 (*SE*= 0.79). The between-subjects' variations on the measure were 20.1 (*SE*= 5.4), whereas the within-subjects variation was 8.5 (*SE*= 1.1). The ICC indicated that the between-subjects' differences could explain 70% of the total variance in MRT-A performance. Finally, the grand mean PicSOr score across all subjects was 0.50 (*SE*= 0.05). The between-subjects variance was 0.08 (*SE*= 0.02), whereas the within-subjects variance was 0.07 (*SE*= 0.01). The ICC for PicSOr suggested that differences between subjects can explain 53% in the total performance variations.

Table 4.3. Values for between-subjects' variations and within-subjects' across all aptitude measures subjects

	Grand mean	Intercept [between-subjects]	Residual [within-subjects]	ICC
PTSOT	68.72 [64.6, 72.8]	98.5	183.4	0.35
GVVT	16.8 [15.05, 18.59]	23.0	15.2	0.60
MRT-A	13.8 [12.2, 15.4])	20.1	8.5	0.70
PicSOr	.50 [0.39, 0.60]	0.08	0.07	0.53

Note: Squared brackets illustrate values of the grand means 95% confidence intervals

Model 2. Unconditional growth models over all subjects and time conditions

In this model, variations in individual trajectories (i.e. growth curves) across all subjects and time conditions were explored. Thus, whereas model 1 quantified the degree of variation across subjects, this current model explored performance variance across subjects *over time*. Using the ML approach, four separate mixed-effect growth models for each aptitude measure were estimated. Studies exploring cognitive skill development have long noted that trajectories do not always follow a linear trend (Grimm, Ram & Hamagami, 2011; Shek & Ma, 2011). Thus, before modelling, trajectories for each aptitude were visually inspected through scatterplot interpolation line fitting to determine whether a linear or a polynomial model (i.e. inclusion of quadratic or cubic term) should be fitted.

2.1. Growth trajectory for the PTSOT

The visual inspection of the data suggested that PTSOT trajectory can be best described using a linear function. A linear mixed-effect growth model was fitted, with time as a fixed effect. An unstructured covariance type[8] was used, as it provided the best fitting model (BIC= 1387.9). Time was a significant predictor of PTSOT trajectory (B= 2.2, $SE = 0.6$, $p = 0.02$, 95% CI [1.0, 3.5]). The mean score at the baseline was 64.18, from which the score increased by 2.2. points at every increment of time. The random error term of the intercept and time was significant ($p < 0.01$) suggesting that the variability in PTSOT scores can be explained by between-subject predictors. Comparing the intraindividual variation between model 1 and model 2 highlighted that the linear change over time was associated with 17.9% of the within-subjects variation (*Model 1* = 183.4, *Model 2* = 165.5)[9] and 9.4% with the between-subjects variation (*Model 1* = 98.5, *Model 2* = 89.1). The correlation between the intercept and the linear growth (i.e. time) was positive (ß = 92.62, $SE = 40.46$, $p = 0.02$, 95% CI [39.33, 99.04]), suggesting that individuals

[8] No constraints are imposed on the values and each variance is estimated uniquely from the data
[9] Calculation [model 1 – model 2]

with higher scores did show a faster linear growth over time. The scatterplot illustrating the growth curve can be seen in figure 4.1.

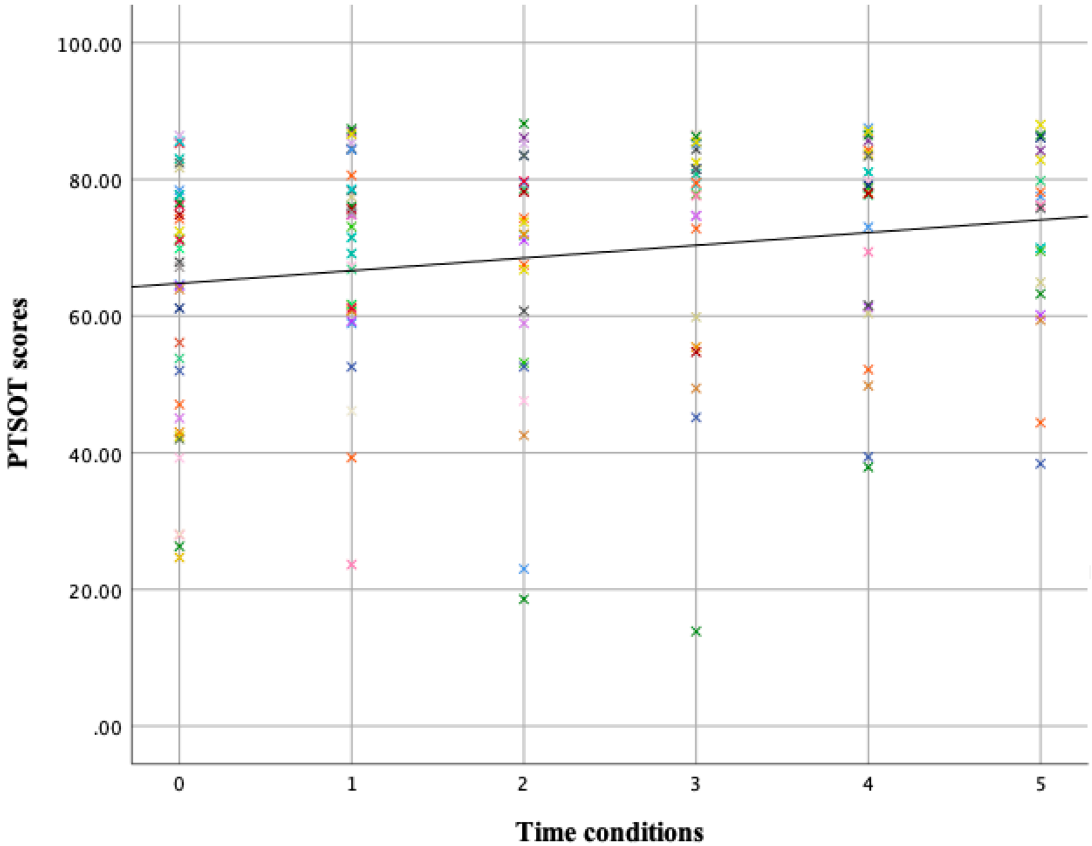


Figure 4.1. Scatterplot illustrating the PTSOT score trajectories across all subjects over time

Note: Time conditions codes are (0) baseline, (1) 6th month, (2) 12th month, (3) 18th month, (4) 24th month, (5) 27th month.

2.2. Growth trajectory for the GVVT

Visual inspection of the GVVT data indicated that a quadratic term (i.e. polynomial curve) was a better fit to describe the trend. A mixed-effect polynomial model was estimated, with linear and quadratic time terms included as fixed effects. An unstructured covariance type was used to estimate the model (BIC= 1003.2). Time was a significant predictor of GVVT trajectory (B = 2.4, SE = 0.6, p < 0.01, 95% CI [1.3, 3.5]). The mean score at baseline was 13.6 after which the score increased by 2.4 points at every increment of time. The quadratic term was significant but negative (B = - 0.3, SE = 0.1, p < 0.01, 95% CI [-0.5, -0.1]), indicating that the linear trend of growth decreased by 0.3 points over time. The negative quadratic term highlights a downturned bend in the regression slope (i.e. concave in the slope). Together, these findings indicate a curvilinear trajectory: an initial increase followed by the plateau in performance (i.e. aptitude ability). Comparing the intraindividual variation between model 1 and model 2 revealed that the linear change over time was associated with 3.6% of the within-subjects variation (*Model 1* = 15.2, *Model 2* = 11.6) and 0.8% of the between-subjects variation (*Model 1* =23.0, *Model 2* = 22.2). A moderate negative correlation between linear time and squared time (r = -0.45) was found, indicating that subjects with the fastest linear increase in GVVT score at the beginning reached the plateau faster. The scatterplot illustrating the growth curve can be seen in figure 4.2.

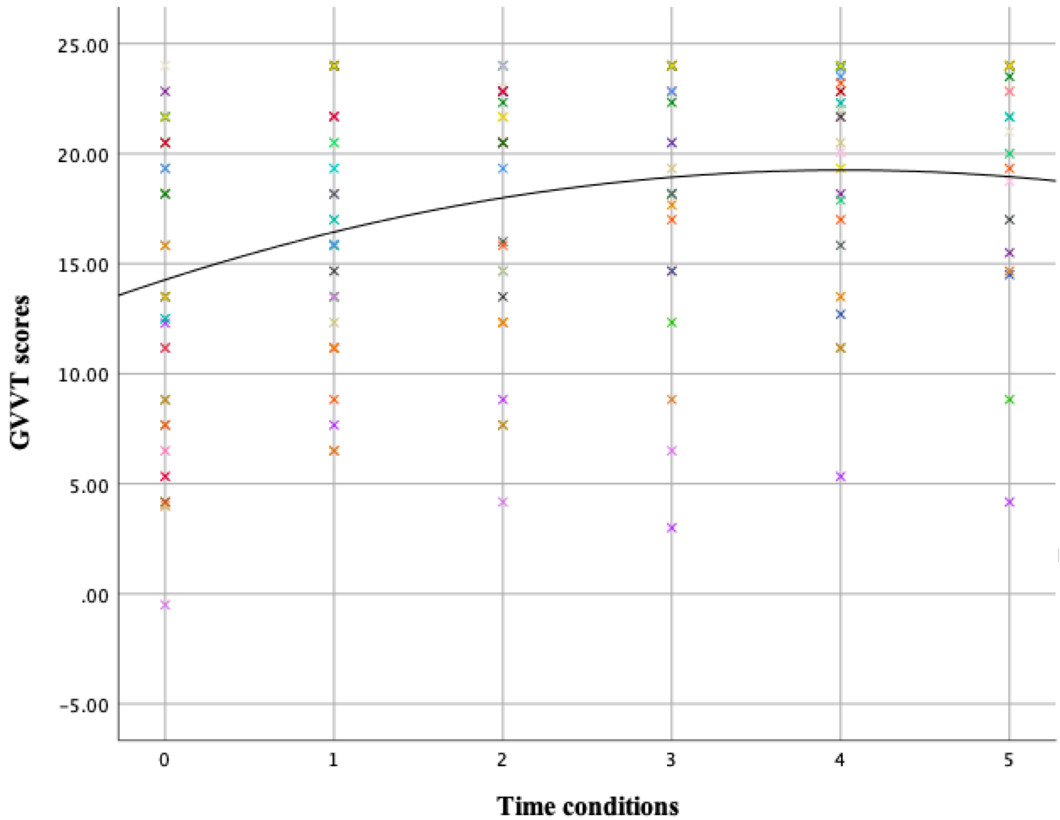


Figure 4.2. Scatterplot illustrating the GVVT score trajectories across all subjects over time

Note: Time conditions codes are (0) baseline, (1) 6th month, (2) 12th month, (3) 18th month, (4) 24th month, (5) 27th month.

2.3. Growth trajectory for the MRT-A

The visual inspection of the MRT-A scores revealed the quadratic term showed the best fit. A polynomial mixed-effect model was fitted using the linear and quadratic terms as fixed effects. The model was estimated using an unstructured covariance structure (BIC= 872.80). Time was a significant predictor of MRT-A trajectory (B= 2.6, *SE* = 0.3, $p < 0.01$, 95% CI [2.0, 3.2]). Mean baseline score for MRT-A was 10.3, after which the score increased by 2.6 points at every increment of time. The quadratic term was significant but negative (B = -0.3, *SE*= 0.1, $p < 0.01$, 95% CI [-0.4, -0.2]), indicating that the initial linear growth did decreased by 0.3 points over time. That is, the MRT-A showed a similar growth curve trajectory as was observed on the GVVT measure, a trend categorised by a concaved bend in the regression slope, indicating subjects reached the plateau in their performance (i.e. aptitude ability). Comparing the intraindividual variation between model 1 and model 2 revealed that linear change over time was associated with 8.1 % of the within-subjects variation (*Model 1* = 8.5, *Model 2* = 0.4) and 0.4 % of the between-subjects variation (*Model 1* = 20.1, *Model 2* = 19.7). A moderate negative correlation between linear time and squared time (r = -0.40) was found, indicating that subjects with the fastest initial linear growth score reached the plateau faster. The scatterplot illustrating the growth curve can be seen in figure 4. 3.

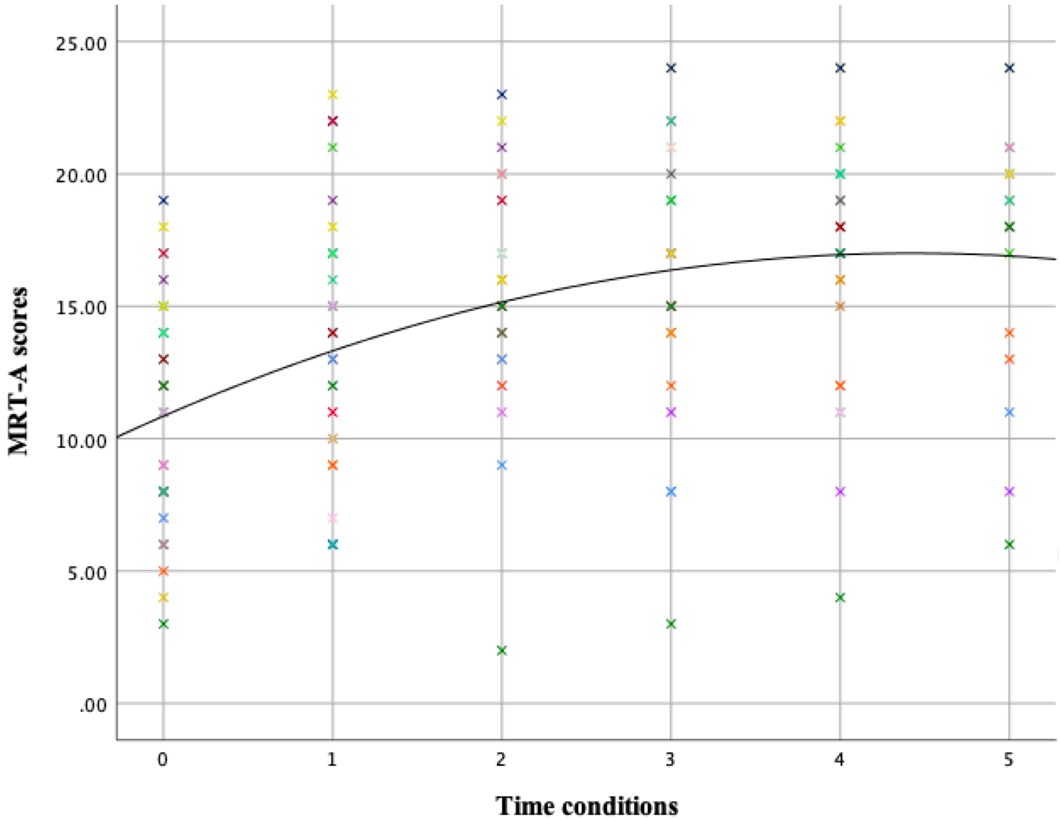


Figure 4.3. Scatterplot illustrating the MRT-A score trajectories across all subjects and time conditions

Note: Time conditions codes are (0) baseline, (1) 6th month, (2) 12th month, (3) 18th month, (4) 24th month, (5) 27th month.

2.4. Growth trajectory for the PicSOr

The visual inspection of the PicSOr scores revealed that the cubic term fitted the shape of the trend. A polynomial mixed-effect model was fitted using the linear and cubic time as fixed and random effect. The model was estimated using an unstructured covariance structure (BIC= 113.32). Both linear time and cubic time contributed significantly to the model. Linear time was negative (B= -0.25, SE= 0.07, $p < 0.01$, 95% CI [-0.39, -0.11]) suggesting an initial linear decrease in PicSOr scores. The cubic term showed a negative effect on PicSOr trajectory (B= -0.25, SE= 0.07, p < 0.01, 95% CI [-0.39, -0.11]), suggesting the that the decelerating trend gradually diminished over time. In other words, a curvature trend was observed, as seen in figure 4.4. Comparing the intraindividual variation between model 1 and model 2 revealed that cubic change was associated with 0.01 % of the within-subjects variation (*Model 1* = 0.07, *Model 2* = 0.06) and 0% of the between-subjects' variation (*Model 1* = 0.08, *Model 2* = 0.08).

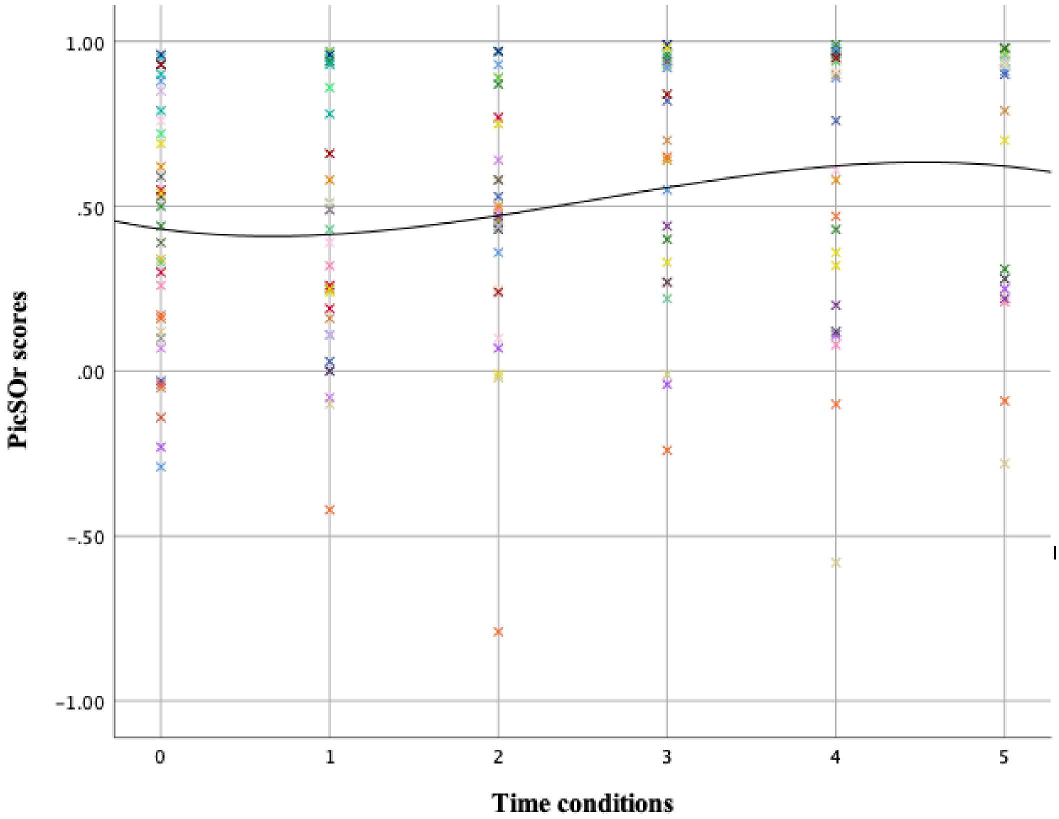


Figure 4.4. Scatterplot illustrating the score trajectories for PicSOr across all subjects and time conditions

Note: Time conditions codes are (0) baseline, (1) 6th month, (2) 12th month, (3) 18th month, (4) 24th month, (5) 27th month.

Model 3. Multilevel modelling exploring group differences in growth trajectories

Mixed-effect modelling was used to explore whether the effect of group (resident surgeons and control group) can predict the shape of individual growth trajectories on aptitude measures. Group was treated as a time-invariant covariate in an attempt to explore group differences in growth trajectories. A group x time interaction was included into the models. Group was treated as a binary variable (0= control group, 1= resident surgeons). The descriptive statistics illustrating the groups' percentage of score changes from the baseline across all time conditions are presented in table 4.4 below.

Table 4.4 Descriptive summary of aptitude score for both groups across all time condition

	Resident surgeons					Control group				
		PTSOT	GVVT	MRT-A	PicSOr		PTSOT	GVVT	MRT-A	PicSOr
	n	Median (IQR)	Median (IQR)	Median (IQR)	Median (IQR)	n	Median (IQR)	Median (IQR)	Median (IQR)	Median (IQR)
Baseline	18	71.73 (17.63)	18.17 (8.33)	9.50 (7.50)	.57 (.59)	18	64.15 (33.09)	11.73 (11.38)	11.00 (4.25)	.28 (.66)
6th month	14	79.58 (15.61)	21.09 (7.28)	14.50 (7.75)	.55 (.42)	18	67.07 (17.79)	15.25 (8.46)	13.50 (7.75)	.25 (.47)
% score change		+ 10.9 %	+16.2%	+52. 6 %	-3.5 %		+4.6%	+30.1%	+22.7%	-10.7%
12th month	10	79.61 (13.09)	22.50 (6.87)	14.50 (3.75)	.67 (.50)	17	71.10 (26.23)	20.50 (12.00)	15.00 (8.00)	.45 (.38)
% score change		+ 11.0 %	+28. 3 %	+52.6%	+17.5%		+10.1 %	+74.8%	+36.4%	+60.7%
18th month	8	81.50 (23.92)	23.42 (6.20)	15.00 (6.75)	.93 (.29)	17	77.83 (15.32)	19.33 (9.33)	17.00 (8.50)	.55 (.65)
% score change		+13.6 %	+ 28.9 %	+57.9 %	+63.2%		+21.3%	+67.8%	+54.6%	+96.4%
24th month	8	81.28 (8.97)	23.55 (6.42)	17.50 (5.00)	.96 (.59)	17	75.37 (22.14)	19.69 (8.14)	17.50 (8.75)	.54 (.77)
% score change		+13.3 %	+ 29.6 %	+84.2%	+68.4%		+17.5 %	+67.9%	+59.1%	+92.9%
27th month	4	86.31 (7.49)	24.00 (0.00)	19.00 (8.75)	.84 (.87)	16	69.73 (18.23)	19.67 (7.66)	18.50 (6.75)	.91 (.68)
% score change		+20.3 %	+ 32.1 %	+100%	+47.4%		+ 8.7%	+67.7%	+68.2%	+105.9%
Average change from the baseline (%)		+13.8 %	+27.0%	+58.9%	+38.6%		+12.4%	+61.7 %	+48.2%	+68.9%

3.1. The effect of group on PTSOT trajectories

For the PTSOT, the visual inspection of the data indicated a cubic term was a better description of the groups scores trajectories over time. A polynomial mixed-effect model was fitted with linear and cubic terms as fixed effects. An unstructured covariance type was used for estimation (BIC= 1461.9). Group was not a significant predictor of linear growth (B= 2.37, *SE*= 3.24, *p*= 0.89) nor the cubic growth (B= 1.40, *SE*= 1.0, *p* = 0.16, 95% CI [-0.57, 3.37]), suggesting group characteristics did not predict the shape of individual growth trajectories over time. See figure 4.5 below. The predictor of group explained 33% of the total overall variability in the PTSOT measure (*Model 2* = 165.5, *Model 3* = 132.5).

