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**Author:** Spruit, E.N.
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Introduction

Over the past two decades, the use of Minimally Invasive Surgery (MIS) has increased substantially in the disciplines of General Surgery, Gynecology and Urology. In practice, MIS has many advantages over traditional open surgery; like reduced damage to bodily tissue, less pain, shorter hospitalization, lower rates of morbidity and mortality, smaller scars and a faster return to normal every-day life (Banta, 1993). For these reasons, patients have demanded this type of surgery more frequently over the past decades, resulting in a wider implementation of the technique. Due to this fast application, research and extensive education on the skills and training required for excellent surgical performance has not yet fully caught up.

The use of a camera, a monitor and laparoscopic tools make MIS operations more complex due to the lack of depth perception, the Fulcrum effect and the reduction in tactile feedback (Hiemstra, Kolkman & Jansen, 2008). As a result of this increase in complexity, different types of skills are required from practitioners in order to ensure safe and efficient surgical performance.

Laparoscopic Surgery

MIS refers to a set of surgical techniques that aim to reduce the size of incisions during surgery. Most MIS procedures are performed in the abdominal cavity (which are called laparoscopic operations), but MIS techniques are also used in the pelvic cavity, in vascular surgery and in other areas like the limbs. During laparoscopic surgical procedures, a few (usually one to five) small incisions are made in the body, thru which a camera and instruments are inserted. The camera (laparoscope) projects to monitors in the operating room visible to the operating surgeon(s) and assisting staff.

Because smaller incisions are made, less damage to bodily tissue is done, typically resulting in less pain for the patient and a faster recovery time. This results in lower chances for infection, morbidity and mortality, shorter hospitalization and better cosmetics (smaller scars). The drawback is that laparoscopic procedures are more difficult to perform than traditional open (laparotomy) procedures. Operating with laparoscopic techniques requires more complex skills and thus makes a procedure more challenging for the operating surgeon.
Challenges of Laparoscopic Surgery

Because laparoscopic procedures make use of small incisions, a camera and monitors, the surgeon and operating team have no direct view of the operating site. As a surgeon is required to look at a monitor to see what is going on, his hand-eye coordination is altered substantially. Also, the captured image of the laparoscope is enlarged several times resulting in a transformation of visual-motor proportions. This means that a very fine motor movement of the hand on an operating instrument results in a much larger movement of the corresponding instrument on the monitor screen.

Another limitation of viewing the operating site from a monitor screen is that the surgeon’s visual perception is limited to a two-dimensional video image. This hampers the estimation of depth relations in the operating field. In traditional open surgery the surgeon can use both eyes to directly look into the body of a patient, but in laparoscopic surgery (LS) this default perception of depth (called stereopsis) is lost. Furthermore, the laparoscope can only provide one perspective (at a time) of the inside of the abdominal cavity, depending on the angle and position that it is being placed. This implies that the surgeon has to cope with an incomplete image of the operating site, which increases chances of unnoticed injury occurring outside of the visual field.

In addition to these perceptual constraints, LS makes use of long instruments and surgeons cannot use their hands directly to operate. In traditional open surgery, the operating surgeon can feel the texture and warmth of different bodily structures and make judgments and decisions about anatomy accordingly. In LS however, this degree of haptic sensation is lost, as laparoscopic instruments provide very little tactile feedback. Also, the instruments tilt around an axis (the abdominal wall), resulting in inversed movements. Moving the handle of an instrument to the left, results in a movement to the right of the tip of the instrument inside the body of the patient (and vice-versa for left to right and up and down). This is called the Fulcrum Effect (Gallagher, McClure, McGuigan, Ritchie & Sheehy, 2008); since it is the same inverse movement that pilots have to face in handling a control stick in an airplane (the base of a control stick is called the fulcrum). This makes the handling of laparoscopic instruments very counter-intuitive and it requires more practice to become proficient at it. All of these challenges make anatomical orienting and mobilization of organs and bodily tissues during an operation a lot more difficult.