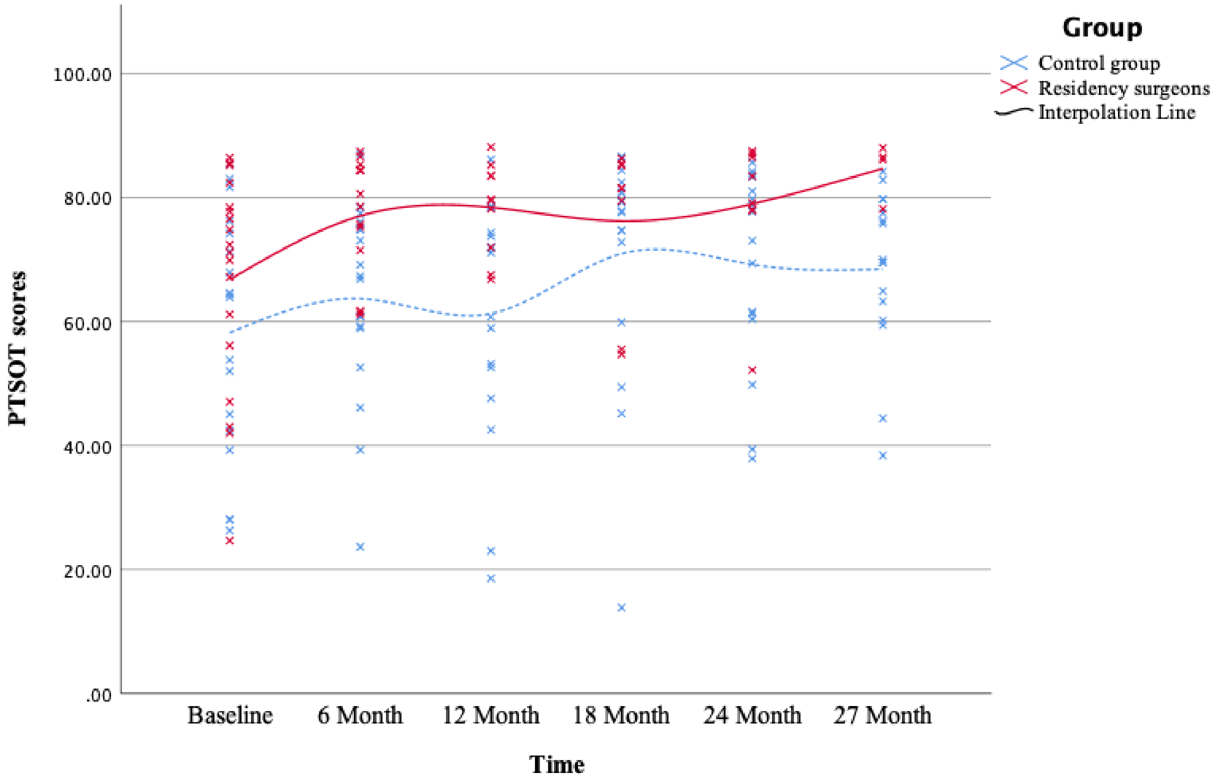


Figure 4.5. PTSOT growth trajectory for both resident surgeons and control group

3.2. The effect of group on GVVT trajectories

For the GVVT, the visual inspection of the data indicated that the linear and quadratic term better describe the scores trajectories for both groups over time. A polynomial mixed-effect model was fitted with linear and quadratic terms as fixed effects. An unstructured covariance type was used to estimate the model (BIC=

906.3). Group was found to be a significant predictor of linear growth ($p < 0.01$) but not the quadratic growth (p = 0.07). Resident surgeons showed a faster rate of growth (B= 4.01, *SE* = 1.83, p = 0.02, 95% CI [0.40, 7.63]) compared to control subjects. That is, the characteristic of group was able to predict the individual growth curves in the residency surgeon cohort. Whereas resident surgeons improved their scores over time, the control subject's linear growth plateaued over time, as seen in figure 4.6. The predictor of group explained 16.3% of the total variation on the GVVT measure over time (*Model 2* = 22.2, *Model 3* = 5.95).

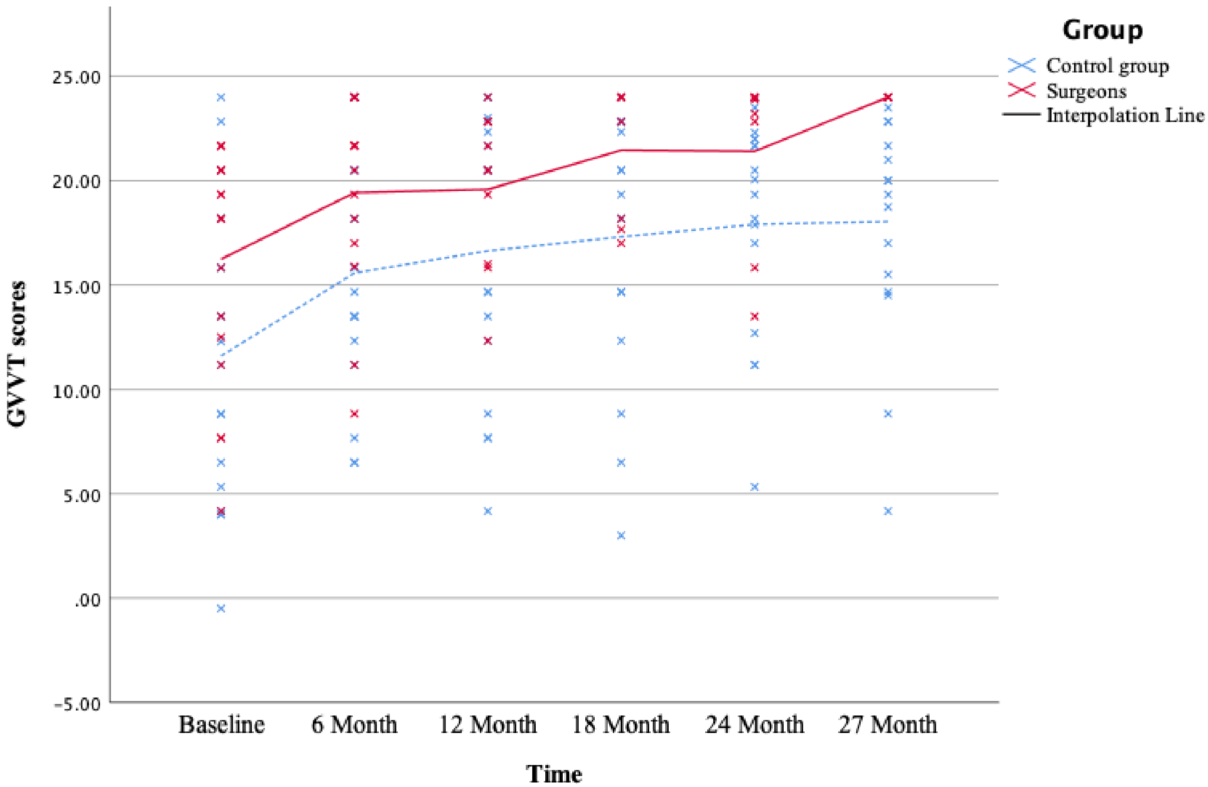


Figure 4.6. The GVVT growth trajectories for residency surgeons and control group

3.3. The effect of group on MRT-A trajectories

The visual inspection showed the MRT-A trajectories for both groups were best described using the linear and quadratic terms. A polynomial model was fitted using both terms as fixed effects. An unstructured covariance type was used to estimate the model (BIC= 801.65). Group was not a significant predictor of the linear growth (B= 0.49, *SE*= 1.25, p= 0.70, 95% CI [-2.00, 1.97]) nor quadratic growth (B= -0.04, *SE* = 0.66, p= 0.95, 95% CI [-1.34, 1.27]), as seen in figure 4.7.

The predictor of group explained 0.1 % of the total variation on the MRT-A measure over time (*Model 2* = 19.7, *Model 3* = 19.6).

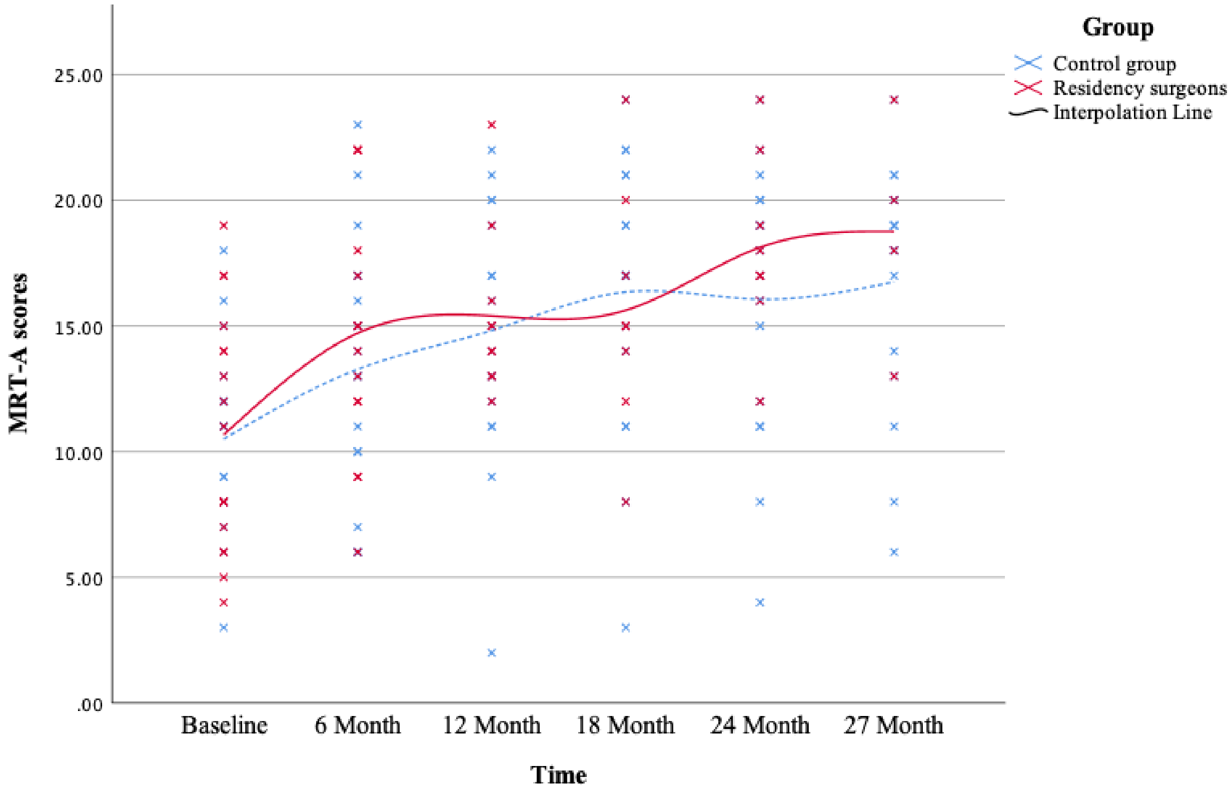


Figure 4.7. MRT-A growth trajectory for both residency surgeons and control group

3.4. The effect of group on PicSOr trajectories

The visual inspection revealed a cubic trend for both groups. A polynomial mixed-effect model was fitted to explore the effect of group on PicSOr growth rates with linear and cublic terms as fixed effects. An unstructured covariance type was used to estimate the model was it provided a better fit (BIC= 89.59). Group was not a significant predictor of PicSOr linear growth (B= 0.03, *SE* = 0.04, *p* = 0.49, 95% CI [-0.05, 0.11]) or cubic growth (B= -0.01, *SE* = 0.02, *p* = 0.52, 95% CI [-0.04, 0.02]), suggesting the characteristics of a group were not able to predict individual growth trajectories over time. See figure 4.8 for the illustration of the growth trajectory per group. The predictor of group explained 0.02 % of the total variation on the PicSOr measure over time (*Model 2* = 0.06, *Model 3* = 0.04).

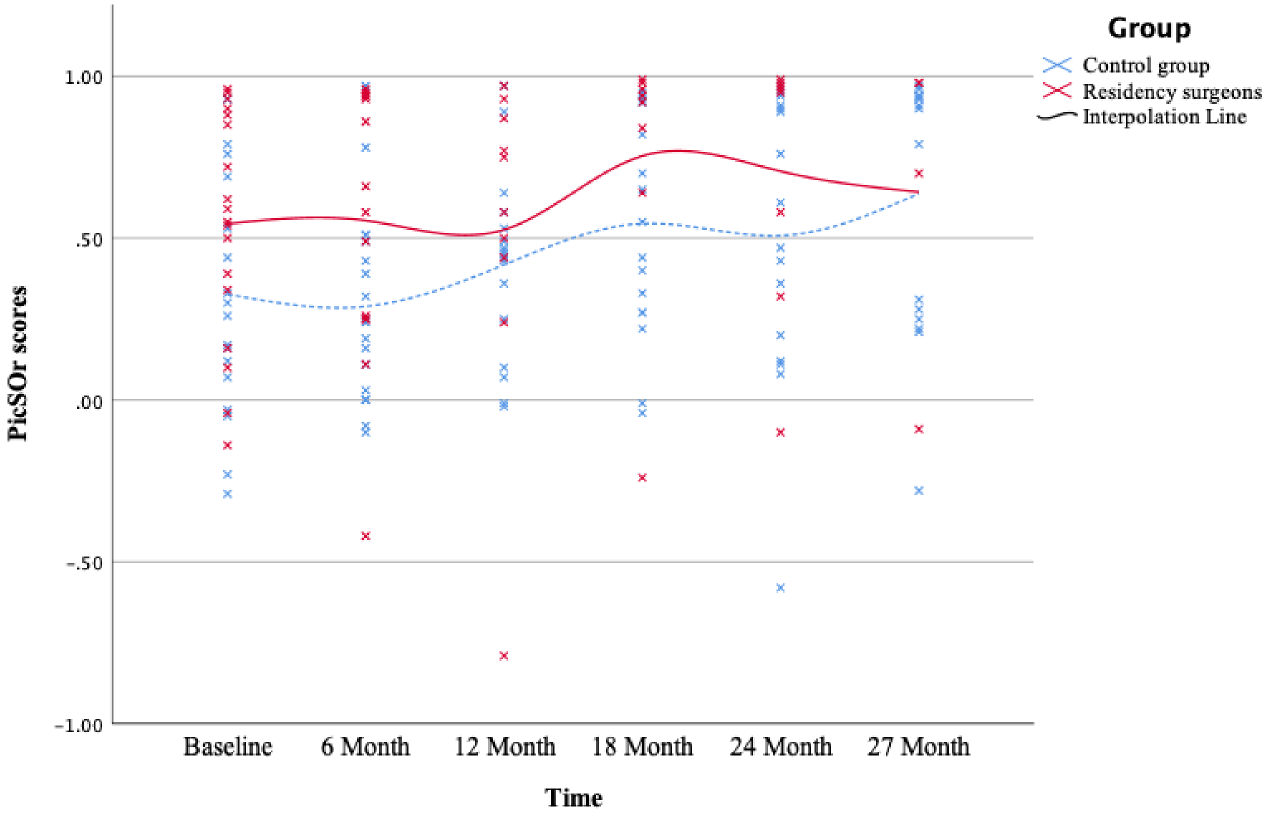


Figure 4.8. Growth trajectory for PicSOr per residency surgeons and control group

4. The effect of gender on visuospatial skill development

As was demonstrated in study one of this thesis, the future generation of surgeons is female. The results from study three, investigation one, revealed no effect of gender over the baseline performance on visuospatial abilities of surgeons, yet, an effect over aptitude performance in the control group. This analysis aims to determine whether the same effect can be observed when considering the development of visuospatial abilities over time. A linear mixed-effect models were fitted for each aptitude. A binary group variable (0= control group, 1= resident surgeons) was treated as a fixed effect and time as an invariant predictor. Interaction terms between fixed factors (i.e. group) and the covariate (i.e. gender) was included. For the PTSOT, the cross-level interaction between group (fixed effect) x gender (covariate) was found, $F(1, 21)$, 8.74, $p < 0.01$. In the control group, females performed better on the PTSOT measure as compared to males (B = -14.46, $SE = 4.21$, $p < 0.01$, 95% CI [-23.36, -5.56], whereas in the resident surgeon's group, males performed better than females (B = 11.18, $SE = 4.67$, $p = 0.02$, 95%

CI [1.65, 20.70]. See figure 4.9 for a graphical illustration of the PTSOT trajectory per gender and group.

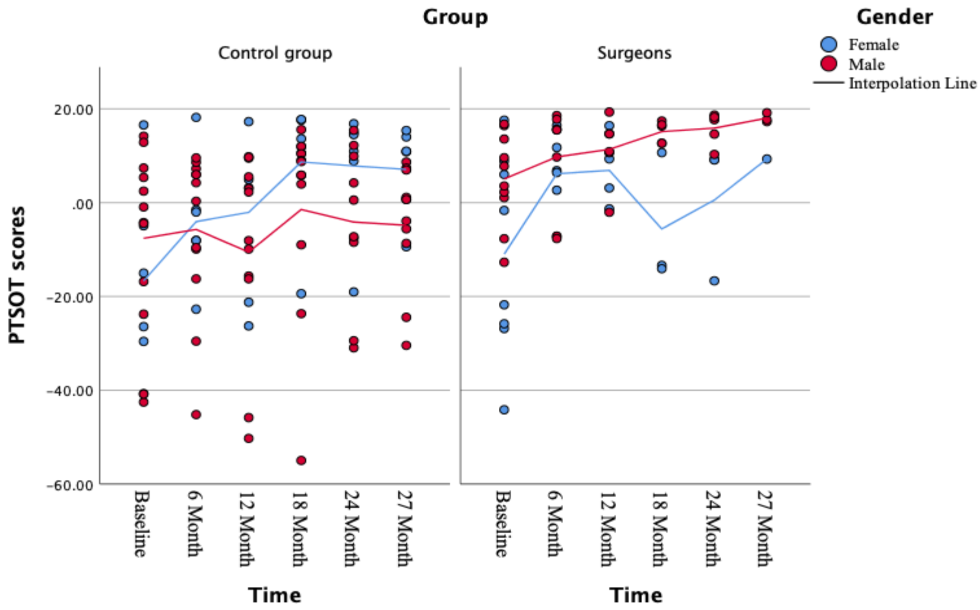


Figure 4.9. A group comparison of the PTSOT growth trajectories per gender

For the GVVT, no cross-level interaction between group x gender (β = 6.06, *SE* = 6.10, *p* = 0.33, 95% CI [-6.43, 18.54]) was found. On the MRT-A, a significant cross interaction between resident surgeon group x gender was found, suggesting males are better achievers on the MRT-A test as compared to women (B = - 18.88, *SE* = 4.31, *p* < 0.01, 95% CI [-27.0, -0.02], as seen in figure 4.10. On the PicSOr, no significant interaction between group x gender (β = - 0.28, *SE* = 0.38, *p*= 0.46, 95% CI [-1.07, 0.50]) was found.

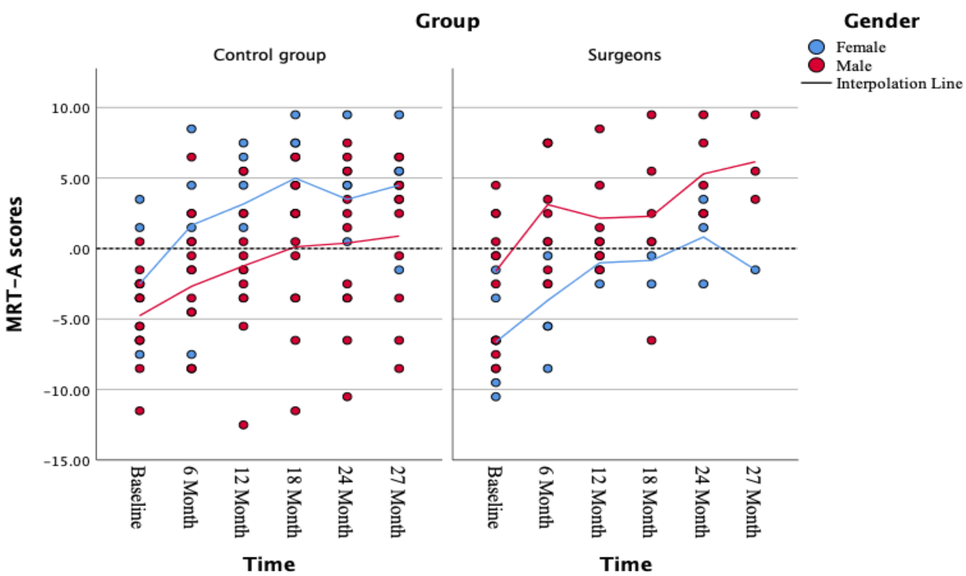


Figure 4.10. A group comparison on the MRT-A growth trajectories per gender

Research question 2: How does visuospatial ability influence laparoscopic skill acquisition?

This research question aims to explore how visuospatial abilities influence the acquisition of laparoscopic skills over time. Two types of analyses were performed in the scope of the stated aim. Section 1 introduces the linear mixed-effect growth curve modelling of laparoscopic technical skills over the three-year period was performed. The aim was to quantify the degree of variation and change in intraoperative scores over time. This was deemed as an important prerequisite to facilitate the interpretations from the repeated measures correlations. As with aptitude growth modelling, three models were performed on each of the five intraoperative items. First, an *unconditional mean model* was fitted to determine the degree of interindividual variations in intraoperative scores across all subjects. Second, an *unconditional linear growth model* was performed to explore the individual variations in intraoperative growt rates over *time.* Third, *a multilevel linear model* testing the effect of gender as a predictor of individual growth trajectories was computed. Such a model aimed to determine whether gender carries any effect on the growth of intraoperative scores over time. This model will allow us to better understand whether females, which were found to be the future of surgery in study one, are at any disadvantage when acquiring laparoscopic skills.

Section 2 introduces repeated measures correlations exploring the relationship between visuospatial abilities and technical laparoscopic skills at the within-subjects level (i.e. does an increase in one variable in the individual lead to an increase in another variable) and the between-subject level (i.e. do residents with higher scores on one variable tend to have a higher score on another variable). The exploration of intraoperative trajectories as a first step was deemed as an important prerequisite for the subsequent interpretation of repeated measures correlations. In other words, before exploring the relationship between visuospatial abilities and laparoscopic skills over time it is useful to first better understand how, and whether, these technical skills actually changed.

2.1 Descriptive overview of the intraoperative assessments

A total of 603 intraoperative assessments were collected over the 27-months. Laparoscopic skills were assessed across 255 (42.1%) laparoscopic cholecystectomies (CHE), 202 (33.4%) totally extraperitoneal (TEP) inguinal hernia repairs, 66 (10.9%) diagnostic / exploratory laparoscopies (DI/EX), 59 (9.4 %) appendectomies (APP), 12 (2 %) intraperitoneal onlay mesh (IPOM) hernia repairs, seven (1.2 %) sigmoid resections (SR) and two other (1 %) individual laparoscopic procedures (i.e. nephrectomy and lymphadenectomy). Across all intraoperative measures, the average difficulty of the procedures was rated as 'medium'. The average ASA scale of the patient operated by the resident surgeon' was 2 (i.e. a mild systemic diseases). The average total score across all resident surgeons and laparoscopic procedures was 15 (IQR = 4.0) out of 25, with the average score for each of the five GOALS domains being 3.0 (IQR = 1) (i.e. good). Seven (1.2 %) of these procedures were converted to open surgery, largely because of poor visualisation caused by a severe inflammation or unsuspected bleeding. The conversions happened in procedures rated as 'medium' or 'hard' and in patients rated as ASA scale 2 and 3. The conversions occurred in CHE, APP and the IPOM procedures. The learning curves for all intraoperative skills are illustrated in figure 4.11 below.

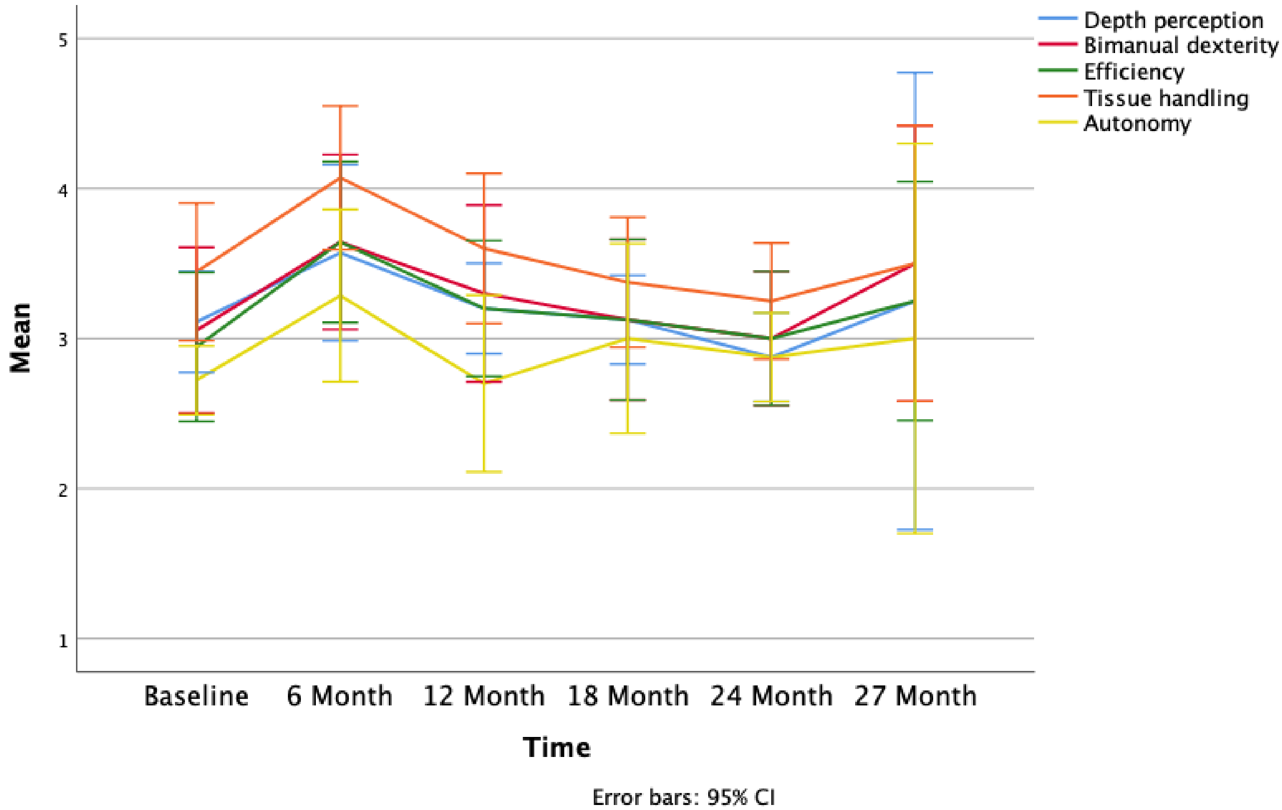


Figure 4.11. Intraoperative learning curves for each technical skill across all resident surgeons and time conditions.

Section 1. Intraoperative linear mixed-effect growth modelling

Following the same method of growth modelling used for visuospatial aptitude tests, linear mixed-effect models were fitted to explore the growth trajectories of intraoperative technical skills. First, an unconditional mean model for each intraoperative item was fitted to quantify the degree of intraindividual variation across all residency surgeons. Second, unconditional growth models were fitted to explore intraoperative growth rates across the three years.

1.1. Unconditional mean model for intraoperative scores

Unconditional mean models were computed for each intraoperative item across all residency surgeons to examine the degree of individual variation in all intraoperative scores without the regard for *time.* Subject ID was treated as random effects to allow for slopes to vary across all resident surgeons. The intraclass correlation coefficient (ICC) was calculated to quantify the total between-subject variance in aptitude performances. A maximum likelihood (ML) approach was used to estimate the model with the scaled identify set as the covariance type. The ICC's for all intraoperative measures are illustrated in the table 4.5.

Table 4.5. Unconditional mean model values for intraoperative scores

	Grand mean	Intercept [between-subjects]	Residual [within-subjects]	ICC
Depth perception	3.30 [3.07, 3.53]	0.25	0.42	0.37
Bimanual dexterity	3.22 [2.96, 3.48]	0.31	0.45	0.41
Efficiency	3.25 [2.99, 3.50]	0.31	0.50	0.38
Tissue handling	3.58 [3.36, 3.80]	0.21	0.43	0.33
Autonomy	2.88 [2.66, 3.11]	0.22	0.52	0.30

Note: Squared brackets illustrate values of the grand means 95% confidence intervals

The results revealed that across all technical skills and all residency surgeons, the highest total variation in the scores on bimanual dexterity (41% variation), efficiency (38% variation) and depth perception (37% variation) were attributed to differences between resident surgeons. On the other hand, the scores of autonomy (30% variation) and tissue handling (33% variation) showed a higher within-subject variation and the smallest proportion of interindividual differences in the total variation. The grand mean across all technical skills indicated all performed around the 'good performance' mark (i.e. around rank of 3 on the GOALS measure).

1.2. Unconditional growth modelling for intraoperative scores

In these models, a linear mixed-effect baseline growth curves for all intraoperative matric assessed by the GOALS assessment were fitted to examine individual variation and change in growth trajectories over *time*. In this model, time was treated in years (i.e. a three-year interval). Unlike with aptitude tests, there was no specific time interval in which operative assessments were collected. The collection ranged from three-assessments per day per resident to one assessment per month for another resident. Thus, categorisation per years allowed for a more consistent time categorisation of assessments. Time was treated as both fixed and random effect and subject ID treated as random to allow for the slopes to vary across all resident surgeons and time conditions. A maximum likelihood (ML) approach was used to estimate the model with the scaled identify set as the covariance type. Time was a significant predictor for all intraoperative matrices ($p < 0.01$) suggesting that the intraoperative performance on all measures did increase over the three years. See table 4.6 for the descriptive overview and the corresponding p values and 95% confidence intervals.

Table 4.6. Mixed-effect values describing the rate of growth for each intraoperative skill over time.

	B	***p-value***	**95% CI**
Depth perception	3.73	0.01	3.41, 4.05
Bimanual dexterity	3.60	0.01	2.97, 3.47
Efficiency	3.49	0.01	3.14, 3.84
Tissue handling	3.86	0.01	3.55, 4.17
Autonomy	3.15	0.01	2.82, 3.48

1.3. The effect of gender on laparoscopic skill acquisition

In this model, a predictive effect of gender on individual growth trajectories across all intraoperative items was explored. A binary group variable (0= females, 1= males) was examined as a time-invariant covariate to determine whether gender differences can predict change in intraoperative scores over time. Time and gender were treated as fixed effects. Time and subjects were also treated as a random effect to allow for all individual slopes to vary across all time conditions and subjects. An unstructured covariance structure was used to estimate the model. Interaction terms of gender x time were included. The results revealed that gender was not a significant predictor of any individual growth trajectories over time. See table 4.7 for a descriptive overview of the gender x time interaction values for all intraoperative items.

Table 4. 7. Overview of the gender x time interaction values per intraoperative item

	B	***p-value***	**95% CI**
Depth perception	-0.01	0.97	--0.51, 0.50
Bimanual dexterity	0.33	0.24	-0.23, 0.88
Efficiency	0.05	0.90	-0.64, 0.73
Tissue handling	-0.04	0.90	-0.65, 0.57
Autonomy	-0.23	0.49	-0.87, 0.42

Section 2. Repeated-measures correlations

2.1 Within-subjects correlation: is an increase in surgeons visuospatial scores associated with an increase in intraoperative score?

A within-subjects repeated measures correlation using "rmcorr" was computed to determine whether an increase in visuospatial scores within an individual is associated with an increase in the individuals intraoperative score over time. The results of the rmcorr revealed a significant positive association between GVVT and autonomy (p = 0.05) only, as visualised in figure 4.13 below. These results suggest that an increase in GVVT score within an individual was positively associated with an increase in individual's autonomy scores over time. Other associations showed only very small to medium size effect. This indicates that these relationship between visuospatial abilities and intraoperative items varied extensively across subjects. It has been stated that when between-subjects variation is larger than is within-subject, the rmcorr effect sizes and their corresponding confidence intervals will be near zero (Bakdash & Marusich, 2017). Looking at the confidence intervals, it can be observed that the GVVT is the only measure whose intervals, apart on tissue handling, do not contain a 0. The same was observed for the correlation between PicSOr and autonomy, which was marginally significant and whose intervals also do not contain a 0. Although these correlation coefficients were not statistically significant, the confidence intervals suggest they may be practically significant. In other words, it cannot be concluded that the within-subject effect between GVVT and intraoperative items alongside the PicSOr and autonomy does not exist. These results once again point towards the issue of type 2 errors in this study due to the small sample sizes. All rmcorr correlation values are displayed in table 4.8 below.

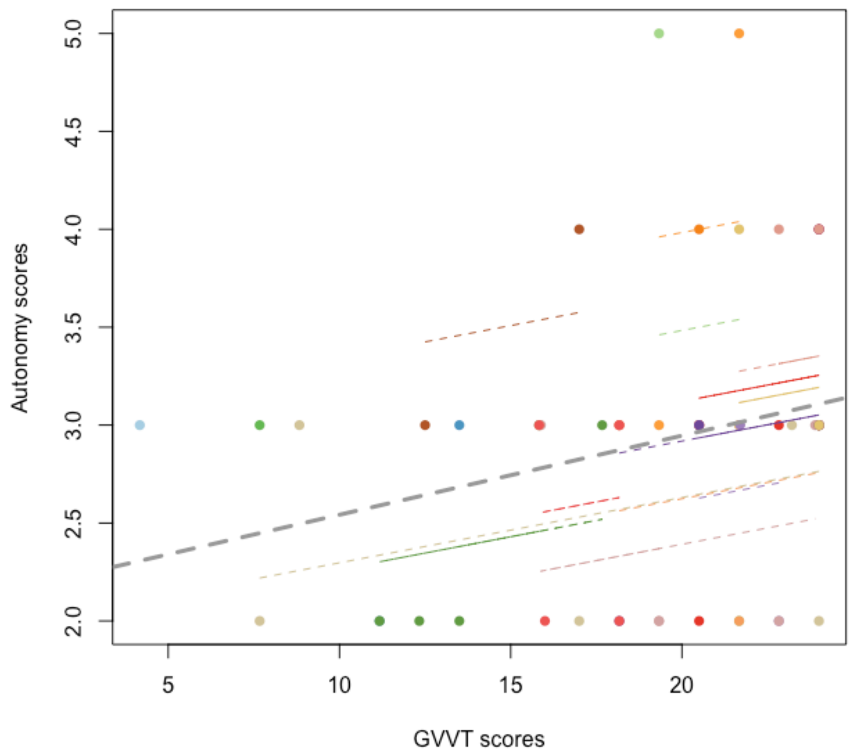


Figure 4.13. Rmcorr plot illustrating the within-subject association between GVVT and autonomy.

Note: Colour lines representing slopes for each individual. The dotted line represents a common regression slope across individuals.

Table 4.8. Rmcorr correlation matrix describing the relationship between VSA and intraoperative skills

df= 43	Depth perception	Bimanual dexterity	Efficiency	Tissue handling	Autonomy	Total score
PTSOT						
r_{rm}	-0.13	-0.07	-0.09	0.07	-0.21	-0.09
p value	0.38	0.67	0.55	0.66	0.18	0.55
95% CI	-0.28, 0.10	-0.12, 0.32	-0.19, 0.17	-0.33, 0.20	-0.29, 0.08	-0.25, 0.14
GVVT						
r_{rm}	0.15	0.03	0.08	-0.07	0.35	0.08
p value	0.34	0.86	0.60	0.42	**0.05***	0.59
95% CI	0.03, 0.51	0.06, 0.48	0.05, 0.50	-0.24, 0.10	0.12, 0.49	0.02, 0.54
MRT-A						
r_{rm}	0.14	0.09	0.17	0.03	0.28	0.17
p value	0.35	0.58	0.26	0.85	0.08	0.28
95% CI	-0.20, 0.30	-0.16, 0.27	-0.20, 0.29	-0.21, 0.33	-0.03, 0.43	-0.10, 0.36
PicSOr						
r_{rm}	-0.08	0.14	0.17	-0.00	0.26	0.17
p value	0.58	0.37	0.27	0.99	0.09	0.28
95% CI	-0.19, 0.27	-0.02, 0.46	-0.16, 0.22	-0.21, 0.19	0.13, 0.50	-0.02, 0.37

2.2 Repeated-measures correlations across subjects: Do resident surgeons with higher visuospatial ability also have higher intraoperative scores?

The results from the within-subjects correlation revealed small effect sizes for the vast majority of the associations between visuospatial abilities and intraoperative items. This suggests that the relationships between the two variables varied extensively across subjects. In this analysis, between-subjects relationship between visuospatial abilities and intraoperative items will be explored to determine whether resident surgeons with higher visuospatial scores also tend to have higher intraoperative scores. A weighted Spearman correlation coefficient was computed on visuospatial scores and intraoperative scores averaged around the subjects mean, following a method for repeated measures between-subjects correlation by Bland & Altman (1995). Three types of between-subjects relationship were explored: (1) the relationship between visuospatial abilities and intraoperative scores, (2) the relationship between visuospatial scores and time-aggregated intraoperative scores and (3) the relationship between the relationship between visuospatial scores and procedure-aggregated intraoperative scores. Such an approach aims to determine whether residents with higher visuospatial scores have higher intraoperative scores and whether the relationships between the two variables change over time and across different types of laparoscopic procedures.

2.2.1 Correlation between subjects' visuospatial abilities and intraoperative scores

Overall, spatial visualisation, mental rotation and perceptual-motor skills all showed a strong to moderate positive association with operative autonomy ($p < 0.01$). The PTSOT test showed no significant relationship with any of the intraoperative skills, whereas the GVVT was significantly and positively related with all items. The strongest relationships were found between GVVT and autonomy ($r = 0.53$), bimanual dexterity ($r = 0.46$) and depth perception ($r = 0.41$), all which were significant at alpha 0.01. The MRT-A was positively and moderately related with depth perception ($r = 0.38$, $p < 0.01$) and efficiency ($r = 0.34$, $p < 0.01$). PicSOr was positively and moderately correlated with depth perception ($r = 0.39$, $p < 0.01$) and weak associations with bimanual dexterity ($r = 0.25$, $p < 0.01$) and efficiency ($r = 0.28$, $p < 0.01$). The between-subjects correlation matrix is displayed in table 4.9.

Table 4.9. Spearman's between-subjects correlation for visuospatial abilities and intraoperative scores

N= 18	Depth perception	Bimanual dexterity	Efficiency	Tissue handling	Autonomy	Total score
PTSOT	0.15	0.09	0.16	-0.01	0.16	-0.12
GVVT	**0.41***	**0.46***	**0.39***	**0.31***	**0.53***	**0.26***
MRT-A	**0.38***	0.23	**0.34***	0.12	**0.44***	0.12
PicSOr	**0.39***	**0.25***	**0.28***	0.11	**0.44***	0.11

Note: * **Bold** values are significant at p < 0.01

2.2.2. Time-series correlations

This analysis aims to determine whether the relationships between visuospatial abilities and intraoperative performance changes over time. The results of study three have already suggested that the strength of the associations change when considering the average operative experience of the residency surgeon. A weighted Spearman correlation coefficient was computed to explore the between-subjects relationship between visuospatial abilities and intraoperative scores across each time condition. The intraoperative scores were aggregated around the subjects mean on four time-based categories: 6th month, 12th month, 18th month and the 24th month. This aggregation timeframe was chosen to match the timeline and data points of the aptitude measures. All intraoperative assessments collected between the baseline and 6th month were grouped into month 6, assessments collected between 6th and 12th months were grouped into the month 12 etc. No correlation coefficient was computed for the 27th month due to the small sample of collected measures (n= 4).

At the 6th month mark, an increase in the GVVT score led to a positive and statistically significant increase in the intraoperative scores of depth perception ($r = 0.61$, $p < 0.01$), bimanual dexterity ($r = 0.59$, $p < 0.01$) and autonomy ($r = 0.65$, $p < 0.01$). A moderate positive association between MRT-A and autonomy ($r = 0.45$, $p < 0.01$) was also observed. See table 4.10 for the correlation matrix for month 6.

Table 4.10. Spearman's between-subjects correlation matrix for month 6

Month 6						
N= 14	Depth perception	Bimanual dexterity	Efficiency	Tissue handling	Autonomy	Total score
PTSOT	0.05	0.11	0.10	-0.01	0.22	-0.29
GVVT	**0.61***	**0.59***	0.02	0.48	**0.65***	0.26
MRT-A	0.25	0.04	0.14	0.11	**0.45***	0.12
PicSOr	0.42	0.24	0.30	0.23	0.45	0.11

Note: * **Bold** significant at p < 0.01

At the 12-month mark, an increase in the GVVT score was strongly and positively correlated with an increase in depth perception ($r = 0.67$, $p < 0.01$), bimanual dexterity ($r = 0.60$, $p < 0.01$), autonomy ($r = 0.78$, $p < 0.01$) and the total score ($r =$

0.70, $p < 0.01$). The MRT-A was strongly and positively associated with autonomy ($r = 0.70$, $p < 0.01$) only. Correlation matrix for month 12 is displayed in table 4.11.

Table 4.11. Spearman's between-subjects correlation matrix for month 12

Month 12						
N= 10	Depth perception	Bimanual dexterity	Efficiency	Tissue handling	Autonomy	Total score
PTSOT	0.19	0.17	0.06	0.11	0.13	-0.30
GVVT	**0.67***	**0.60***	0.58	0.56	**0.78***	**0.70***
MRT-A	0.41	0.33	0.39	0.41	**0.70***	0.48
PicSOr	0.26	0.18	0.17	0.09	0.24	0.22

Note: * **Bold** significant at p < 0.01

At the 18-month mark, only a positive and strong associations between GVVT and depth perception ($r = 0.74$, $p < 0.01$), dexterity ($r = 0.72$, $p < 0.01$), autonomy ($r = 0.86$, $p < 0.01$) and total score ($r = 0.74$, $p < 0.01$) remained. See table 4.12 for the correlation matrix for month 18.

Table 4.12. Spearman's between-subjects correlation matrix for month 18

Month 18						
N= 8	Depth perception	Bimanual dexterity	Efficiency	Tissue handling	Autonomy	Total score
PTSOT	-0.10	-0.20	-0.07	0.03	0.04	-0.37
GVVT	**0.74***	**0.72***	0.68	0.61	**0.86***	**0.74***
MRT-A	0.58	0.52	0.51	0.57	0.55	0.55
PicSOr	0.54	0.48	0.08	0.02	0.49	0.25

Note: * **Bold** significant at p < 0.01

At the 24-month mark, only a strong association between GVVT and autonomy ($r = 0.89$, $p < 0.01$) and the total score was observed ($r = 0.80$, $p < 0.01$). See table 4.13 for the correlation matrix for month 24.

Table 4.13. Spearman's between-subjects correlation matrix for month 24

Month 24

N= 8	Depth perception	Bimanual dexterity	Efficiency	Tissue handling	Autonomy	Total score
PTSOT	0.34	-0.27	-0.24	0.12	-0.30	-0.37
GVVT	0.69	0.69	0.69	0.61	**0.89***	**0.80***
MRT-A	0.41	0.58	0.47	0.41	0.58	0.18
PicSOr	0.26	0.22	0.52	0.59	0.59	0.11

Note: * **Bold** significant at p < 0.01

2.2.3. Procedure-aggregated between-subjects correlation

In this analysis, the correlation between residents visuospatial scores and procedure-specific intraoperative scores was explored. The aim was to determine whether the relationship between visuospatial abilities and intraoperative scores changes depending on the type of laparoscopic intervention performed. Intraoperative scores were aggregated around the subjects mean for each laparoscopic technique under which the performance was assessed on: laparoscopic cholecystectomy (CHE), appendectomy (APP) and total extra-peritoneal hernia repair (TEP). Other laparoscopic procedures, such as hernia repair IPOM and diagnostic and exploratory laparoscopy, were not included in this analysis due to the small sample size of the data available for that procedure.

On the CHE intervention, numerous strong positive relationships between the resident's increase in GVVT score and an increase in intraoperative scores across subjects were observed. The GVVT showed a positive and moderate relationship with intraoperative matrices of depth perception (r = 0.53, p < 0.01), bimanual dexterity (r = 0.52, p < 0.01), tissue handling (r = 0.43, p < 0.01) and GOALS total score (r = 0.58, p < 0.01). A particularly strong statistical relationship was observed between the GVVT and efficiency (r = 0.63, p < 0.01) and autonomy (r = 0.65, p < 0.01). The MRT-A showed a positive and moderate relationship with depth perception (r = 0.43, p < 0.01), efficiency (r = 0.41, p < 0.01) and autonomy (r = 0.48, p < 0.01). Similarly, PicSOr also showed a positive and moderate relationship between depth perception (r = 0.59, p < 0.01), bimanual dexterity (r = 0.44, p < 0.01), efficiency (r = 0.45, p < 0.01) and autonomy (r = 0.58, p < 0.01). On the APP intervention, a strong positive relationship was found between the GVVT and depth perception ($r = 0.74$, $p < 0.01$) and bimanual dexterity ($r = 0.67$, $p < 0.01$). On the TEP intervention, the GVVT was strongly and positively related to all intraoperative scores: depth perception ($r = 0.80$, $p < 0.01$), bimanual dexterity ($r = 0.77$, $p < 0.01$), efficiency ($r = 0.80$, $p < 0.01$), tissue handling ($r = 0.80$, $p < 0.01$) and autonomy ($r = 0.82$, $p < 0.01$). The MRT-A showed a positive moderate relationship between depth perception ($r = 0.69$, $p < 0.01$) and bimanual dexterity ($r = 0.77$, $p < 0.01$).

4 DISCUSSION

This longitudinal study sought to break new ground by providing the first ever insight into how visuospatial abilities develop and influence intraoperative laparoscopic skill learning in the scope of actual surgical residency training over a 27-month period. The results contribute two new key findings to the existing literature. First, the relationship between visuospatial abilities and intraoperative performance was found to change over time. These findings highlight the notion that different visuospatial abilities are called upon at different stages of laparoscopic skill learning, or arguably, at different stages of experience. Second, the results of this study add yet another piece of empirical support to the systematic trend observed in the scope of this doctoral thesis implicating spatial visualisation ability as an important attribute underlying laparoscopic experience. The results reveal that resident surgeons' spatial visualisation did improve in the context of laparoscopic training and did show an enduring influence over promoting laparoscopic skill learning over time. These findings corroborate many of the proposed hypotheses in the scope of this doctoral thesis and contribute new understanding into the possible underlying mechanism driving the divergent findings in the existing literature. In an attempt to provide a more cohesive and comprehensive overview of this study's findings, the discussion section is divided into three sections. Section 1 addresses the first research question of how visuospatial abilities develop over time. Section 2 addresses the second research questions on how visuospatial abilities influence laparoscopic skill learning over time. And section 3 discusses the implication of the research findings.

1. How do visuospatial abilities develop over time?

The first research question addressed how visuospatial abilities develop over time. The results revealed that all subjects improved their aptitude performance over the 27-month period. Yet, only spatial visualisation (i.e. GVVT) showed a significant difference in growth trajectory between residency surgeons and control subjects. In other words, resident surgeons showed a faster rate of linear change in spatial visualisation score over time as did control subjects. It was observed that at the 18-month mark, residency surgeons attained maximum performance on spatial visualisation measure, a trend they maintained until the end of the study when the ceiling (i.e. maximum total score) in performance was achieved. These findings corroborate the hypothesis that spatial visualisation is closely associated with laparoscopic experience and does appear to improve in the context of surgical training beyond the re-testing effect (e.g. natural improvement in score due to repeated testing) or any other confounding factors such as gender, as was the case for other aptitudes. In other words, these findings solidify the emerged trend implicating spatial visualisation as a notable attribute underlying laparoscopic competence and expertise. The results from study three have shown that laparoscopic surgeons possess better spatial visualisation skills as compared to medical laypeople. Expert surgeons were found to possess superior spatial visualisation skills performing around the maximum level of performance on the measure. Furthermore, years of laparoscopic experience was found to predict performance on spatial visualisation test. Thus, although the possibility that spatial visualisation improved due to some other aspects of surgical training cannot be ruled out, the clear and systematic trend observed throughout this doctoral thesis does hold the hypothesis that this trend is laparoscopy-specific as plausible.