Teaching Laparoscopic Surgery

Aside from bearing a larger burden on the cognitive skills of the surgeon and operating team, these challenges also open a window of risk for the patient. In the hands of an
under-skilled surgeon, the choice to opt for a laparoscopic procedure may actually result in more damage to bodily tissue, rather than less. Jordan, Gallagher, McGuigan and McClure (2000) suggest that experience of surgeons and complication rates are associated. The authors highlight the findings of Wherry et. al. (1994), pointing out that most complications occur in the first ten laparoscopic procedures a surgeon performs. They state that: “it is important to identify scientifically the problems that face the trainee laparoscopic surgeon, and also to investigate strategies to overcome these difficulties.” (Jordan et. al., 2000).

Reduction of damage to bodily tissue is one of the most important drives behind the development of MIS (Hamming, 2005), which makes the importance of proficient surgeons apparent.

Surgical procedures are traditionally taught to residents in a Halstedian mentor-apprenticeship model (Gallagher & O’Sullivan, 2012). In this scenario, residents are allowed to perform steps in an operation under the direct supervision of an experienced surgeon. In the first years of training, the resident mainly assists in basic surgical procedures and performs relatively easier tasks during an operation. As experience and skill accumulate, residents learn to perform more difficult steps in surgery.

Since the introduction of LS in the late eighties, the necessity of alternative training methods has become apparent, as the skills required for LS are more difficult to teach in the OR. Also, public awareness regarding the safety of surgery had altered substantially as a result of iatrogenic errors reported in popular media and authority assessments (Gallagher & O’Sullivan, 2012; van der Wal, 2007). The combination of these factors led to the questioning of the traditional mentor-apprentice model of teaching surgical skills. Most surgeons will agree that there is no substitute for operating on real patients in learning to perform surgery. There are, however, several drawbacks to this model and trainees can be taught specific laparoscopic skills through simulation training.

First of all, it is not ethically appropriate to let an inexperienced surgeon operate on patients, even in the presence of a mentor. The equality of health care distribution cannot be guaranteed when some patients receive treatment in a teaching hospital, whereas some patients are operated on by experienced surgeons. To ensure quality of health care, sufficient skills need to be mastered by residents before the first contact with patients.

Second, residents are working fewer hours in a week than before, which minimizes the amount of time that is available for teaching (Reznick & MacRae, 2006). This lack of time allocated to training may pose problem to learning efficiency. Therefore, training surgical skills in the traditional model may not be ideal. In the OR, providing quality health care to the is the primary goal (i.e. a successful surgical procedure with no complications and a positive outcome for the patient). The residents’ learning process will always be secondary to providing quality health care, making it a less than optimal learning environment. In
these circumstances, the teaching process of a surgical resident will always be subjugated to the safe, fast, and successful completion of the operation. In contrast, in a training that is primarily geared towards teaching a resident key knowledge and skills, the learning process of is the primary goal and the trainee determines the speed and complexity level to train at.

Third, the mentor-apprenticeship model creates a very diverse training program for different surgical residents. What is learned is dependent on the case-load and preferences of a specific proctoring surgeon, so that all residents receive different curriculum content during their training. Proficiency-based training on the other hand, focuses on identifying the important skills needed for excellent performance in LS and measuring and documenting the level of those skills (Aggarwal & Darzi, 2006). A more evidence-based approach to the design of curriculum is desirable (Levinson 2010), for surgical training, as well as medical education in general.

In the Netherlands, the risks of MIS have received more attention from the Dutch government, highlighting the incident rates of complications during LS (van der Wal, 2007). In 2008, the inspection of Health Care asked all Dutch hospitals to write a plan of action for improving safety and competence of LS procedures.