These results highlight an additional new insight concerning spatial ability in the context of laparoscopic competence development. The results have shown that spatial abilities (i.e. spatial orientation and mental rotation) are positively correlated with laparoscopic performance, yet, diminish in importance over time. Only the predictive nature of spatial visualisation remained throughout training, even when competence in the technique was attained. Spatial visualisation is defined by complex spatial tasks where sequence of transformations are required (Lohman, 1979). These changing correlations and the captured enduring importance of spatial visualisation can be interpreted in the context of skill acquisition. The results suggest that with experience and skill acquisition, a shift from strategic visuospatial processing to spatial transformation processing may occurs. That is, whereas mental rotation and perceptual-motor skills may strategically facilitate surgeon's laparoscopic skill learning and information processing at initial stages of skill acquisition, as experience is attained, only complex spatial transformation processing remains. Utilisation of numerous spatial processes in one task is cognitively demanding. This could explain why the influence of mental rotation and perceptual-motor skills diminish as spatial visualisation abilities are improved and competence in the technique is acquired. I speculate that when surgeons acquire experiences and knowledge of what they are doing and what they are looking it, it is more than conceivable to assume that only reliance on spatial visualisation representation system remains (Lohman, 1979.

This hypothesis can be further supported by findings that residency surgeons and control subjects showed no group differences in trajectories on spatial orientation (i.e. PTSOT), mental rotation (MRT-A) and perceptual-motor skills (i.e. PicSOr). In other words, beyond the mere re-testing effect, residency surgeons did not show any performance advantage on these tests as compared to control subjects over time. However, gender was found to carry a significant confounding effect over the growth trajectories on the PTSOT and the MRT-A measure. In the residency group, male surgeons showed a significantly better performance on both measures, whereas in the control group, females outperformed male subjects. Although no definitive answer can be provided to explain these gender differences, some possible factors can be ruled out. First, all subjects in this study were tested under identical conditions. The possibility that these gender divergences derived from varying testing conditions can be ruled out. Second, the results from study three have shown that experience with musical instruments and video games did not predict aptitude performance. The postulation that these factors could explain the observed gender differences can also be ruled out. The true underlying reasons as to why male surgeons outperformed female surgeons, yet female control subjects outperformed male control subjects, therefore remains largely unclear. In the control group, one possible explanation could lie in the educational characteristics of the female participants. As was previously argued, a larger number of female participants were psychology students. Thus, perhaps their general knowledge of psychological testing and their principles could have carried some influence over their performance. In respect to the residency group, the finding that male surgeons outperformed and maintained better performance on the PTSOT and MRT-A measure were interesting, considering no gender differences were found at the baseline. Gender differences in cognitive performance have long been acknowledged in the literature, especially in the context of spatial cognition (Reilly, Neumann, & Andrews, 2017). Mental rotation in particular shows one of the most consistent gender gaps in favour of males (Voyer, Voyer & Bryden, 1995; Yang & Chen, 2010). However, the findings of this study challenge such a notion, as in the control group, females were the higher performers. In light of these findings, there is a high possibility that these captured gender differences could lie in other underlying psychobiosocial factors that were not considered in the scope of this study.

4.2. How do visuospatial abilities influence the acquisition of laparoscopic skills over time?

The second research questions addressed how visuospatial abilities influence the acquisition of laparoscopic skills over time. Three key findings emerged from the conducted analyses. First, the results revealed that all resident surgeons improved their laparoscopic performance and attained competence in the technique at the end of the study. Second, the results revealed that only spatial visualisation showed an enduring influence over operative autonomy scores. In other words, an increase in spatial visualisation score in an individual was positively associated with an increase in the individual’s autonomy score. These results are in line with the findings from study three, indicating that spatial visualisation is closely associated with promoting residency surgeons safe and independent laparoscopic performance. Additionally, these findings lend additional support to the hypothesis put forward in study three, that the relationship between spatial visualisation and operative autonomy appears to be interdependent on the laparoscopic experience levels of the surgeon. Third, the results corroborated the hypothesis that different visuospatial abilities are seemingly called upon at different stages of laparoscopic skill learning and different laparoscopic interventions. Although spatial visualisation showed an enduring influence on laparoscopic performance over time, mental rotation skills and perceptual-motor skills also showed a positive correlation with various intraoperative skills. However, resident surgeons with higher mental rotation and perceptual-motor skills only showed initial performance advantages. After a year of laparoscopic training these advantages diminished and only a strong positive correlation between spatial visualisation and autonomy remained. These results coupled with the findings from the within-subjects correlation and growth curve modelling put forward a first convincing indication that spatial visualisation may be malleable in the context of laparoscopic training. The results of this study also offered additional insight into the changing relationship between visuospatial abilities and intraoperative performance on different types of laparoscopic interventions. The results revealed that visuospatial abilities were correlated only with the more technically demanding laparoscopic procedures such as cholecystectomy, appendectomy and TEP hernia repairs. These findings can be interpreted as resident surgeons with higher visuospatial abilities also having higher intraoperative scores on these specific laparoscopic interventions. These findings carry significant implication for future researchers and surgical education. Future empirical investigations on the topic are encouraged to categorise the relationships between visuospatial abilities and laparoscopic performance in respect to the specific laparoscopic interventions explored. Doing so with further enhance our overall understanding of the dynamic interplay between various visuospatial abilities and laparoscopic performance outcomes.

In the context of the existing literature, the findings of this longitudinal study provide additional support to the claim that visuospatial ability is positively associated with laparoscopic skill acquisition (Harrington et al., 2018; Keehner et al., 2006; Stefanidis et al., 2006). Yet, this study offers additional insight that it is spatial visualisation ability in particular that shows an enduring influence over laparoscopic skill learning. Yet, these findings could also offer an explanation as to the underlying mechanism driving the divergent findings in the literature. Studies by Groenier et al. (2013) and Keehner et al. (2004) both found the correlation between visuospatial ability and laparoscopic performance to diminish with experience. The authors concluded that the importance of visuospatial ability *should* diminish with practice (Keehner et al., 2004). Yet, these studies tested their subjects on spatial reasoning tests (e.g. paper folding) (Keehner et al., 2004) and several measures of mental rotation (e.g. MRT-A, rotating shape tests) (Gronier et al., 2013) before correlating these aptitude scores with the performance on the simulator. The results of this current longitudinal study provided clear indication that different visuospatial abilities are called upon at different phases of laparoscopic learning. With this in mind, their postulation that mental rotation abilities diminish in importance over time is confirmed by this study. Yet, their overall conclusions that the influence of visuospatial ability should diminish with training are refuted. Spatial visualisation showed a clear trend of endured influence over operative autonomy with the relationship strengthening with experience.

When interpreting the practical significance of the correlational findings in this study, some important considerations should be highlighted. First, this study is prone to type II error due to its small sample size and low statistical power. This resulted in some correlations showing no statistical significance yet a medium effect size indicating a possibility of practical significance. For example, the within-subjects correlation between perceptual-motor skills (i.e. PicSOr) and autonomy failed to reach statistical significance, yet, the confidence intervals indicated that the effect may be present. The practical significance of the PicSOr on operative autonomy can therefore not be confirmed nor denied. Second, both intraoperative measures of efficiency and tissue handling were found to be highly unreliable and subject to significant disagreement across senior surgeons. Any significant correlations between these two intraoperative skills should be interpreted with caution. The GOALS assessment tool is an internationally utilised tool for evaluating laparoscopic performance, found to be highly reliable with excellent construct validity (Hogle, Liu, Ogden & Fowler, 2014: Kurashima, Feldman, Al-Sabah, Kaneva, Fried & Vassiliou, 2011). However, the results of this study indicated that the tool may be prone to systematic bias when the data is collected from several different assessors. Future researchers wishing to use the GOALS assessment tools are advised to ensure that the same senior surgeons evaluate the intraoperative performance of the same resident surgeons. Researchers designing operative assessment tools are also encouraged to consider these findings when designing measures of judging efficiency and tissue handling skills.

3. Implications of the findings

The results of this longitudinal study carry important implications for surgical education. Different visuospatial abilities were found to influence performance outcomes at different stages of laparoscopic training. Yet, only spatial visualisation was found to bear a notable and enduring influence over laparoscopic performance outcomes. Not only do these results explain the divergent findings in the existing literature, they also serve to caution surgical educators who wish to utilise visuospatial testing for purposes of pre-selection to residency training. Considering different patterns of abilities influence performance outcomes at different stages of laparoscopic training, the assessment and training principles need to be structured for each experience level and laparoscopic intervention. This might prove to be a difficult task. Yet, spatial visualisation skills, as measured by the GVVT test, could serve as the starting point towards achieving such an objective. By determining the normative sample (i.e. population-based reference scores) of laparoscopic surgeons across all experience levels, the test could be used as a valuable point of reference for means of assessing individual scores and informing decision-making. However, such an approach would be contingent on an extensive data collection process and construct validation. Furthermore, prior to the measure being used for any decision-making purposes, the findings of this study ought to be replicated in laparoscopic surgeons of varying educational and practice background. This current study bases its findings on a cohort of residency surgeons training in the context of the German residency system. The question as to whether certain other aspects of the German training system – from the structure of the medical schools to residency systems-could have promoted spatial visualisation abilities of residency surgeons in this study remains open. Yet, considering the observed trend in the scope of this doctoral study, the proposition that the GVVT could prove to be a useful tool for the purposes of assessment of laparoscopy specific visuospatial abilities does seem viable.

As was observed in study one, residency surgeons reported insufficient experience with laparoscopic technique, and consequently inaptitude and low confidence. Yet, the results of this study clearly highlighted the notable and enduring role of spatial visualisation in laparoscopic performance outcomes. This raises an important question as to whether surgical cognitive training system could prove to be a useful tool in facilitating the acquisition of laparoscopic skills outside the operating rooms. Spatial visualisation can be enhanced through deliberate computer-based training (Sorby, 2009). Implementing the characteristics of the GVVT measure into a computerised training system could therefore prove to be a valuable addition to surgical training. We have already proposed such a concept of a multi-modal cognitive training approach of minimally invasive surgery (Vajsbaher, Ziemer & Schultheis, 2020), which combines principles of cognitive training and assistance to help the surgeons to acquire and overcome visuospatial complexities encountered during minimally invasive approaches such as laparoscopy. Such a multi-modal approach carries a promising potential to provide surgeons with a training curriculum tailored around their levels of visuospatial abilities. Whether such an approach can help to accelerate laparoscopic skill learning will be determined once the simulation tool is validated.

In respect to other minimally invasive approaches, our understanding that spatial visualisation plays an important role in technology (Lowrie, Logan & Hegarty, 2019) raises a probable hypothesis that the ability could also play an important role in other surgical applications such as robotic surgery. As technological advances continue to reshape the surgical practice we know today, spatial visualisation may prove to play a critical role in ensuring competence in these systems is acquired and safe patient care is maintained. This opens up a new interesting avenue for future empirical investigations.

Limitations

This longitudinal study is not without its limitations. As was argued in study three, the sample size in this study small and prone to type 2 error. Recruiting actual practising surgeons is always a challenging task, especially when a long-term commitment is required. This study utilised a convenience sampling technique, recruiting all surgical staff from two departments of general and visceral surgery of two hospitals. Recruiting more surgeons to the study was not possible. Yet, to compensate for the small sample and low statistical power, all analyses were accompanied by measures of uncertainties and both statistical significances and practical significances were discussed. Considering this was the first longitudinal attempt at exploring the topic in actual residency surgeons training laparoscopy in operating settings, the small sample size still offered valuable qualitative insight. The second limitation of this study is the unbalanced data set in the resident surgeon's sample. Unfortunately, the data from a number of resident surgeon subjects were lost during the course of the study, mainly due to unforeseen reasons such as maternity leaves or residents changing training houses. For these reasons, the mixed effect modelling was utilised as a primary statistical tool. Additionally, the complex data in this study hindered the types of statistical analyses that could have been performed. For these reasons, all statistical approaches in this study, in particular the correlational approaches, were purposively selected based on a very careful considerations of the complex data at hand. Finally, this study did not include resident surgeons with little to none laparoscopic experience. Therefore, it remains unclear as to how visuospatial abilities develop and influence intraoperative skill learning from the complete 'beginning' of training. Future researchers are encouraged to expand on this current study by testing complete novice residency surgeons at the start of their laparoscopic training. The results could serve to complete our understanding on the topic of visuospatial ability and laparoscopic competence.

Conclusion

This longitudinal study breaks new ground by contributing new insights into how visuospatial abilities develop and influence intraoperative laparoscopic skill learning of actual residency surgeons over a 27-month period. The results revealed that different abilities are called upon at different stages of laparoscopic skill learning and laparoscopic procedures. Yet, spatial visualisation showed a constant and enduring influence over laparoscopic performance outcomes over time. With its empirical effort, this study puts forwards a first indication that spatial visualisation may be malleable in the context of laparoscopic training and is notably associated with promoting laparoscopic skills learning. These findings carry important implications for surgical education and future researchers alike by demonstrating that the involvement of visuospatial ability in laparoscopic surgery is as complex as is the sole act of performing surgery itself.

3

FINAL DISCUSSION

This chapter brings together key findings and contributions of this thesis and places them into the broader context of surgical education.

Surgery is a field of medicine with little room for error. People in their most vulnerable time entrust their lives and well-being into the hands of strangers they hope are highly trained and competent to provide the care needed. However, with the advent of laparoscopic surgery, the quality and safety of patient care has been challenged by the observed difficulties associated with performance and mastering of the technique (Schijven & Bemelman, 2011; Vogel & Vogel, 2019). Considering that large aspects of laparoscopy relate to visual and spatial information processing, it seems natural to assume that visuospatial ability may play an important role in promoting laparoscopic performance. There have been several empirical attempts at exploring the influence of visuospatial ability on laparoscopic performance in lab-based settings (Ahlborg et al., 2011; Groenier et al., 2014; Harrington et al., 2018; Hegarty et al., 2007; Keehner et al., 2004; Louridas et al., 2017; Luursema et al., 2010; Risucci et al., 2001; Wanzel et al., 2002). Yet, these studies reported largely divergent findings, raising acute uncertainties as to the true involvement of visuospatial abilities in laparoscopic performance and skill learning of actual surgeons currently training in the operating theatre. This doctoral thesis sought to break new grounds by clarifying these empirical uncertainties and contribute comprehensive new insight into the role and influence of visuospatial ability in laparoscopic surgery. The results of this thesis revealed that visuospatial ability does appear to play a notable role in laparoscopy and is closely associated with laparoscopic expertise and competency development. This thesis has resulted in two significant contributions to the topic of spatial cognition in laparoscopic practice. It has been shown that different visuospatial abilities are called upon at different stages of laparoscopic training and in different types of laparoscopic interventions. Yet, spatial visualisation was found having an enduring influence over laparoscopic performance and was closely associated with laparoscopic competence and expertise.

Throughout the results of this doctoral thesis, a clear and systematic trend has emerged underlining spatial visualisation as an important attribute to laparoscopic competence, expertise and skill development. Study one highlights how inexperienced junior surgeons perceive visuospatial aspects of laparoscopy as particularly challenging. Study two, on the other hand, reveals that surgical educators attribute spatial visualisation as one of the core components of laparoscopic competence. Together, these findings provided the first indication that spatial visualisation may play a notable role in laparoscopic performance. This hypothesis was further supported by the results from study three, which has shown that laparoscopic surgeons possess superior spatial visualisation abilities compared to medical laypeople. Years of laparoscopic experience was found to predict performance on spatial visualisation and expert laparoscopic surgeons performed around the maximum level of performance on the spatial visualisation measure. These results put forward a second hypothesis that spatial visualisation is closely associated with laparoscopic experience. The correlational analysis conducted in study three adds additional support to the hypothesis. At baseline, spatial visualisation, mental rotation and perceptual-motor skills all showed a positive association with operative autonomy. Among the abilities, spatial visualisation showed the weakest association with operative autonomy. Yet, when associations were explored on the aggregated experience-level, spatial visualisation showed the strongest relationship with operative autonomy. These results were interpreted as the first indication that spatial visualisation may be interdependent on laparoscopic experience. The results of the longitudinal study shed further insight into these propositions. First, it was revealed that the influence of mental rotation and perceptual-motor skills between subjects diminished over time. In other words, residency surgeons with higher mental rotation and perceptual-motor skills showed advantages in laparoscopic performance only during the initial stages of learning. This could be interpreted as either 1) laparoscopic experience attenuating individual differences in visuospatial abilities or 2) changes in cognitive strategies as experience is attained. Second, the results revealed that spatial visualisation had an enduring influence over operative autonomy over time, with the strength of the association growing at each time condition. Residency surgeons were also found to significantly improve their spatial visualisation over time as compared to control subjects. Together, these findings provided additional support to the hypothesis that spatial visualisation is interdependent on laparoscopic experience. What is more, the observed trend captured in this thesis does point towards the probability that spatial visualisation did improve in the context of laparoscopic training. As previously argued, correlation does not imply causation. However, the results of this thesis do provide a convincing rationale for such assumptions.

To truly understand the broader implications of these findings, the entire context of surgical education should be considered more carefully. Skill acquisition is contextual, predicted not only by one's abilities, but by external factors such as institutional and educational principle (Uehera, Button, Falcous & Davids, 2016). However, no empirical evidence on the status quo of laparoscopic education in Germany in addition to the conceptualisation of laparoscopic competence was available. Such lack of data was the driving force behind conducting study one and study two. Study one examined institutional influences on laparoscopic skill acquisition and study two explored surgical educators' perceptions on what makes up a competent laparoscopic surgeon. The results of study one revealed that in Germany today, the current status quo of surgical education is being challenged by the demographic changes of the future generation. That is, the current male-dominated field of surgery will soon have to hinge on attracting females into the workforce. Literature exploring the acquisition of surgical skills have caused some concerns in the surgical community about the possible effect of gender on surgical skill learning. Whereas some studies have shown male surgeons as having better surgical performance and skill acquisition rate (Ali, Subhi, Ringsted & Konge, 2015), others found gender to bear no influence over the level of performance or rate of skill acquisition (Chiu, Kang, Wang, Huang, Wu & Hsu, 2020). An additional point for concern is that some studies have found females to possess lower visuospatial abilities and, consequently, lower performance scores (Ali et al., 2015).

In the context of this doctoral thesis, these findings raised an important question as to whether gender carries any effect in influencing the development of visuospatial skills in the context of laparoscopy. The results revealed no evidence to suggest that gender bears any influence over the rate, or the overall attainment, of laparoscopic competence over time. Additionally, females also showed no disadvantage on acquiring spatial visualisation skills (i.e. the only predicting ability), as both males and females showed the same growth rate over time. The only drawback females have is concerning their mental rotation performance. The ability was found to be positively associated at the initial stages of learning. However, these findings cannot be interpreted as evidence that female surgeons are at a disadvantage at the initial stages of learning, considering no gender differences in intraoperative trajectories were observed. Some have argued that female surgeons should receive additional training and one-to-one support during residency to ensure competence is attained (Ali et al., 2015). Such an argument in not supported by the findings of this doctoral thesis. By recognising that female surgeons are not at a disadvantage in acquiring laparoscopic skills, surgical educators ought to focus more on eliminating gender stereotyping in their surgical practices and less on designing gender-based training approaches, which may come across as discriminating.

The results from study two shed light onto the core competencies that surgical educators attribute to a competent laparoscopic surgeon. These were identified as consisting of metacognition, cognitive skills (i.e. visuospatial skills), technical skills, knowledge, professional skills and personal skills. Albeit indirectly, the results from the longitudinal study offered some support to hypothesised framework. First, senior surgeons endorsed cognition, specifically spatial visualisation, as an important attribute underlying laparoscopic competence. These accounts were confirmed by the findings that spatial visualisation does play an enduring role in laparoscopic skill learning. Second, the results from the longitudinal study have shown a positive association between spatial visualisation and operative autonomy over time. This raises a point for speculation as to whether metacognition was also captured in the assessments of autonomy. Metacognitive processes are well-known to foster autonomous performance and learning (Haque, 2019). Yet, the mechanism through which autonomy improves performance is thought to be contingent on two distinct processes (Ismael, 2016). First, cognitive skills are employed to analyse, synthesise and process the incoming information. Second, metacognitive processes are used to plan, monitor, and evaluate these cognitive processes through reflection in action (Pintrich, 2002; Ismael, 2016). Only once both processes are integrated can the autonomous performance be observed. Against this theoretical background, there could be some merit behind the speculations that by assessing operative autonomy, metacognitive abilities were also captured. These speculations provide a convincing rationale that metacognition should be considered by future studies exploring how laparoscopic competence is shaped.

This new gained insight of this doctoral thesis informs surgical education and serves as a solid foundation for future empirical investigations on the topic of spatial cognition in laparoscopy. Spatial visualisation was found to have an enduring influence over laparoscopic performance of residency surgeons over a 27-month period. In addition, it was also found to be closely related to laparoscopic expertise. These findings raised a probable hypothesis that spatial visualisation in the context of laparoscopic training may be malleable. More empirical effort is now needed to confirm these findings in a larger sample and determine the exact clinical significance of its effect. That is, how does spatial visualisation influence performance outcomes and to what extent. Such knowledge carries significant potential for reshaping laparoscopic education and improving operative performance of surgeons. For example, spatial visualisation test (i.e. GVVT) could be used for career counselling, monitoring competency levels, residency training selection and training. The latter is of particular importance, and principles of spatial visualisation could be used to devise training programs that could facilitate the acquisition of both cognitive and dexterous skills both inside and outside the operating theatre. In respect to the observed correlation changes between visuospatial abilities and intraoperative performance, a new insight is contributed suggesting that different abilities are called upon at different stages of learning. These findings carry important implications for surgical educations and researchers on the topic. Surgical educators wishing to account for visuospatial abilities in the context of competence attainment must be aware that as laparoscopic experience is gained, the reliance on different abilities also change.

As was speculated in study four, these changes in correlations could reflect the shift from reliance on strategic visuospatial processes to reliance on the executive spatial transformation processes. This interpretation is also viable in the context of this doctoral thesis, as it could explain why the correlation with mental rotation and perceptual-motor skills diminishes, whereas the correlation with spatial visualisation remains. That is, mental rotation and perceptual-motor skills could reflect a certain strategic cognitive process facilitating laparoscopic performance whilst spatial visualisation skills are acquired. Yet, these findings also offer a possible explanation for the divergent findings reported in the existing literature. First, a large majority of studies administrated different aptitude tests, on a sample of subjects with varying levels of laparoscopic experience, at varying time conditions (e.g. one session vs a course of five weeks). Second, a large majority of studies did use the mental rotation test for the assessment of visuospatial ability. Consequently, these were also the studies which concluded that the influence of visuospatial ability on laparoscopic performance diminishes with time (Groenier et al. 2014; Luursema et al., 2012). With this new contributed insight, future researchers are encouraged to more carefully consider what types of aptitude tests are being used on which sample of participants when drawing any inferences about the role of visuospatial ability in laparoscopy.

Contribution and conclusion

This doctoral thesis provides the first insider's view into the complex role of visuospatial ability in actual intraoperative laparoscopic performance and skill learning. In the scope of this thesis, new insight contributes to pertaining laparoscopic education in Germany ranging from the categorization of laparoscopic competence, the visuospatial profiles of laparoscopic surgeons of all expertise levels to the longitudinal development and influence of visuospatial ability in laparoscopic skill learning. Combined, these results are able to clarify the divergent findings in the existing literature and contribute important new knowledge concerning the role of visuospatial ability in actual intraoperative skill learning.

I hope these findings inspire future researchers to continue empirical exploration on the topic not only in the context of laparoscopy but other minimally invasive procedures, such as robotic surgery. It would be interesting to objectively quantify the role of spatial visualisation in intraoperative performance as a next step of research. For example, do resident surgeons with higher spatial visualisation skills make fewer operative errors? Do resident surgeons with higher spatial visualisation skills complete laparoscopic procedures faster? Do surgeons with overall higher spatial visualisation have lower complication rates? Such understanding would enhance our knowledge of the clinical implications of spatial visualisation on intraoperative performance. Additionally, it could foster collaborative efforts between psychologists and surgical educators in the common aim to improve the certification and training of surgical skills. As technological advances continue to reshape the surgical practices we know today, such collaborative effort could prove especially critical in ensuring that effective, efficient and safe patient care is maintained.

REFERENCES

Agha, R., & Muir, G. (2003). Does laparoscopic surgery spell the end of the open surgeon?. *Journal of the Royal Society of Medicine, 96*(11), 544–546. https://doi.org/10.1258/jrsm.96.11.544

Agrusa, A., Romano, G., Navarra, G., Conzo, G., Pantuso, G., Buono, G. D., Citarrella, R., Galia, M., Monte, A. L., Cucinella, G., & Gulotta, G. (2017). Innovation in endocrine surgery: robotic versus laparoscopic adrenalectomy. Meta-analysis and systematic literature review. *Oncotarget*, *8*(60), 102392–102400. https://doi.org/10.18632/oncotarget.22059

Ahlborg, L., Hedman, L., Murkes, D., Westman, B., Kjellin, A., Felländer-Tsai, L., & Enochsson, L. (2011). Visuospatial ability correlates with performance in simulated gynecological laparoscopy. *European journal of obstetrics, gynecology, and reproductive biology*, *157*(1), 73–77.

Ahlborg, L., Hedman, L., Rasmussen, C., Felländer-Tsai, L. & Enochsson, L. (2012). Non-technical factors influence laparoscopic simulator performance among OBGYN residents. *Gynecolological Surgery, 9*, pp 415–420. https://doi.org/10.1007/s10397-012-0748-2

Ali, A., Subhi, Y., Ringsted, C., & Konge, L. (2015). Gender differences in the acquisition of surgical skills: a systematic review. *Surgical endoscopy*, *29*(11), 3065–3073. https://doi.org/10.1007/s00464-015-4092-2

Ansorg J, Krones CJ, Schröder W (2006): Logbuch und Leistungsdokumentation in der chirurgischen Weiterbildung. *Der Chirurg BDC* 10,, pp M314-315

Arora, S., Aggarwal, R., Sevdalis, N., Moran, A., Sirimanna, P., Kneebone, R., & Darzi, A. (2010). Development and validation of mental practice as a training strategy for laparoscopic surgery. *Surgical endoscopy*, *24*(1), 179–187. https://doi.org/10.1007/s00464-009-0624-y

Axt, S., Johannink, J., Storz, P., Mees, S., Röth, A., & Kirschniak, A. (2016). Chirurgische Weiterbildung an deutschen Kliniken – Wunsch und Realität. *Zentralblatt Für Chirurgie - Zeitschrift Für Allgemeine, Viszeral-, Thorax- Und Gefäßchirurgie*, *141*(03), 290-296. doi: 10.1055/s-0042-102966

Bakdash, J. Z., & Marusich, L. R. (2017). Repeated Measures Correlation. *Frontiers in psychology*, *8*, 456. https://doi.org/10.3389/fpsyg.2017.00456

Baker, J., Misra, S., Manimala, N. J., Kuy, S., & Gantt, G. (2013). The role of politics in shaping surgical training. *Bulletin of the American College of Surgeons*, *98*(8), 17–25.

Bansal, V. K., Krishna, A., Misra, M. C., & Kumar, S. (2016). Learning Curve in Laparoscopic Inguinal Hernia Repair: Experience at a Tertiary Care Centre. *The Indian journal of surgery, 78*(3), 197–202. https://doi.org/10.1007/s12262-015-1341-5

Bland, J. M., & Altman, D. G. (1995). Calculating correlation coefficients with repeated observations: Part 2--Correlation between subjects. *BMJ (Clinical research ed.)*, *310*(6977), 446. https://doi.org/10.1136/bmj.310.6977.446

Bunderärztekammer. (2018, May 04). Montgomery: Es ist höchste Zeit, den Ärztemangel ernsthaft zu bekämpfen. Retrieved January 11, 2021, from https://www.bundesaerztekammer.de/fileadmin/user_upload/downloads/pdf-Ordner/Statistik2018/Stat18AbbTab.pdf/

Bundesärztekammer. (2017, June 23). Ergebnisse der Ärztestatistik zum 31.12.2017. Retrieved January 11, 2021, from https://www.bundesaerztekammer.de/ueber-uns/aerztestatistik/aerztestatistik-der-vorjahre/aerztestatistik-2017/08/147363506X156580

Cagir, B., Rangraj, M., Maffuci, L., & Herz, B. L. (1994). The learning curve for laparoscopic cholecystectomy. *Journal of laparoendoscopic surgery*, *4*(6), 419–427. https://doi.org/10.1089/lps.1994.4.419

Caissie, A. F., Vigneau, F., Bors, D. A, (2009) – What does the Mental Rotation Test measure? An analysis of item difficulty and item characteristics. *The Open Psychology Journal*, *2*, 94-102.

Carroll, J. B. (1993). *Human cognitive abilities: A survey of factor-analytic studies.* Cambridge University Press. https://doi.org/10.1017/CBO9780511571312

Castro-Alonso J.C., Uttal D.H. (2019). *Science Education and Visuospatial Processing*. In: Castro-Alonso J. (eds) Visuospatial Processing for Education in Health and Natural Sciences. Springer, Cham. https://doi.org/10.1007/978-3-030-20969-8_3

Chiu, H., Kang, Y., Wang, W., Tong, Y., Chang, S., Fong, T., Wie, P. (2020). Gender differences in the acquisition of suturing skills with the da Vinci surgical system. *Journal of the Formosan Medical Association,119* (1), pp 462-470,

Cohen, J. (1988). Statistical Power Analysis for the Behavioral Sciences (2nd ed.). Hillsdale, NJ: Lawrence Erlbaum Associates, Publishers.

Conrad, J., Shah, A. H., Divino, C. M., Schluender, S., Gurland, B., Shlasko, E., & Szold, A. (2006). The role of mental rotation and memory scanning on the performance of laparoscopic skills: a study on the effect of camera rotational angle. *Surgical endoscopy*, *20*(3), pp 504–510. https://doi.org/10.1007/s00464-005-0363-7

Coomarasamy, A., Shafi, & Chan. (2016). *Gynecologic and obstetric surgery* (pp 113-118). Wiley-Blackwell (Verlag).

Cooper, S. R., Gonthier, C., Barch, D. M., & Braver, T. S. (2017). The Role of Psychometrics in Individual Differences Research in Cognition: A Case Study of the AX-CPT. *Frontiers in psychology*, *8* (1482). https://doi.org/10.3389/fpsyg.2017.01482

Murgueitio, N., Cuevas, L., Díaz - Castrillon, C., Pinzón, F., & Molina, G. (2019). Experience and Learning Curve of Laparoscopic Appendectomy and Cholecystectomy of General Surgery Residents in a Latin American Hospital. *Universitas Médica*, *60*(2), 1-10. doi: https://doi.org/10.11144/Javeriana.umed60-2.curv

Curtis, N. J., Thomas, C., Dennison, G., Ockrim, J. B., Conti, J. A., Dalton, R., Allison, A. S., & Francis, N. K. (2019). Factors Predicting Operative Difficulty of Laparoscopic Total Mesorectal Excision. Diseases of the colon and rectum, 62(12), 1467–1476. https://doi.org/10.1097/DCR.0000000000000149

Cuschieri A. (1995). Whither minimal access surgery: tribulations and expectations. *American journal of surgery, 169*(1), pp 9–19. https://doi.org/10.1016/s0002-9610(99)80104-4

Cuschieri, A., Francis, N., Crosby, J., & Hanna, G. (2001). What do master surgeons think of surgical competence and revalidation?11See Appendix for participating surgeons. *The American Journal Of Surgery*, *182*(2), pp 110-116. https://doi.org/10.1016/s0002-9610(01)00667-5

Datta, V., Mandalia, M., Mackay, S., Chang, A., Cheshire, N., & Darzi, A. (2002). Relationship between skill and outcome in the laboratory-based model. *Surgery*, *131*(3), pp 318-323. https://doi.org/10.1067/msy.2002.120235

Davis, E. C., Risucci, D. A., Blair, P. G., & Sachdeva, A. K. (2011). Women in surgery residency programs: evolving trends from a national perspective. Journal of the American College of Surgeons, 212(3), 320–326 https://doi.org/10.1016/j.jamcollsurg.2010.11.008

Deary, I. J., Graham, K. S., & Maran, A. G. (1992). Relationships between surgical ability ratings and spatial abilities and personality. *Journal of the Royal College of Surgeons of Edinburgh*, *37*(2), pp 74–79.

DeLucia, P. R., & Griswold, J. A. (2011). Effects of camera arrangement on perceptual-motor performance in minimally invasive surgery. *Journal of Experimental Psychology: Applied, 17*(3), pp 210–232. https://doi.org/10.1037/a0024041

DeLucia, P. R., Mather, R. D., Griswold, J. A., & Mitra, S. (2006). Toward the improvement of image-guided interventions for minimally invasive surgery: three factors that affect performance. *Human factors*, *48*(1), pp 23–38. https://doi.org/10.1518/001872006776412162

DePaola, D., & Slavkin, H. (2004). Reforming Dental Health Professions Education: A White Paper. *Journal Of Dental Education*, *68*(11), pp 1139-1150. https://doi.org/10.1002/j.0022-0337.2004.68.11.tb03859.x

Dominguez, C. (2001). Expertise and Metacognition in Laparoscopic Surgery: A Field Study. *Proceedings Of The Human Factors And Ergonomics Society Annual Meeting*, *45*(17), pp 1298-1302. https://doi.org/10.1177/154193120104501709

Dominguez, C. O., Flach, J. M., McDermott, P. L., McKellar, D. P., & Dunn, M. M. (2003). The Conversion Decision in Laparoscopic Surgery: Knowing Your Limits and Limiting Your Risks. *Psychological Investigations of Competence in Decision Making*, *7*(39).

Drisko, J. (2015). Holistic Competence and Its Assessment. *Smith College Studies In Social Work*, *85*(2), pp 110-127. https://doi.org/10.1080/00377317.2015.1017396

Drossard, S. (2019). Structured surgical residency training in Germany: an overview of existing training programs in 10 surgical subspecialties. *Innovative Surgical Sciences*, *4*(1), pp 15-24. https://doi.org/10.1515/iss-2018-0033

Earnshaw, J.J & Alderson D. (2014). Sustainable global surgery. *British Journal of Surgery. 101*. pp 1-2

Ellaway, R. (2016). CanMEDS is a theory. *Advances In Health Sciences Education*, *21*(5), pp 915-917. https://doi.org/10.1007/s10459-016-9724-3

Fan, C., Dodou, D., Breedveld, P., & Dankelman, J. (2014). Spatial orientation in pathway surgery. *Surgical endoscopy, 29*(9), pp 2705–2719. https://doi.org/10.1007/s00464-014-3993-9

Field, A. P. (2008). *Discovering statistics using SPSS*: (and sex and drugs and rock 'n' roll). Los Angeles [i.e. Thousand Oaks, Calif.: SAGE Publications.

Francis, N. K., Hanna, G. B., Cresswell, A. B., Carter, F. J., & Cuschieri, A. (2001). The performance of master surgeons on standard aptitude testing. *American journal of surgery, 182*(1), pp 30–33. https://doi.org/10.1016/s0002-9610(01)00652-3

Fritz, T., Stachel, N., & Braun, B. (2019). Evidence in surgical training – a review. *Innovative Surgical Sciences*, *4*(1), pp 7-13. https://doi.org/10.1515/iss-2018-0026

Furriel, F. T., Laguna, M. P., Figueiredo, A. J., Nunes, P. T., & Rassweiler, J. J. (2013). Training of European urology residents in laparoscopy: results of a pan-European survey. *BJU international*, *112*(8), 1223–1228. https://doi.org/10.1111/bju.12410

Gallagher, A. G., & Smith, C. D. (2003). From the operating room of the present to the operating room of the future. Human-factors lessons learned from the minimally invasive surgery revolution. *Seminars in laparoscopic surgery, 10*(3), pp 127–139. https://doi.org/10.1177/107155170301000306

Gallagher, A. G., Cowie, R., Crothers, I., Jordan-Black, J. A., & Satava, R. M. (2003). PicSOr: an objective test of perceptual skill that predicts laparoscopic technical skill in three initial studies of laparoscopic performance. *Surgical endoscopy*, *17*(9), pp 1468–1471. https://doi.org/10.1007/s00464-002-8569-4

Gallagher, R., Smith, C.D., Bowers, S.P, Seymour, N.E, Pearson, A., McNatt, S., Hananel, D and Satava, R.M. (2003). Psychomotor skills assessment in practicing surgeons experienced in performing advanced laparoscopic procedures. *Journal of the American College of Surgeons, 197*(3), pp 479-488.

Geiser, C., Lehmann, W., & Eid, M. (2008). A note on sex differences in mental rotation in different age groups. *Intelligence, 36*(6), pp 556–563. doi:10.1016/j.intell.2007.12.003

Gerges, F., Kanazi, G., & Jabbour-Khoury, S. (2006). Anesthesia for laparoscopy: a review. *Journal of clinical anesthesia, 18* (1), pp 67-78 .

Gibbons, R. D., Baker, R. J., & Skinner, D. B. (1986). Field articulation testing: a predictor of technical skills in surgical residents. *The Journal of surgical research*, *41*(1), pp 53–57. https://doi.org/10.1016/0022-4804(86)90008-9

Global Industry Analysts (2018). *Laparoscopic devices: A global strategic business report*. URL: https://www.researchandmarkets.com/research/ qsfkhr/laparoscopic?w=4.

Goldstein, H. (2010). *Multilevel statistical models. (*4th ed.) Hoboken: NJ: Wiley

Grantcharov, T. P., & Funch-Jensen, P. (2009). Can everyone achieve proficiency with the laparoscopic technique? Learning curve patterns in technical skills acquisition. *American journal of surgery*, *197*(4), pp 447–449. https://doi.org/10.1016/j.amjsurg.2008.01.024

Grimm, K. J., Ram, N., & Hamagami, F. (2011). Nonlinear growth curves in developmental research. *Child Development, 82*(5), pp 1357–1371. https://doi.org/10.1111/j.1467-8624.2011.01630.x

Groenier, M., Groenier, K. H., Miedema, H. A., & Broeders, I. A. (2015). Perceptual Speed and Psychomotor Ability Predict Laparoscopic Skill Acquisition on a Simulator. *Journal of surgical education, 72*(6), pp 1224–1232. https://doi.org/10.1016/j.jsurg.2015.07.006

Groenier, M., Schraagen, J. M., Miedema, H. A., & Broeders, I. A. (2014). The role of cognitive abilities in laparoscopic simulator training. *Advances in health sciences education : theory and practice*, *19*(2), pp 203–217. https://doi.org/10.1007/s10459-013-9455-7

Groenier, M., Schraagen, J., Miedema, H., & Broeders, I. (2013). The role of cognitive abilities in laparoscopic simulator training. *Advances In Health Sciences Education*, *19*(2), pp 203-217. https://doi.org/10.1007/s10459-013-9455-7

Hackett, N. J., De Oliveira, G. S., Jain, U. K., & Kim, J. Y. (2015). ASA class is a reliable independent predictor of medical complications and mortality following surgery. *International journal of surgery (London, England)*, *18*, 184–190. https://doi.org/10.1016/j.ijsu.2015.04.079

Hager, P. (1994) Is there a cogent philosophical argument against competency standards?, *Australian Journal of Education, 38*(1), pp. 3-18

Hair, J., Joseph, F., & Fávero, L. (2019). Multilevel modeling for longitudinal data: concepts and applications. *RAUSP Management Journal, 54*(4), pp 459-489.https://doi.org/10.1108/rausp-04-2019-0059

Hall, J. C., Ellis, C., & Hamdorf, J. (2003). Surgeons and cognitive processes. *The British journal of surgery, 90*(1), pp 10–16. https://doi.org/10.1002/bjs.4020

Halverson, A. L., Walsh, D. S., & Rikkers, L. (2012). Leadership skills in the OR. Part 1. Communication helps surgeons avoid pitfalls. *Bulletin of the American College of Surgeons*, *97*(5), pp 8-14.

Haque, M. M. (2019). From Cognition, Metacognition to Autonomy: A Framework for Understanding Language Learning Dynamics. *Arab World English Journal,* pp 207-222. https://dx.doi.org/10.24093/awej/efl1.15

Harrington, C. M., Dicker, P., Traynor, O., & Kavanagh, D. O. (2018). Visuospatial abilities and fine motor experiences influence acquisition and maintenance of fundamentals of laparoscopic surgery (FLS) task performance. *Surgical endoscopy*, *32*(11), pp 4639–4648. https://doi.org/10.1007/s00464-018-6220-2

Hartman, H. (2013). *Metacognition in learning and instruction: theory, research and practice*. Kluwer Academic Publishers. 10.1002/9781118133880.hop207004

Hassan, I., Gerdes, B., Koller, M., Dick, B., Hellwig, D., Rothmund, M., & Zielke, A. (2007). Spatial perception predicts laparoscopic skills on virtual reality laparoscopy simulator. *Child's nervous system : ChNS : official journal of the International Society for Pediatric Neurosurgery*, *23*(6), pp 685–689. https://doi.org/10.1007/s00381-007-0330-9

Haveran, L. A., Novitsky, Y. W., Czerniach, D. R., Kaban, G. K., Taylor, M., Gallagher-Dorval, K., Schmidt, R., Kelly, J. J., & Litwin, D. E. (2007). Optimizing laparoscopic task efficiency: the role of camera and monitor positions. *Surgical endoscopy, 21*(6), pp 980–984. https://doi.org/10.1007/s00464-007-9360-3

Hedman, L., Klingberg, T., Enochsson, L., Kjellin, A., & Felländer-Tsai, L. (2007). Visual working memory influences the performance in virtual image-guided surgical intervention. *Surgical endoscopy*, *21*(11), pp 2044–2050. https://doi.org/10.1007/s00464-007-9287-8

Hedman, L., Ström, P., Andersson, P., Kjellin, A., Wredmark, T., & Felländer-Tsai, L. (2006). High-level visual-spatial ability for novices correlates with performance in a visual-spatial complex surgical simulator task. *Surgical endoscopy, 20*(8), pp 1275–1280. https://doi.org/10.1007/s00464-005-0036-6

Hegarty, M., & Waller, D. (2004). A dissociation between mental rotation and perspective-taking spatial abilities. *Intelligence*, *32*(2), pp 175-191. https://doi.org/10.1016/j.intell.2003.12.001

Hegarty, M., & Waller, D. A. (2005). *Individual Differences in Spatial Abilities.* In P. Shah (Ed.) & A. Miyake, *The Cambridge Handbook of Visuospatial Thinking* (pp 121–169). Cambridge University Press. https://doi.org/10.1017/CBO9780511610448.005

Hegarty, M., Keehner, M., Cohen, C., Montello, D. R., & Lippa, Y. (2007). *The Role of Spatial Cognition in Medicine: Applications for Selecting and Training Professionals.* In G. L. Allen (Ed.), *Applied spatial cognition: From research to cognitive technology* (p. 285–315). Lawrence Erlbaum Associates Publishers.

Hegarty, M., Keehner, M., Khooshabeh, P., & Montello, D. R. (2009). How spatial abilities enhance, and are enhanced by, dental education. Learning and Individual Differences, 19(1), 61-70.

Henn, P., Gallagher, A. G., Nugent, E., Seymour, N. E., Haluck, R. S., Hseino, H., Traynor, O., & Neary, P. C. (2018). Visual spatial ability for surgical trainees: implications for learning endoscopic, laparoscopic surgery and other image-guided procedures. *Surgical endoscopy*, *32*(8), pp 3634–3639. https://doi.org/10.1007/s00464-018-6094-3

Heyes, C., Bang, D., Shea, N., Frith, C. D., & Fleming, S. M. (2020). Knowing ourselves together: The cultural origins of metacognition. *Trends in Cognitive Sciences, 25*(5), pp 349-362. doi:10.1016/j.tics.2020.02.007.