In response to this message, medical associations and institutions (NVEC, 2009) have created more guidelines for MIS and their attention has turned towards finding ways to bring more structure and efficiency to the training of laparoscopic skills to medical residents. On an international level, the need for new kinds of training for surgery was stimulated by a series of reports of malpractice spread across the globe (Gallagher & O’Sullivan, 2012). Media coverage of some of these scandals led to a demand for more rigorous assessment and qualifications of surgical skills. As a result of this, the traditional mentor-apprentice model of learning for the resident surgeon was put into question. Surgeons found that their residents had more difficulty learning laparoscopic skills as the acquisition of these surgical skills is a more complex endeavor. These challenges of learning new laparoscopic procedures, ethical issues, along with a reduction in work hours facilitated the need for a new kind of training. Ultimately, all of these factors combined led to the introduction of simulation training in surgery.

**Optimizing Efficiency of Laparoscopy Simulation Training**

Simulation training of surgical skills must be researched thoroughly, in order to be valid (predictive of later surgical performance). By taking into account the perspectives of multiple disciplines (surgery, educational, cognitive and organizational psychology); ways can be found in order to enhance laparoscopic skills training. A way in which laparoscopic skills training may be improved is by exploring what factors
influence surgical performance, how laparoscopic skills are learned most effectively, how these surgical skills are best maintained over time and how the acquisition of skills differs among individuals as well as training conditions.

The aim of the research project described in this thesis was to study and improve the training of laparoscopic skills for surgeons, in order to increase patient safety in the operating room.

The goal of this project was to take a good look at these research questions by investigating the elements that influence the practice of laparoscopy. The project will be a combination of qualitative and quantitative methods, including a cognitive task analysis and several lab studies that will focus on the following research question:

• Under which training conditions (schedules, training design, feedback, etc.) are laparoscopic skills most efficiently learned and retained on the long-term?

The results and outcomes of these studies will serve as indicators of how current training and curriculum may be modified and optimized. The goal is to facilitate trainers and instructors in medical centers in their decisions regarding training design.

In the studies described, we draw on concepts from educational and cognitive psychology, that have been viable principles to improve learning efficiency and long-term retention in other contexts (knowledge acquisition, basic motor tasks, aviation, sports, medical education). In the chapters to come, we also describe the cognitive capacities inherent to the learner, which are an important part of understand why a learning principle works and may prove useful when considering the use of learning principles in training.

**Chapter Overview**

In order to provide an accurate picture of what the practice of LS entails, a cognitive task analysis was conducted. This analysis included reviewing literature, analyzing recorded video footage of laparoscopic procedures, observing operations in the OR and conducting semi-structured interviews with experienced laparoscopic surgeons. The results of this analysis can be found in Chapter 2. This chapter gives the reader an impression of what an advanced laparoscopic procedure entails and gives a brief summary of all the important aspects for training surgical residents.

The dissertation then continues, zooming in on one of the aspects of training, namely the perceptual and motor skills required to perform laparoscopic surgery. The next Chapter (3) is an in-depth literature review into the possible interventions which can be applied to laparoscopic motor skill training, which serves as a basis for the empirical lab studies that follow in later chapters.

Chapter 4 is a brief commentary on the topic of how instructor feedback influences a trainee’s learning process. Chapter 5 continues on the topic of feedback, but on the level
of the training simulator. It describes a study with the aim of finding the optimal dosage of presenting visual force feedback to trainees during training.

In Chapter 6, a varied practice intervention was tested, by interleaving different variants of laparoscopic training tasks. Also we used alternating angles of the laparoscope during training, since the angle of the laparoscopic is not always constant during LS procedures in the OR. Chapter 7 describes a study focused on comparing two groups with different training time schedules (spacing) in order to assess the viability of (longer) time intervals between training sessions.

In Chapter 8, we revisit the topic of spacing training, so multiple groups with different training schedules are compared. In this study, we aim to specify the influence of breaks, fatigue and sleep consolidation on the effectiveness of spacing training. The final chapter consists of a general discussion with recommendations. A final disclaimer is that this dissertation was written as a collaborative research project between medical and psychological departments. This reflects in the writing with some chapters (and abstracts) being more concise and to the point (medical style, chapter 4, 5, 7 and 8) and some being more theoretical, descriptive, elaborate and with an overall more thorough exploration of the existing literature (psychological style, chapter 2, 3 and 6).