Höffler, T. (2010). Spatial Ability: Its Influence on Learning with Visualizations—a Meta-Analytic Review: Educational Psychology Review. *Educational Psychology Review , 22*(3), pp 245-269. https://doi.org/10.1007/s10648-010-9126-7

Hogle, N. J., Liu, Y., Ogden, R. T., & Fowler, D. L. (2014). Evaluation of surgical fellows' laparoscopic performance using Global Operative Assessment of Laparoscopic Skills (GOALS). *Surgical endoscopy*, *28*(4), pp 1284–1290. https://doi.org/10.1007/s00464-013-3324-6

Hsu, K. E., Man, F. Y., Gizicki, R. A., Feldman, L. S., & Fried, G. M. (2008). Experienced surgeons can do more than one thing at a time: effect of distraction on performance of a simple laparoscopic and cognitive task by experienced and novice surgeons. *Surgical endoscopy*, *22*(1), pp 196–201. https://doi.org/10.1007/s00464-007-9452-0

Huddle, T., & Heudebert, G. (2007). Viewpoint: Taking Apart the Art: The Risk of Anatomizing Clinical Competence. *Academic Medicine*, *82*(6), pp 536-541. https://doi.org/10.1097/acm.0b013e3180555935

Husserl, E. (1999). The Idea of Phenomenology translated by Edmund Hussler. *Journal of the British Society for Phenomenology.* *32*(3), pp 333-334. 10.1080/00071773.2001.11007353

Irish, B., Carr, A., Sowden, D., Douglas, N., & Patterson, F. (2011). Recruitment into specialty training in the UK. *BMJ*, c7473. https://doi.org/10.1136/bmj.c7473

Ismael, H. (2016). The Role of Metacognitive Knowledge in Enhancing Learners Autonomy. *International Journal of Language and Linguistics, 2*(4), pp 95- 102

Jackson, D. L., Gillaspy, J. A., & Purc-Stephenson, R. (2009). Reporting practices in confirmatory factor analysis: an overview and some recommendations. *Psychological methods*, *14*(1), 6–23. https://doi.org/10.1037/a0014694

Kassenärztliche Bundesvereinigung. (2020, Dezember 2020). Die Medizin wird weiblich. *Kassenärztliche Bundesvereinigung.* Avaiable under https://gesundheitsdaten.kbv.de/cms/html/16396.php

Keehner, M. M., Tendick, F., Meng, M. V., Anwar, H. P., Hegarty, M., Stoller, M. L., & Duh, Q. Y. (2004). Spatial ability, experience, and skill in laparoscopic surgery. *American journal of surgery*, *188*(1), pp 71–75. https://doi.org/10.1016/j.amjsurg.2003.12.059

Keehner, M., Hegarty, M., Cohen, C., Khooshabeh, P., & Montello, D. R. (2008). Spatial reasoning with external visualizations: what matters is what you see, not whether you interact. *Cognitive science*, *32*(7), 1099–1132. https://doi.org/10.1080/03640210801898177

Keehner, M., Lippa, Y., Montello, D., Tendick, F., & Hegarty, M. (2006). Learning a spatial skill for surgery: how the contributions of abilities change with practice. *Applied Cognitive Psychology*, *20*(4), pp 487-503. https://doi.org/10.1002/acp.1198

Khooshabeh, P., Hegarty, M., & Shipley, T. F. (2013). Individual differences in mental rotation: Piecemeal versus holistic processing. *Experimental Psychology, 60*(3), pp 164–171. https://doi.org/10.1027/1618-3169/a000184

Kim, F. J., da Silva, R. D., Gustafson, D., Nogueira, L., Harlin, T., & Paul, D. L. (2015). Current issues in patient safety in surgery: a review. *Patient safety in surgery, 9*, 26. https://doi.org/10.1186/s13037-015-0067-4

Klein, M. I., Warm, J. S., Riley, M. A., Matthews, G., Gaitonde, K., & Donovan, J. F. (2008). Perceptual distortions produce multidimensional stress profiles in novice users of an endoscopic surgery simulator. *Human factors*, *50*(2), pp 291–300. https://doi.org/10.1518/001872008X288312

Kolkman, W., Wolterbeek, R. & Jansen, F.W. (2005). Gynecological laparoscopy in residency training program: Dutch perspectives. *Surgical endoscopy, 19*, pp 1498–1502 https://doi.org/10.1007/s00464-005-0291-6

Kolozsvari, N. O., Andalib, A., Kaneva, P., Cao, J., Vassiliou, M. C., Fried, G. M., & Feldman, L. S. (2011). Sex is not everything: the role of gender in early performance of a fundamental laparoscopic skill. *Surgical endoscopy, 25*(4), pp 1037–1042. https://doi.org/10.1007/s00464-010-1311-8

Komesu, Y., Urwitz-Lane, R., Ozel, B., Lukban, J., Kahn, M., Muir, T., Fenner, D., & Rogers, R. (2009). Does mental imagery prior to cystoscopy make a difference? A randomized controlled trial. *American journal of obstetrics and gynecology, 201*(2), pp 218.e1–218.e2189. https://doi.org/10.1016/j.ajog.2009.04.008

Koo, T. K., & Li, M. Y. (2016). A Guideline of Selecting and Reporting Intraclass Correlation Coefficients for Reliability Research. *Journal of chiropractic medicine*, *15*(2), pp 155–163. https://doi.org/10.1016/j.jcm.2016.02.012

Kozhevnikov, M., Hegarty, M., & Mayer, R. E. (2002). Revising the visualizer-verbalizer dimension: Evidence for two types of visualizers. *Cognition and Instruction, 20*(1), pp 47–78. https://doi.org/10.1207/S1532690XCI2001_3

Kozhevnikov, M., Motes, M. A., Rasch, B., & Blajenkova, O. (2006). Perspective-Taking vs. Mental Rotation Transformations and How They Predict Spatial Navigation Performance. *Applied Cognitive Psychology, 20*(3), pp 397–417. https://doi.org/10.1002/acp.1192

Kramp, K. H., van Det, M. J., Veeger, N. J., & Pierie, J. P. (2016). Validity, reliability and support for implementation of independence-scaled procedural assessment in laparoscopic surgery. *Surgical endoscopy*, *30*(6), pp 2288–2300. https://doi.org/10.1007/s00464-015-4254-2

Krizek, T. (2000). Surgical Error. *Archives Of Surgery*, *135*(11), 1359. doi: 10.1001/archsurg.135.11.1359

Krüger, J. K., & Suchan, B. (2016). You Should Be the Specialist! Weak Mental Rotation Performance in Aviation Security Screeners - Reduced Performance Level in Aviation Security with No Gender Effect. *Frontiers in psychology*, *7*,333. https://doi.org/10.3389/fpsyg.2016.00333

Kumar, U., & Gill, I. S. (2006). Learning curve in human laparoscopic surgery. *Current urology reports*, *7*(2), pp 120–124. https://doi.org/10.1007/s11934-006-0070-5

Kurashima, Y., Feldman, L. S., Al-Sabah, S., Kaneva, P. A., Fried, G. M., & Vassiliou, M. C. (2011). A tool for training and evaluation of laparoscopic inguinal hernia repair: the Global Operative Assessment Of Laparoscopic Skills-Groin Hernia (GOALS-GH). *American journal of surgery*, *201*(1),pp 54–61. https://doi.org/10.1016/j.amjsurg.2010.09.006

Li, Y., Kong, F., Ji, M., Luo, Y., Lan, J., & You, X. (2019). Shared and Distinct Neural Bases of Large- and Small-Scale Spatial Ability: A Coordinate-Based Activation Likelihood Estimation Meta-Analysis. *Frontiers in neuroscience, 12*, 1021. https://doi.org/10.3389/fnins.2018.01021

Lin, C. J. & Chen, H. J. (2013). The Investigation of Laparoscopic Instrument Movement Control and Learning Effect. *BioMed Research International.2013,* 349825. https://doi.org/10.1155/2013/349825

Linn, M. C., & Petersen, A. C. (1985). Emergence and characterization of sex differences in spatial ability: A meta-analysis. *Child Development, 56*(6), pp 1479–1498. https://doi.org/10.2307/1130467

Lohman, D. F. (1979). *Spatial Ability: A Review and Reanalysis of the Correlational Literature.* Stanford University. Office of Naval Research. (pp 1870-1991). School of Education, Stanford University

Lohman, D. F. (1988). *Spatial abilities as traits, processes, and knowledge.* In R. J. Sternberg (Ed.), *Advances in the psychology of human intelligence, Vol. 4* (pp 181–248). Lawrence Erlbaum Associates, Inc.

Louridas, M., Bonrath, E. M., Sinclair, D. A., Dedy, N. J., & Grantcharov, T. P. (2015). Randomized clinical trial to evaluate mental practice in enhancing advanced laparoscopic surgical performance. *The British journal of surgery, 102*(1),pp 37–44. https://doi.org/10.1002/bjs.9657

Louridas, M., Quinn, L.E. & Grantcharov, T.P. (2016.) Predictive value of background experiences and visual spatial ability testing on laparoscopic baseline performance among residents entering postgraduate surgical training. *Surgical Endoscopy, 30,* pp 1126–1133 https://doi.org/10.1007/s00464-015-4313-8

Louridas, M., Szasz, P., Fecso, A. B., Zywiel, M. G., Lak, P., Bener, A. B., Harris, K. A., & Grantcharov, T. P. (2017). Practice does not always make perfect: need for selection curricula in modern surgical training. *Surgical endoscopy*, *31*(9), pp 3718–3727. https://doi.org/10.1007/s00464-017-5572-3

Luursema, J-M., Verwey, W.M., & Burie, R. (2012). Visuospatial ability factors and performance variables in laparoscopic simulator training. *Learning and Individual Differences. 22*(5),pp 632-638. https://doi.org/10.1016/j.lindif.2012.05.012

Mayring, P.(2001). Kombination und Integration qualitativer und quantitativer Analyse. *Forum Qualitative Sozialforschung, 2*(1). Available under https://www.ph-freiburg.de/fileadmin/dateien/fakultaet3/sozialwissenschaft/Quasus/Volltexte/1-01mayring-d_kombination_quali_quan.pdf

Mikhail, E., Scott, L., & Hart, S. (2014). Surgical Techniques of the Total Laparoscopic Hysterectomy (TLH) Procedure among AAGL Members. *Journal Of Minimally Invasive Gynecology*, *21*(6), S15. https://doi.org/10.1016/j.jmig.2014.08.064

Mistry, M., Roach, V. A., & Wilson, T. D. (2013). Application of stereoscopic visualization on surgical skill acquisition in novices. *Journal of surgical education*, *70*(5), pp 563–570. https://doi.org/10.1016/j.jsurg.2013.04.006

Mitchell, E., Arora, S., Moneta, G., Kret, M., Dargon, P., & Landry, G., Eidt, J., Sevdalis, N. (2014). A systematic review of assessment of skill acquisition and operative competency in vascular surgical training. *Journal Of Vascular Surgery*, *59*(5), pp 1440-1455. https://doi.org/10.1016/j.jvs.2014.02.018

Mohamadipanah, H., Perrone, K. H., Nathwani, J., Parthiban, C., Peterson, K., Wise, B., Garren, A., & Pugh, C. (2019). Screening surgical residents' laparoscopic skills using virtual reality tasks: Who needs more time in the sim lab?. *Surgery, 166*(2), pp 218–222. https://doi.org/10.1016/j.surg.2019.04.013

Morse, J., & Field, P. (1996). *Qualitative research methods for health professionals*. Sage Publications. ISBN 0803973276

Muavha, D. A., Ras, L., & Jeffery, S. (2019). Laparoscopic surgical anatomy for pelvic floor surgery. *Best practice & research. Clinical obstetrics & gynaecology*, *54*, 89–102. https://doi.org/10.1016/j.bpobgyn.2018.11.005

Newcombe, N. S., Mathason, L., & Terlecki, M. (2002). *Maximization of spatial competence: More important than finding the cause of sex differences.* In A. McGillicuddy-De Lisi & R. De Lisi (Eds.), *Advances in applied developmental psychology, Vol. 21. Biology, society, and behavior: The development of sex differences in cognition* (pp 183–206). Ablex Publishing.

Ostroff, C. (1993). Comparing correlations based on individual-level and aggregated data. *Journal of Applied Psychology, 78*(4), 569–582. https://doi.org/10.1037/0021-9010.78.4.569

Oussi, N., Renman, P., Georgiou, K., & Enochsson, L. (2020). Baseline characteristics in laparoscopic simulator performance: The impact of personal computer (PC)–gaming experience and visuospatial ability. *Surgery Open Science*. https://doi.org/10.1016/j.sopen.2020.06.002

Ovaere, S., & Jansen, Y. (2017). *Gender Diversity in Belgian Surgical Training*. Bast.be. Retrieved 11 January 2021, from https://bast.be/wp-content/uploads/2017/06/2Opinion-article-on-gender-diversity-SoMe.pdf.

Oviedo-Peñata, C. A., Tapia-Araya, A. E., Lemos, J. D., Riaño-Benavides, C., Case, J. B., & Maldonado-Estrada, J. G. (2020). Validation of Training and Acquisition of Surgical Skills in Veterinary Laparoscopic Surgery: A Review. *Frontiers in veterinary science*, *7*, 306. https://doi.org/10.3389/fvets.2020.00306

Park, A., Lee, G., Seagull, F. J., Meenaghan, N., & Dexter, D. (2010). Patients benefit while surgeons suffer: an impending epidemic. *Journal of the American College of Surgeons, 210*(3), pp 306–313. https://doi.org/10.1016/j.jamcollsurg.2009.10.017

Peters, M., Laeng, B., Latham, K., Jackson, M., Zaiyouna, R., & Richardson, C. (1995). A redrawn Vandenberg and Kuse Mental Rotations Test: Different versions and factors that affect performance. *Brain and Cognition, 28*(1),pp 39–58. https://doi.org/10.1006/brcg.1995.1032

Pintrich, P. (2002). The Role of Metacognitive Knowledge in Learning, Teaching, and Assessing. *Theory Into Practice, 41*(4), 219-225. Available under http://www.jstor.org/stable/1477406

Qin, S., Nelson, L., McLeod, L., Eremenco, S., & Coons, S. J. (2019). Assessing test-retest reliability of patient-reported outcome measures using intraclass correlation coefficients:

recommendations for selecting and documenting the analytical formula. *Quality of life research : an international journal of quality of life aspects of treatment, care and rehabilitation*, *28*(4), 1029–1033. https://doi.org/10.1007/s11136-018-2076-0

Reilly D., Neumann D.L., Andrews G. (2017). *Gender Differences in Spatial Ability: Implications for STEM Education and Approaches to Reducing the Gender Gap for Parents and Educators*. In: Khine M. (eds) *Visual-spatial Ability in STEM Education.* Springer, Cham. https://doi.org/10.1007/978-3-319-44385-0_10

Risucci D. A. (2002). Visual spatial perception and surgical competence. *American journal of surgery, 184*(3), pp 291–295. https://doi.org/10.1016/s0002-9610(02)00937-6

Risucci, D., Geiss, A., Gellman, L., Pinard, B., & Rosser, J. (2001). Surgeon-specific factors in the acquisition of laparoscopic surgical skills. *American journal of surgery*, *181*(4), pp 289–293. https://doi.org/10.1016/s0002-9610(01)00574-8

Roach, V. A., Mistry, M. R., & Wilson, T. D. (2014). Spatial visualization ability and laparoscopic skills in novice learners: evaluating stereoscopic versus monoscopic visualizations. *Anatomical sciences education*, *7*(4), pp 295–301. https://doi.org/10.1002/ase.1412

Robertson, L. C., & Palmer, S. E. (1983). Holistic processes in the perception and transformation of disoriented figures. *Journal of Experimental Psychology: Human Perception and Performance, 9*(2), pp 203–214. https://doi.org/10.1037/0096-1523.9.2.203

Rolstad, S., Adler, J., & Rydén, A. (2011). Response burden and questionnaire length: is shorter better? A review and meta-analysis. *Value in health : the journal of the International Society for Pharmacoeconomics and Outcomes Research*, *14*(8), 1101–1108. https://doi.org/10.1016/j.jval.2011.06.003

Schijven, M. P., & Jakimowicz, J. (2004). The learning curve on the Xitact LS 500 laparoscopy simulator: profiles of performance. *Surgical endoscopy, 18*(1), pp 121–127. https://doi.org/10.1007/s00464-003-9040-x

Schijven, M., & Bemelman, W. (2011). Problems and pitfalls in modern competency-based laparoscopic Training. *Surgical Endoscopy*, *25*(7), pp 2159-2163. https://doi.org/10.1007/s00464-010-1515-y

Schlickum, M., Hedman, L., & Felländer-Tsai, L. (2016). Visual-spatial ability is more important than motivation for novices in surgical simulator training: a preliminary study. *International journal of medical education*, *7*, pp 56–61. https://doi.org/10.5116/ijme.56b1.1691

Schostek, S., Schurr, M. O., & Buess, G. F. (2009). Review on aspects of artificial tactile feedback in laparoscopic surgery. *Medical engineering & physics, 31*(8), pp 887–898. https://doi.org/10.1016/j.medengphy.2009.06.003

Schraw, G. (2008). A conceptual analysis of five measures of metacognitive monitoring. *Metacognition And Learning*, *4*(1), pp 33-45. https://doi.org/10.1007/s11409-008-9031-3

Schröder, W. (2006). Is German surgical training attractive for residents?. Ann R Coll Surg Eng (Suppl); 88, 338-340, DOI:10.1308/147363506X156580

Schueneman, A. L., Pickleman, J., Hesslein, R., & Freeark, R. J. (1984). Neuropsychologic predictors of operative skill among general surgery residents. *Surgery, 96*(2), pp 288–295.

Shafqat A, Ferguson E, Thanawala V, Bedforth NM, Hardman JG, McCahon RA. (2015). Visuospatial ability as a predictor of novice performance in ultrasound-guided regional anesthesia. *Anesthesiology*; 123, pp 1188–97.

Sharpe, S. M., Talamonti, M. S., Wang, C. E., Prinz, R. A., Roggin, K. K., Bentrem, D. J., Winchester, D. J., Marsh, R. D., Stocker, S. J., & Baker, M. S. (2015). Early National

Experience with Laparoscopic Pancreaticoduodenectomy for Ductal Adenocarcinoma: A Comparison of Laparoscopic Pancreaticoduodenectomy and Open Pancreaticoduodenectomy from the National Cancer Data Base. *Journal of the American College of Surgeons*, *221*(1), pp 175–184. https://doi.org/10.1016/j.jamcollsurg.2015.04.021

Shea, N., Boldt, A., Bang, D., Yeung, N., Heyes, C., & Frith, C. D. (2014). Supra-personal cognitive control and metacognition. *Trends in cognitive sciences*, *18*(4), 186–193. https://doi.org/10.1016/j.tics.2014.01.006

Shek, D. T., & Ma, C. M. (2011). Longitudinal data analyses using linear mixed models in SPSS: concepts, procedures and illustrations. *The Scientific World Journal*, *11*, pp 42–76. https://doi.org/10.1100/tsw.2011.2

Smith, J. (2011). Evaluating the contribution of interpretative phenomenological analysis. *Health Psychology Review*, *5*(1), pp 9-27. https://doi.org/10.1080/17437199.2010.510659

Smith, J.A. & Osborn, M. (2008) Interpretative phenomenological analysis. In J.A. Smith (Ed.) Qualitative Psychology: A practical guide to research methods. ISBN: 9781412930840

Sodergren, M. H., Orihuela-Espina, F., Clark, J., Teare, J., Yang, G. Z., & Darzi, A. (2010). Evaluation of orientation strategies in laparoscopic cholecystectomy. *Annals of surgery, 252(*6), pp 1027–1036. https://doi.org/10.1097/SLA.0b013e3181e49683

Sodergren, M. H., Orihuela-Espina, F., Froghi, F., Clark, J., Teare, J., Yang, G. Z., & Darzi, A. (2011). Value of orientation training in laparoscopic cholecystectomy. *The British journal of surgery, 98*(10), pp 1437–1445. https://doi.org/10.1002/bjs.7546

Sorby, S. (2009) Developing spatial cognitive skills among middle school students. *Cognitive Process 10,* **pp** 312–315. https://doi.org/10.1007/s10339-009-0310-y

Spence, I., & Feng, J. (2010). Video games and spatial cognition. *Review of General Psychology, 14*(2),pp 92–104. https://doi.org/10.1037/a0019491

Srnka, K.J. & Koeszegi, S.T. (2007). From Words to Numbers: How to Transform Qualitative Data into Meaningful Quantitative Results. *Schmalenbach Bus Rev 59,* pp 29–57. https://doi.org/10.1007/BF03396741

Steinhaeuser, J., Chenot, J., Roos, M., Ledig, T., & Joos, S. (2013). Competence-based curriculum development for general practice in Germany: a stepwise peer-based approach instead of reinventing the wheel. *BMC Research Notes*, *6*(1). https://doi.org/10.1186/1756-0500-6-314

Stiller J, Kulka K. (2007). Ärztlicher Nachwuchs: Ernüchternder Berufseinstieg. *Dtsch Ärztebl,* 104, pp 530-532.

Subramonian, K., DeSylva, S., Bishai, P., Thompson, P., & Muir, G. (2004). Acquiring surgical skills: a comparative study of open versus laparoscopic surgery. *Journal of European Urology, 45*, pp 346–351. doi:10.1016/j.eururo. 2003.09.021.

Sudman, S. (1985). *Applied sampling*. New York: Academic Press.

Tan, H. J., Wolf, J. S., Jr, Ye, Z., Hafez, K. S., & Miller, D. C. (2014). Population level assessment of hospital based outcomes following laparoscopic versus open partial nephrectomy during the adoption of minimally invasive surgery. *The Journal of urology, 191*(5), pp 1231–1237. 10.1016/j.juro.2013.11.002.

Techentin, C., Voyer, D., & Voyer, S. D. (2014). Spatial abilities and aging: A meta-analysis. *Experimental Aging Research, 40*(4), 395–425. https://doi.org/10.1080/0361073X.2014.926773

Tekkis, P. P., Senagore, A. J., Delaney, C. P., & Fazio, V. W. (2005). Evaluation of the learning curve in laparoscopic colorectal surgery: comparison of right-sided and left-sided resections. *Annals of surgery*, *242*(1),pp 83–91. https://doi.org/10.1097/01.sla.0000167857.14690.68

Thomas, D. R. (2006). A General Inductive Approach for Analyzing Qualitative Evaluation Data. *American Journal of Evaluation*, *27*(2), 237–246. https://doi.org/10.1177/1098214005283748

Lowrie, T., Logan, T. & Hegarty, M. (2019) The Influence of Spatial Visualization Training on Students' Spatial Reasoning and Mathematics Performance, *Journal of Cognition and Development, 20*(5),pp 729-751.10.1080/15248372.2019.1653298

Torricelli, F. C., Guglielmetti, G., Duarte, R. J., & Srougi, M. (2011). Laparoscopic skill laboratory in urological surgery: tools and methods for resident training. *International braz j urol : official journal of the Brazilian Society of Urology*, *37*(1), pp 108–112. https://doi.org/10.1590/s1677-55382011000100014

Tubbs, & Sing. (2015). "Surgery is simple-it requires only anatomy and hemostasis". *Clinical Anatomy*, *28*(7), pp 821-821. https://doi.org/10.1002/ca.22618

Turns, S. R., & Van Meter, P. N. (2011). Applying knowledge from educational psychology and cognitive science to a first course in thermodynamics. *ASEE Annual Conference and Exposition, Conference Proceedings*.

Uehara, L., Button, C., Falcous, M. & Davids, K. (2016). Contextualised skill acquisition research: a new framework to study the development of sport expertise, *Physical Education and Sport Pedagogy, 2*1(2), pp 153-168, 10.1080/17408989.2014.924495

Ullman, K., & Sorby, S. (1995). Enhancing the visualization skills of engineering students through computer modeling. *Computer Applications in Engineering Education, 3*(4), pp 251-258. http://doi.org/10.1002/cae.6180030407

Utesch, T.(2014). *Effects of cognitive aptitude on initial performance on a laparoscopic simulator.* (Bachelor Thesis). Retrieved from http://purl.utwente.nl/essay/65809

Vajsbaher T, Schultheis H, Sa-ngasoongsong P, Watcharopas R, Yin M, Haddawy P.(2020). The Role of Spatial Cognition in Surgical Navigation in Arthroscopic Surgery. *Spatial Cognition X: 12th Int'l Conf*, Germany 2020

Vajsbaher, T., Schultheis, H. & Francis, N.K. (, 2018). Spatial cognition in minimally invasive surgery: a systematic review. *BMC Surgery* 18, 94. https://doi.org/10.1186/s12893-018-0416-1

Vassiliou, M. C., Feldman, L. S., Andrew, C. G., Bergman, S., Leffondré, K., Stanbridge, D., & Fried, G. M. (2005). A global assessment tool for evaluation of intraoperative laparoscopic skills. *American journal of surgery*, *190*(1), 107–113. https://doi.org/10.1016/j.amjsurg.2005.04.004

Vogel, P., Vogel, D.H.V.(2019). Cognition errors in the treatment course of patients with anastomotic failure after colorectal resection. *Patient Safety Surgery*. 13, 4. https://doi.org/10.1186/s13037-019-0184-6

Voyer, D., Voyer, S., & Bryden, M. P. (1995). Magnitude of sex differences in spatial abilities: A meta-analysis and consideration of critical variables. *Psychological Bulletin, 117*(2), pp 250–270. https://doi.org/10.1037/0033-2909.117.2.250

Wanzel, K. R., Hamstra, S. J., Anastakis, D. J., Matsumoto, E. D., & Cusimano, M. D. (2002). Effect of visual-spatial ability on learning of spatially-complex surgical skills. *The Lancet, 359*(9302), pp 230–231. https://doi.org/10.1016/S0140-6736(02)07441-X

Wentik. (2001). Eye-hand coordination in laparoscopy - an overview of experiments and supporting aids. (2001). *Minimally invasive therapy & allied technologies*, *10*(3), pp 155–162. https://doi.org/10.1080/136457001753192277

White, M.T & Welch, K. (2012). Does gender predict performance of novices undergoing Fundamentals of Laparoscopic Surgery (FLS) training?. *American Journal of Surgery*, *203*(3), pp 397-400. https://doi.org/10.1016/j.amjsurg.2011.09.020.

Whitehead, C., Austin, Z., & Hodges, B. (2011). Flower power: the armoured expert in the CanMEDS competency framework?. *Advances In Health Sciences Education*, *16*(5), pp 681-694. https://doi.org/10.1007/s10459-011-9277-4

Wilhelmsson, M., Pelling, S., Uhlin, L., Owe Dahlgren, L., Faresjö, T., & Forslund, K. (2012). How to think about interprofessional competence: a metacognitive model. *Journal of interprofessional care*, *26*(2), 85–91. https://doi.org/10.3109/13561820.2011.644644

Yang, J. C., & Chen, S. Y. (2010). Effects of gender differences and spatial abilities within a digital pentominoes game. *Computers & Education, 55*(3), pp 1220–1233. https://doi.org/10.1016/j.compedu.2010.05.019

Yue, S. and Pilon, P. (2004) A Comparison of the Power of the t Test, Mann-Kendall and Bootstrap for Trend Detection. *Hydrological Sciences Journal, 49*, pp 21-37. http://dx.doi.org/10.1623/hysj.49.1.21.53996

Zhang, L & Cao, C. (2010). The Effect of Image Orientation on a Dynamic Laparoscopic Task. *Proceedings of the Human Factors and Ergonomics Society Annual Meeting. 54*(11), pp 774-778. 10.1177/154193121005401108

APPENDIX 1

Study 1- The national online survey in collaboration with the professional associations for German surgeons (BDC)

' Raumkognition in der Laparoskopie'

Universität Bremen* *EXCELLENT.

Creative Unit: Intra-operative information.

BDC Berufsverband der Deutschen Chirurgen e.V.

Liebe Teilnehmerinnen und Teilnehmer,

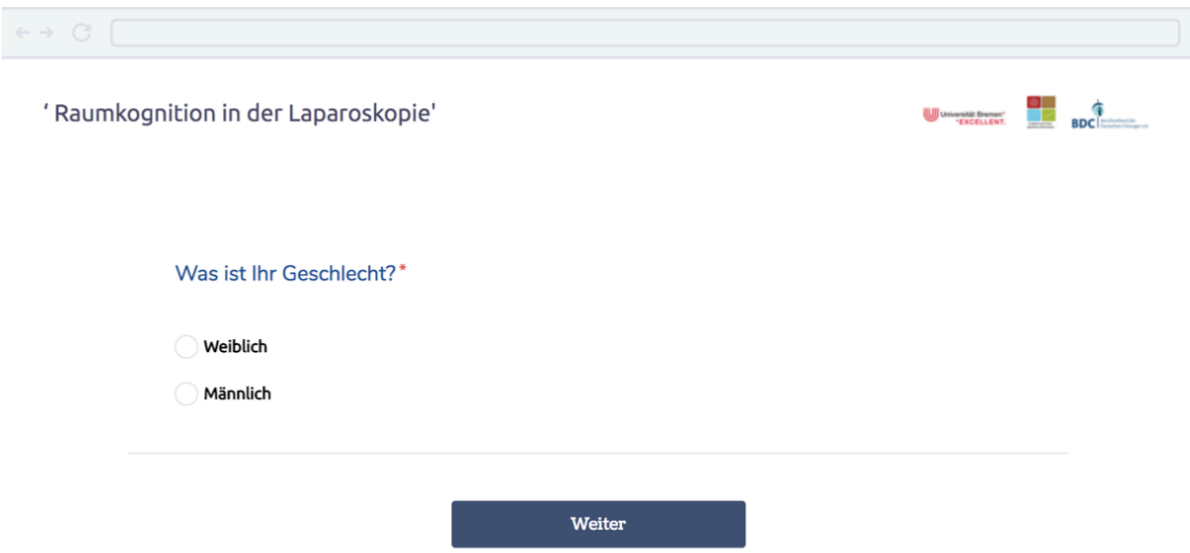
Vielen Dank, dass Sie sich die Zeit nehmen, diesen Fragebogen zum Thema 'Raumkognition in der Laparoskopie', der in Zusammenarbeit zwischen der Universität Bremen und dem BDC entstanden ist, auszufüllen. Der Fragebogen ist Teil eines Forschungsprojekts (von Tina Vajsbaher, Universität Bremen), das das Ziel hat, den Zusammenhang zwischen räumlich-kognitiven Faktoren einerseits und der erfolgreichen Durchführung laparoskopischer chirurgischer Eingriffe andererseits genauer zu untersuchen. Die Bearbeitung wird ca. 10 Minuten dauern. Anfangs werden Sie um einige Angaben zu Ihrer Person gebeten. Diese und alle weiteren Antworten werden selbstverständlich anonym gespeichert.

Es ist wichtig, dass Sie alle Fragen beantworten.

Vielen Dank!

Tina Vajsbaher, MSc

Email: tina.vajsbaher@uni-bremen.de
Fon: +49-421-218-64285
Web: http://bscc.spatial-cognition.de/
Web: http://ioi.cs.uni-bremen.de/

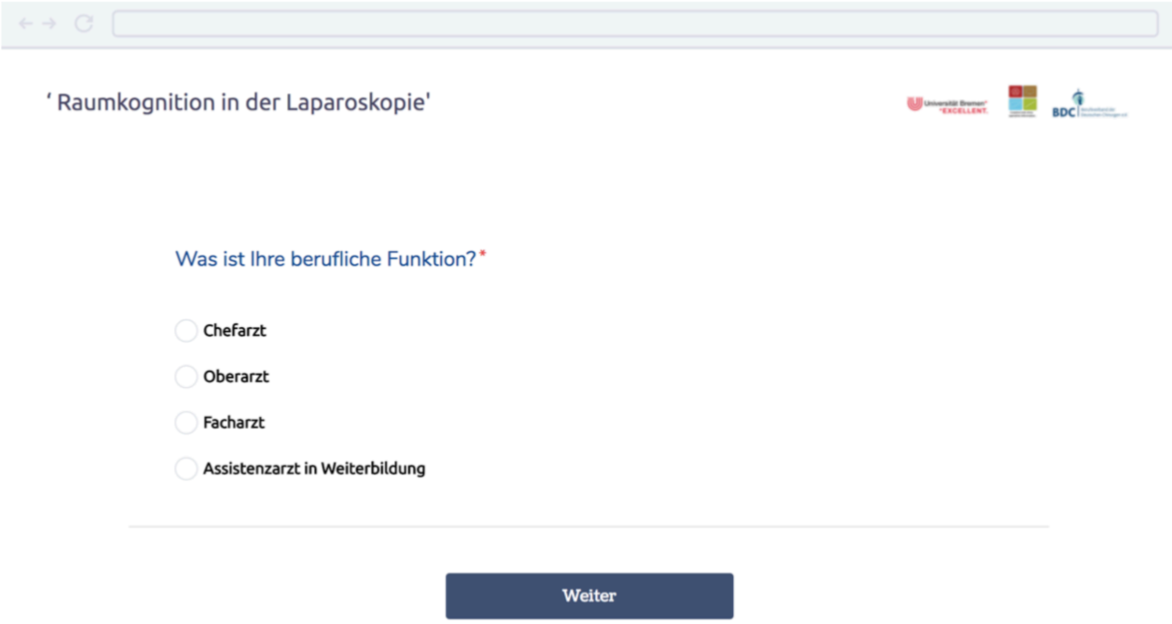


' Raumkognition in der Laparoskopie'

Was ist Ihr Geschlecht?*

- Weiblich
- Männlich

Weiter


' Raumkognition in der Laparoskopie'

Was ist Ihre berufliche Funktion?*

- Chefarzt
- Oberarzt
- Facharzt
- Assistenzarzt in Weiterbildung

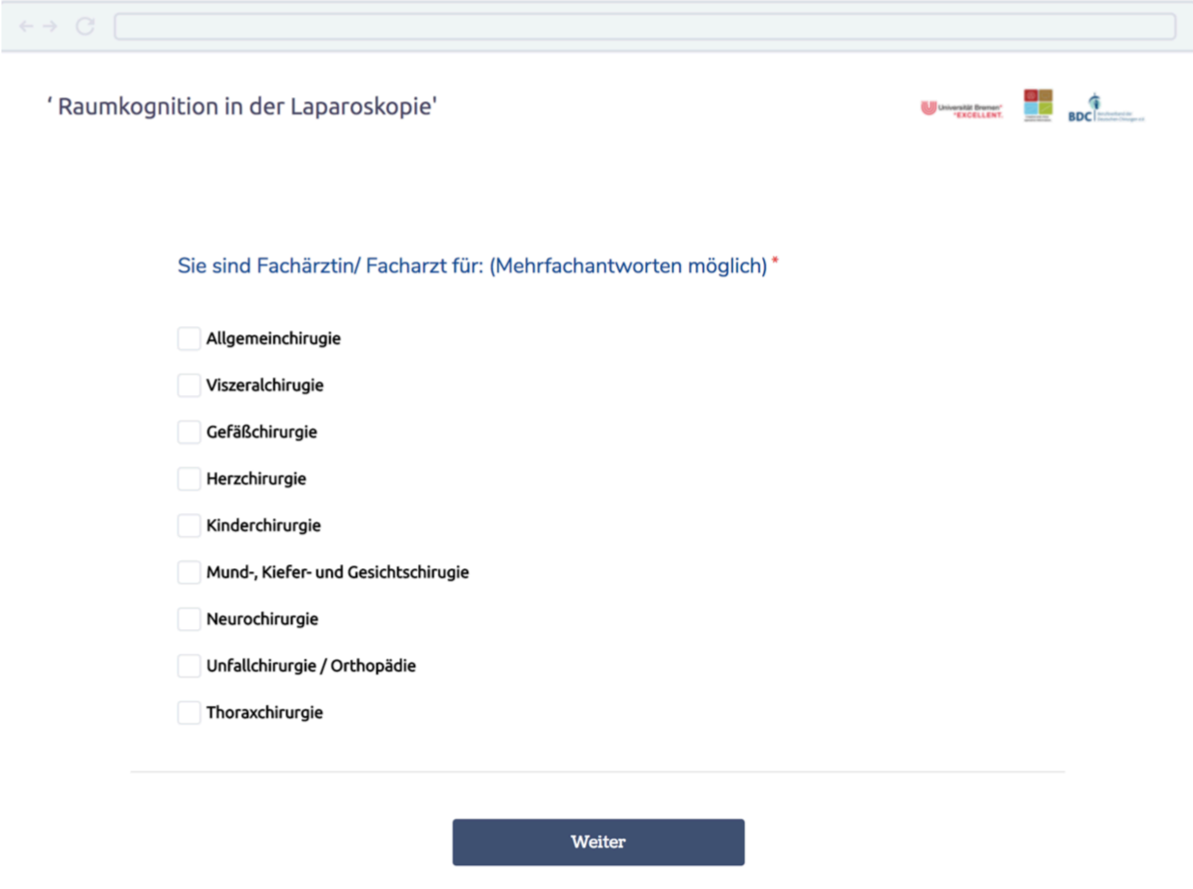
Weiter


' Raumkognition in der Laparoskopie'

Wie alt sind Sie?*

Wert

Weiter

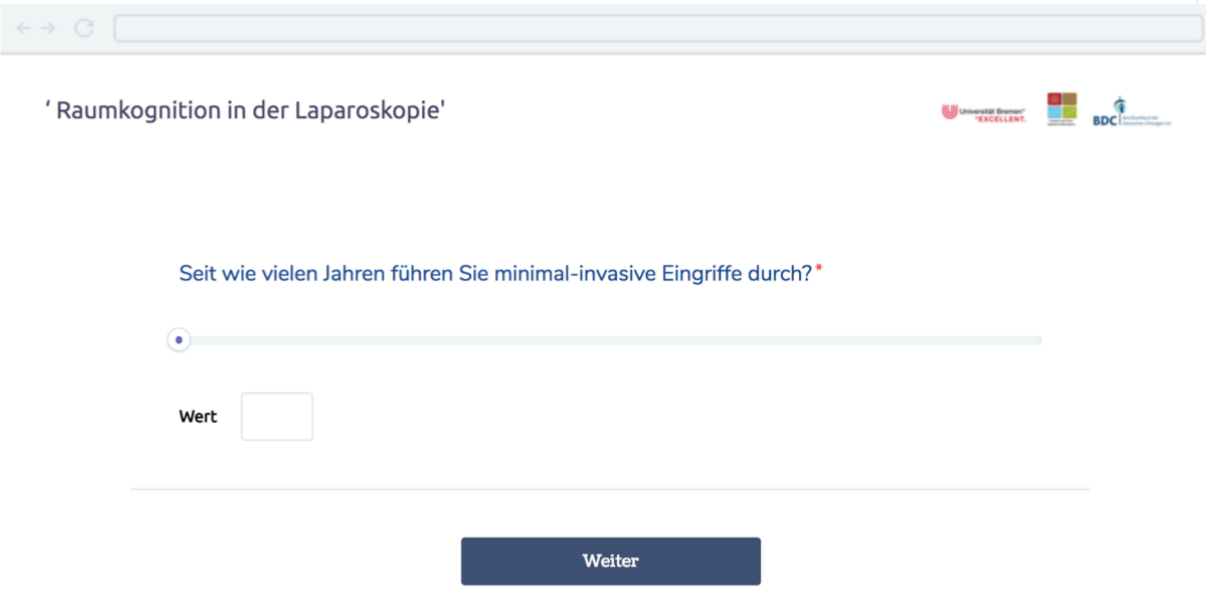


' Raumkognition in der Laparoskopie'

Sie sind Fachärztin/ Facharzt für: (Mehrfachantworten möglich) *

- [ ] Allgemeinchirugie
- [ ] Viszeralchirugie
- [ ] Gefäßchirurgie
- [ ] Herzchirurgie
- [ ] Kinderchirurgie
- [ ] Mund-, Kiefer- und Gesichtschirugie
- [ ] Neurochirurgie
- [ ] Unfallchirurgie / Orthopädie
- [ ] Thoraxchirurgie

Weiter



' Raumkognition in der Laparoskopie'

Seit wie vielen Jahren führen Sie minimal-invasive Eingriffe durch? *

Wert

Weiter

' Raumkognition in der Laparoskopie'

Wie viele m*inimal-invasive chirurgische Eingriffe* führen Sie pro Woche durch? *

Wert

Weiter

' Raumkognition in der Laparoskopie'

Wie viele laparoskopische Eingriffe führen Sie pro Woche durch? *

Wert

Weiter

' Raumkognition in der Laparoskopie'

Wie schätzen Sie selbst Ihren augenblicklichen Erfahrungsstand bezüglich minimal-invasiver Eingriffe ein? *

	Anfänger						Experte
	0	1	2	3	4	5	6
Erfahrungsstand	○	○	○	○	○	○	○

reset

Weiter

' Raumkognition in der Laparoskopie'

Wie bewerten Sie die Schwierigkeiten bei der Durchführung der **laparoskopischen Chirurgie**, gegenüber einer *offenen Operation*? *

- Sehr schwierig
- Schwierig
- Neutral
- Machbar
- Mit Leichtigkeit

Weiter

' Raumkognition in der Laparoskopie'

Welche der folgenden Faktoren würden Sie als größte Herausforderung bei der *Laparoskopie* identifizieren? *

	Keine Herausforderung 1	2	3	4	Große Herausforderung 5
Orientierung und Navigation im Körper	○	○	○	○	○
Reduzierte taktile und visuelle Information	○	○	○	○	○
Bewegungskoordination mit den Instrumenten	○	○	○	○	○
Platzierung der Trokare	○	○	○	○	○
Die Identifizierung der wichtigen Strukturen	○	○	○	○	○

reset

Sonstige

Weiter

' Raumkognition in der Laparoskopie'

Welche der genannte Faktoren (bzgl. Laparoskopie), waren für Sie *am Anfang* besonders herausfordernd?*

- Reduzierte visuelle Informationen
- Reduzierte taktile Informationen
- Navigation im Körper (Kamera)
- Räumlichen Orientierung

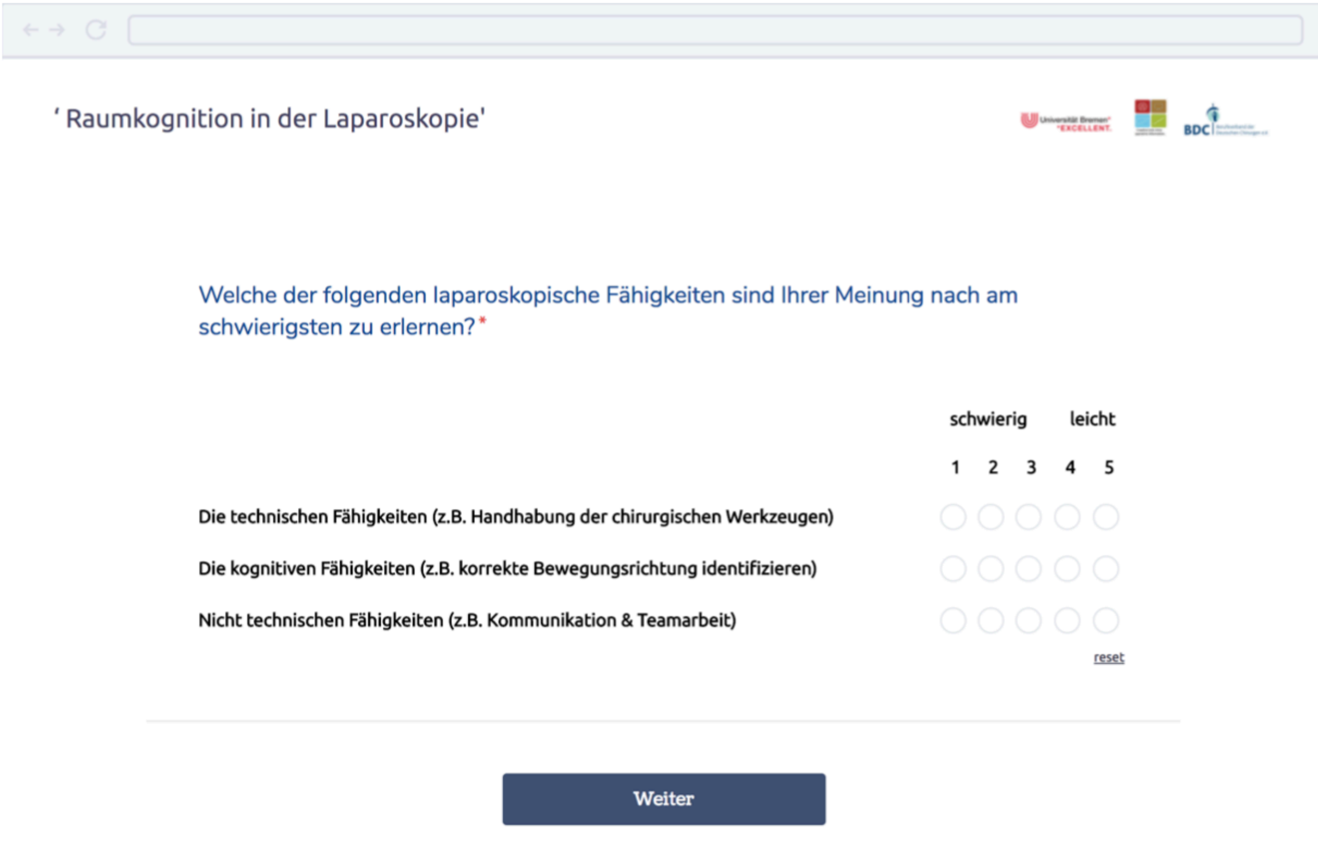
Weiter

' Raumkognition in der Laparoskopie'

Würden Sie sagen, dass Sie während Ihrer chirurgischen Ausbildung genug Erfahrung mit *laparoskopischen Eingriffen* sammeln konnten?*

- Ja
- Nein
- Kann ich (noch) nicht beurteilen

Weiter

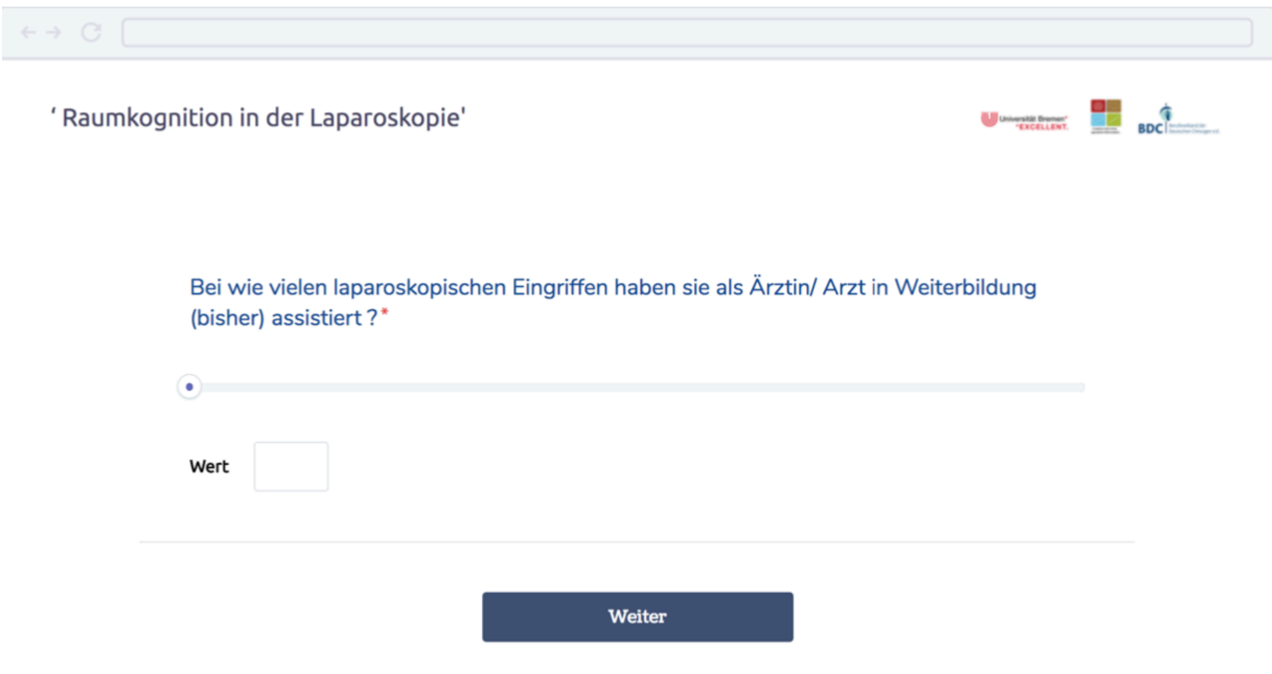

' Raumkognition in der Laparoskopie'

Welche der folgenden laparoskopische Fähigkeiten sind Ihrer Meinung nach am schwierigsten zu erlernen?*

	schwierig 1	2	3	4	leicht 5
Die technischen Fähigkeiten (z.B. Handhabung der chirurgischen Werkzeugen)	○	○	○	○	○
Die kognitiven Fähigkeiten (z.B. korrekte Bewegungsrichtung identifizieren)	○	○	○	○	○
Nicht technischen Fähigkeiten (z.B. Kommunikation & Teamarbeit)	○	○	○	○	○

reset

Weiter


' Raumkognition in der Laparoskopie'

Bei wie vielen laparoskopischen Eingriffen haben sie als Ärztin/ Arzt in Weiterbildung (bisher) assistiert ?*

Wert

Weiter

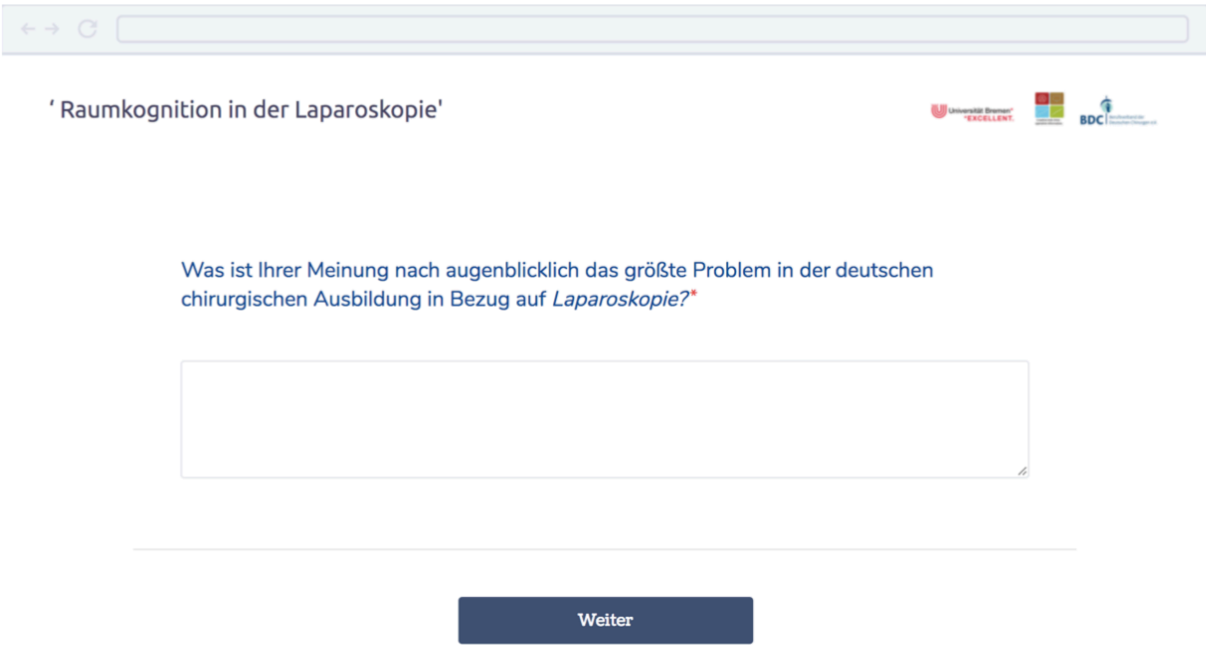

' Raumkognition in der Laparoskopie'

Wie sicher waren Sie am Ende Ihrer Facharztweiterbildung (falls Sie noch in der Ausbildung sind, wie sicher wären Sie augenblicklich) in der selbständigen Durchführung laparoskopischer Eingriffe.*

Sehr sicher				Sehr Unsicher
1	2	3	4	5
○	○	○	○	○

reset

Weiter


' Raumkognition in der Laparoskopie'

Was ist Ihrer Meinung nach augenblicklich das größte Problem in der deutschen chirurgischen Ausbildung in Bezug auf *Laparoskopie?**

Weiter

APPENDIX 2

Study 2- Semi-structured interview protocol with senior surgical educators

(1)Fragen bezüglich chirurgischer/laparoskopischer Kompetenz und Fähigkeit

- Leitfragen: 1) Wie würden Sie chirurgische Kompetenz definieren?

Folgefrage; a) Welche Kenntnisse, Fertigkeiten und Fähigkeiten würden Sie sagen, gehören dazu?

- 2) Was zeichnet, Ihrer Meinung nach, einen kompetenten laparoskopischen Chirurg aus?

- 3) Würden Sie sagen, dass Sie selbst Schwierigkeiten beim Erlenen laparoskopischer Fertigkeiten hatten, oder ist es Ihnen eher leicht gefallen?

a) Wenn Sie zurückdenken an die Zeit, als Sie selbst ein Assistentsarzt waren - können Sie sich erinnern/ mir sagen was Ihnen beim Erlenen laparoskopischer Fertigkeiten geholfen hat?

- 4) Macht Ihnen die Rolle als chirurgischer Ausbilder Spaß?

a) Aus Ihrer Sicht, was würden Sie sagen, macht einen guten Ausbilder in allgemein/visceralchirurgie aus? ODER Was würden Sie sagen, sind die Rollen und Aufgaben des Ausbilders?

b) Was sind Ihrer Meinung nach, die wichtigsten Aufgaben für Ausbilder in der Chirurgie?

c) Wann haben Sie die Rolle des Ausbilders übernommen?

Wie sind Sie zu Ihrer Ausbilderrolle gekommen?

d)Haben Sie einen bestimmten Lehrstil, oder verwenden Sie bestimmte Lehrmethoden?

e) Inwiefern unterscheiden sich laparoskopische Verfahren darin wie schwierig es ist sie zu lehren. Welche Verfahren sind am schwierigsten/einfachsten zu lehren? Warum?

- 5) Um ein Assistentsarzt/in als kompetent bezeichnen zu können, welche Fertigkeiten müssen vorliegen und was müssen die alles können?

(2) Reden wir jetzt ein bisschen über Operieren mit Assistentsärzten

- **Würden Sie sagen, dass operieren mit dem Assistenzarzt einen Einfluss auf Ihrer chirurgischen Leistung hat?**

a) *Wie ansträngend/stressig finden Sie die Kombination von Operieren und Lehre*

(3) DaVinci Operativsystem

- Sind sie qualifiziert für das DaVinci Operationssystem?

- 2) Wie bewerten Sie den Schwierigkeitsgrad beim Erlernen des DaVinci System, gegenüber dem Erlernen laparoskopischer Operationen ohne DaVinci?

- 3)Der Hersteller behauptet, dass DaVinci mehrere Vorteile gegenüber der konventionelle Laparoskopie enthalt. Wie ist Ihre Meinung dazu?

- *Welche wesentlichen Vorteile bietet das DaVinci System, die der konventionelle laparoskopische Technik nicht bietet?*

- 4) Was würden Sie davon halten, wenn die Assistenzärzten verpflichtet wäre, Eingriffe am die DaVinci System,während Ihrer Weiterbildung, durchzufuhren?

(4) Fragen bezüglich Technische (Motorisch/Handwerklich) Fertigkeiten

- Chirurgen wird nachgesagt Sie bräuchten vor allem handwerkliche/technische Fähigkeiten. Wie ist Ihre Meinung dazu? Welche anderen Fertigkeiten (außer handwerklichen) sind entscheidend für einen erfolgreichen Chirurgen?

- In Bezug auf Laparoskopie, welche Fähigkeiten, Fertigkeiten und Tätigkeiten würde Sie als ‘technisch‘ bezeichnen?

- Welche technischen Fähigkeiten und Fertigkeiten sollte der Assistenzarzt während des Facharzt Weiterbildung Erlenen müssen, ihrer Meinung nach?

- Gibt es bestimmte laparoskopische Verfahren, oder Eingriffen, die technisch besonders anspruchsvoll sind?

- Welche technischen Kenntnisse würden Sie sagen, finden die Assistenzärzten am schwersten zu erlernen?

- Welche technischen Fertigkeiten und Fähigkeiten würden Sie sagen, sollte ein Assistenzarzt erwerben, um als kompetenter Chirurg bezeichnet zu werden?

a) Würden Sie sagen, dass diese technische Kenntnisse von jedem Assistentsarzt während der Weiterbildung erlernt werden?

- 8) Manche Chirurgen beschreiben kompetente Assistenzärzten im Sinne von 'das Gefühl für Chirurgie zu haben'- Was halten Sie davon?

a) Welche kognitiven und technischen Fertigkeiten und Fähigkeiten denken Sie, gehören zu diesem Gefühl?

(5) Fragen bezüglich kognitiver Fertigkeiten

- Laparoskopie ist auch kognitiv sehr anspruchsvoll, denken Sie, dass Ärzte das Konzept von Kognition überhaupt verstehen?

- Könnten Sie mir vielleicht ein paar Beispiele geben von Herausforderungen, die Ihrer Meinung nach kognitiv sind?

- Denken Sie, dass die mentale Fähigkeiten die einen guten Chirurgen ausmachen angeboren sind oder können diese Fähigkeiten erworben werden?

- Aus ihrer Erfahrungen, würden Sie sagen, dass auch Assistenzärzte, die anfangs schwache Leistungen zeigen, sich am Ende der Weiterbildung zu sehr kompetenten Chirurgen entwickeln können?

- Gibt es bestimmte laparoskopische Verfahren, oder Eingriffen, die Sie für kognitiv besonders anspruchsvoll halten?

- Wenn Sie mit einem Assistenzarzt operieren, wie wichtig sind Ihrer Meinung nach die Fähigkeit die Schritte des Verfahrens zu erkennen, zu antizipieren und zu kommunizieren?

- Denken Sie, dass Fähigkeiten wie Kommunikation, Entscheidungsprozess, Identifizierung von Landmarken usw. laparoskopische Kompetenz voraussagen?

(6) Fragen bezüglich der Gesundheitswesen in Deutschland

- Auf welche Fertigkeiten, Erfahrungen und Kenntnissen achten Sie bei der Bewertung von Ärzten in Weiterbildung?

- Was würden Sie -- im Bezug auf allgemein-viszeral Chirurgie -- als die größten und wichtigsten Herausforderungen im aktuellen deutschen Gesundheitswesen für die Ärzte in Weiterbildung identifizieren,?

- Wenn Sie die Möglichkeit hätten, das ganze Weiterbildungs-Curriculum zum Facharzt für Viszeralchirugie zu ändern, wie würde Sie es strukturieren?

- Würden Sie sagen, dass die aktuelle Weiterbildungs-Curriculum in Viszeralchirurgie tatsächlich für die Kompetenzentwicklung in laparoskopische Verfahren sorgt?

- Könnten Sie mit Sicherheit sagen, dass jeder Assistenzarzt am Endes der Weiterbildung als ein kompetenter und selbstständiger Chirurg zum Facharzt wird?

- Manche sind der Meinung, dass Assistenzärzte in ihrer chirurgischen Ausbildung zuerst an virtuellen **Patienten trainieren** sollten, bevor sie Eingriffe an lebenden Patienten ausführen dürfen. Wie ist Ihre Meinung dazu?

APPENDIX 3

Study 2- Consent form for surgical educators

Einwilligungserklärung

Forschungsprojekt: ***Raumkognition in der Laparoskopie***

Durchführende Institution: ***Universität Bremen***

Interviewerin: ***MSc. T. Vajsbaher***

Chefarzt / Oberarzt: Dr.______________________

Interviewdatum: ____

Beschreibung des Forschungsprojekts (zutreffendes bitte ankreuzen):

❒ mündliche Erläuterung

❒ schriftliche Erläuterung

Die Interviews werden mit einem Aufnahmegerät aufgezeichnet und sodann von den Mitarbeiterinnen und Mitarbeitern des Forschungsprojekts in Schriftform gebracht. Für die weitere wissenschaftliche Auswertung der Interviewtexte werden alle Angaben, die zu einer Identifizierung der Person führen könnten, verändert oder aus dem Text entfernt. In wissenschaftlichen Veröffentlichungen werden Interviews nur in Ausschnitten zitiert, um gegenüber Dritten sicherzustellen, dass der entstehende Gesamtzusammenhang von Ereignissen nicht zu einer Identifizierung der Person führen kann. Personenbezogene Kontaktdaten werden von Interviewdaten getrennt für Dritte unzugänglich gespeichert. Nach Beendigung des Forschungsprojekts werden Ihre Kontaktdaten automatisch gelöscht, es sein denn, Sie stimmen einer weiteren Speicherung zur Kontaktmöglichkeit für themenverwandte Forschungsprojekte ausdrücklich zu. Selbstverständlich können Sie einer längeren Speicherung zu jedem Zeitpunkt widersprechen. Die Teilnahme an den Interviews ist freiwillig. Sie haben zu jeder Zeit die Möglichkeit, ein Interview abzubrechen, weitere Interviews abzulehnen und Ihr Einverständnis in eine Aufzeichnung und Niederschrift des/der Interviews zurückziehen, ohne dass Ihnen dadurch irgendwelche Nachteile entstehen.

Ich bin damit einverstanden, im Rahmen des genannten Forschungsprojekts an einem Interview/ an mehreren Interviews teilzunehmen.

❒ja ❒nein

Ich bin damit einverstanden, für zukünftige themenverwandte Forschungsprojekte kontaktiert zu werden. Hierzu bleiben meine Kontaktdaten über das Ende des Forschungsprojektes hinaus gespeichert.

❒ja ❒nein

____Name

____ Ort, Datum / Unterschrift

APPENDIX 4

Consent forms for the participation in study 3

1.) Consent form for senior surgeons

Einwilligungserklärung für Fach/Ober/Chefärzte

Titel	**O** Facharzt	**O** Oberarzt	**O** Chefarzt
Klinikum	**O** Bremen-Mitte	**O** Bremen-Ost	**O** Pius Oldenburg

Ich bin über Wesen, Bedeutung und Tragweite der geplanten Untersuchung aufgeklärt worden. Ich habe die Information zum Zweck der Untersuchung und den Aufklärungsbogen gelesen und verstanden. Zusätzlich bin ich ausführlich mündlich aufgeklärt und informiert worden.

Ich bin darauf aufmerksam gemacht worden, dass die Teilnahme jederzeit von beiden Seiten ohne Angabe von Gründen widerrufen werden kann, ohne dass mir daraus Nachteile entstehen. Die laufende Untersuchung kann jederzeit unterbrochen werden. Eine eventuelle Vergütung erfolgt anteilig.

Meine Testdaten werden anonymisiert gespeichert. Ich bin aber damit einverstanden, dass meine personenbezogenen Daten verschlossen auf einem nicht an ein Netzwerk angebundenen Rechner, getrennt von allen weiteren Untersuchungsdaten, aufbewahrt werden. Wenn das Forschungsprojekt es notwendig macht, diese Test- und persönlichen Daten zusammenzuführen, wird dies nur unter Einschaltung eines Datentreuhänders möglich sein, der auf die Einhaltung von Schweigepflicht und gesetzlichen Datenschutzvorschriften achtet. Sämtliche Daten werden nach der von der Deutschen Forschungsgemeinschaft geforderten und gesetzlich vorgeschriebenen zehnjährigen Nachweispflicht gelöscht.

Ich erkläre mich hiermit freiwillig zur Teilnahme an der geplanten Untersuchung bereit. Ich bestätige hiermit, dass ich durch Frau Vajsbaher, mündlich aufgeklärt wurde.

______________	________________________	______________________
Ort, Datum	Unterschrift Untersuchungsteilnehmer/in	Unterschrift Untersucher

2.) Consent forms for residency surgeons and control subjects

Einwilligungserklärung

Persönlische ID: (01) / 02 / 03 ___________ ______

Über Art und Durchführung der Untersuchung hat mich Frau Vajsbaher in einem Aufklärungsgespräch ausführlich informiert. Das Informationsblatt für Probanden ist mir ausgehändigt worden. Ich konnte alle mir wichtig erscheinenden Fragen stellen. Die mir erteilte Information habe ich verstanden.

Mir ist bekannt, dass im Rahmen dieser Studie meine Daten in pseudonymisierter Form (also in einer Form, bei der Identifikationsmerkmale wie Name durch ein Kennzeichen – z.B. eine Codenummer – ersetzt sind, so dass eine Zuordnung zu meiner Person nur über weitere Hilfsmittel – etwa eine Referenzliste – möglich ist) erhoben und auf elektronischen Datenträgern gespeichert und verarbeitet werden. Zugang zu den Daten haben die Studienleitung und auf Nachfrage die Lehrenden Chef- und Oberärzte.

Ich nehme freiwillig an dieser Studie teil und bin informiert worden, dass ich jederzeit und ohne Angabe von Gründen meine Teilnahme an der Studie beenden und diese Einwilligungserklärung widerrufen kann, ohne dass dabei für mich persönliche Nachteile entstehen. Dieser Widerruf kann auch teilweise erfolgen, so dass zum Beispiel die Einwilligung zur Durchführung der kognitive Tests widerrufen wird, aber die Einwilligung zur Erhebung der GOALS Daten bestehen bleibt. Ich habe verstanden, dass im Falle des Widerrufs der (ganzen oder teilweisen) Einverständniserklärung die bereits erhobenen Daten pseudonymisiert weiter genutzt werden.

Ich erkläre mich hiermit bereit, an der im Informationsblatt beschriebenen freiwilligen Untersuchung im Rahmen der oben genannten wissenschaftlichen Studie teilzunehmen.

Hiermit erkläre ich, dass:

- ich über den Zweck, den Ablauf, die Bedeutung und Bindung der Längsschnittstudie, sowie die Vorteile und Risiken, die damit verbunden sein können, mündlich aufgeklärt worden bin.
- ich die schriftliche Probandeninformation gelesen habe.
- mir bewusst ist, dass aus meinen gewonnenen Daten Rückschlüsse auf meine berufliche Leistung gezogen werden können.
- alle meine Fragen zu meiner Zufriedenheit beantwortet worden sind.
- mir eine Kopie der Probandeninformation und Einverständniserklärung ausgehändigt wurde.
- ich genügend Zeit hatte, um meine Entscheidung zur Studienteilnahme zu überdenken, und frei zu treffen.
- meine Erklärungen nur so weit reichen, wie mir dies im Rahmen der schriftlichen Probandeninformation bzw. im Rahmen der mündlichen Erläuterung dargelegt wurde.

______________	___________________________	________________________
Ort, Datum	Unterschrift Untersuchungsteilnehmer/in	Unterschrift Untersucher

APPENDIX 5

Study 3- Pair-matched data for longitudinal analysis

Pairs		PTS	GVVT	MRT-A	PicSOr
1	Resident	90.7	17	10	0.80
	Control	87.8	16	13	0.79
2	Resident	65.7	11	4	0.45
	Control	63.3	7	3	0.44
2	Resident	89.5	23.5	17	0.95
	Control	86.7	20	16	0.93
3	Resident	84.2	6	9	0.50
	Control	82.0	4	11	0.49
4	Resident	79.4	9	8	0.25
	Control	76.8	7	9	0.17
5	Resident	58.6	23	9	0.37
	Control	60.3	22	11	0.33
6	Resident	33.2	13	6	0.40
	Control	35.9	16	8	0.43
7	Resident	29.1	10	9	0.20
	Control	12.9	11	7	0.23
8	Resident	55.9	18	9	0.80
	Control	50.7	17	7	0.76
9	Resident	26.7	10	10	0.42
	Control	22.5	9	12	0.39
10	Resident	76.2	13	14	0.95
	Control	71.3	11	15	0.93
11	Resident	72.6	17	10	0.57
	Control	67.9	15	12	0.53
12	Resident	52.1	19	16	0.73
	Control	42.4	19	18	0.69
13	Resident	70.9	16	9	0.33
	Control	64.4	14	8	0.23
14	Resident	60.2	17	8	0.32

	Control	64.6	15	6	0.22
15	Resident	60.3	10	10	0.18
	Control	63.9	11	12	0.14
16	Resident	44.7	14	7	0.38
	Control	38.8	11	9	0.31
17	Resident	22.6	20	14	0.74
	Control	28.1	17	16	0.68
18	Resident	75.9	18	11	0.89
	Control	70.0	16	9	0.81

APPENDIX 6

Study 3- Control group financial compensation information sheet

Universität Bremen*
*EXCELLENT.

BREMEN SPATIAL COGNITION CENTER

Teilnehmer/Innen *für* die Studie ‚Raumkognition beim chirurgischen Lernen'

Das Bremen Spatial Cognition Center *an der Universität Bremen sucht TeilnehmerInnen für eine Studie zur* **medizinischen Kognition.**

Hierbei soll untersucht werden, welche visuell-räumlichen Prozesse wichtig sind für das Erlernen chirurgischer Fähigkeiten und wie sich diese im längeren Lernverlauf entwickeln.

Um genauer feststellen zu können, wie sich diese Fähigkeiten auch bei Personen die **nicht Chirurgie (Medizin) studiert** *haben entwickeln, suchen wir als* ***Kontrollgruppe TeilnehmerInnen ohne vorherige oder gegenwärtige berufliche Verbindung zur Medizin***.

Was müssen Sie tun?
Es handelt sich um eine **Längsschnittstudie über zwei Jahre**, wobei **vier räumlich-kognitive Tests** (mit einer Dauer von insgesamt 30-40 Minuten) in der Regel alle **zwei Monate über zwei Jahre** hinweg,durchgeführt werden.

Teilnahme-Voraussetzungen?
Gesunde Personen (im Alter zwischen 20-40), die weder psychisch- noch suchtkrank sind und waren und bereit sind die gesamten **zwei Jahre an unserer Studie teilzunehmen.**

Wo findet es statt?
Im Bremen Spatial Cognition Center (Gebäude Cartesium) an der Universität Bremen.

Was bekommen Sie dafür?
Für den gesamten Teilnahmezeitraum wird eine **Aufwandsentschädigung in Höhe von insgesamt 264 Euro ausgezahlt.** Diese Aufwandsentschädigung wird halbjährlich aus-gezahlt. Nach den beiden ersten Halbjahren werden je **50 Euro ausgezahlt**. Nach dem dritten **Halbjahrwerden 64 Euro** ausgezahlt und nach dem vierten Halbjahr die restlichen **100 Euro.** In jedem Halbjahr werden drei Tests gemacht, die ca. 30-40 Mi-nuten dauern werden.

APPENDIX 7

Study 4- The intraoperative assessment form

Globale Beurteilung von laparoskopischen Fähigkeiten – (GOALS)

Datum:_________________________ Anwender:______________________

Teilnehmer ID:___________________ Art der Operation: _______________________

Bitte kreuzen Sie die richtige Antwort an

Klinikum: **O** Bremen-Mitte **O** Bremen-Ost **O** Pius Oldenburg

Schwierigkeitsgrad: **O** Leicht **O** Mittel **O** Schwer

Der körperliche Zustand der Patienten (ASA-Klassifikation): **O** I **O** II **O** III **O** IV **O** V

Umwandlung zum offenen Verfahren? **O** Ja **O** Nein

Bitte kreuzen sie die korrekte Ziffer an; alle Antwortmöglichkeiten zwischen 1 und 5 sind möglich

1. Tiefenempfinden

1. Schießt stets über das Ziel hinaus, weite Schwenks, langsame Korrekturen
2.
3. Gelegentliches Verfehlen des Ziels oder darüber Hinausschießen, aber schnelle Korrektur
4.
5. Steuert die Instrumente exakt in der richtigen Ebene zum Ziel

2. Beidhändiges Arbeiten

1. Benutzt nur eine Hand, ignoriert die nicht dominante Hand, schlechte Koordination zwischen den Händen
2.
3. Benutzt beide Hände, jedoch kein optimales Zusammenspiel der Hände
4.
5. Benutzt fachmännisch beide Hände ergänzend, um eine optimale Darstellung zu erreichen

3. Effizienz

1. Unsicher, ineffizientes Arbeiten, viele Versuche, ständige Ausrichtungswechsel oder Innehalten ohne Fortschritt
2.
3. Langsame, aber geplante Bewegungen, die passabel organisiert sind
4.
5. Überzeugende, effiziente und sichere Durchführung, arbeitet fokussiert, bis ein Arbeiten über einen anderern Zugang besser ist

4. Behandlung der Gewebe

1. Grobe Bewegungen, zerreißt Gewebe, verletzt Nachbarstrukturen, schlechte Zangenkontrolle, Zange rutscht häufig ab
2.
3. Behandelt das Gewebe passabel, geringe Verletzung von Nachbargewebe (d. h. gelegentlich unnötige Blutung oder Abrutschen der Zange)
4.
5. Behandelt das Gewebe gut, übt den richtigen Zug aus, so gut wie keine Verletzung der Nachbarstrukturen

5. Selbstständigkeit

1. Kann die gesamte Aufgabe auch bei verbaler Führung nicht bewältigen
2.
3. Kann die Aufgabe mit geringer Führung sicher bewältigen
4.
5. Kann die Aufgabe selbstständig ohne Hinweise von außen bewältigen