

Individual differences in laparoscopic surgical skills acquisition



Bas Kengen

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Bas Lodewijck Kengen

Author: Bas Lodewijck Kengen

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Individual differences in laparoscopic surgical skills acquisition

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Bas Lodewijck Kengen
geboren op 5 maart 1992
te Groningen

Promotor:

Prof. dr. H. van Goor

Copromotor:

Dr. J-M. Luursema

Manuscriptcommissie:

Prof. dr. E.J.M. Tanck

Prof. dr. K.M. Stegers-Jager

Prof. dr. J.A. van der Hage (Leids Universitair Medisch Centrum)

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by

Bas Lodewijck Kengen
born on March 5, 1992
in Groningen (the Netherlands)

Supervisor:

Prof. dr. H. van Goor

Co-supervisor:

Dr. J-M. Luursema

Manuscript Committee:

Prof. dr. E.J.M. Tanck

Prof. dr. K.M. Stegers-Jager

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CHAPTER 1

General Introduction

DEVELOPMENTS IN SURGICAL TRAINING

Over the past two decades, surgical training has undergone profound changes to adapt to the dynamic landscape of healthcare and advancements in technology. These developments have been driven by a collective effort to continue to produce highly skilled and competent surgeons who prioritize patient safety and quality care in a field that is rapidly changing. Technological innovations in the area of minimally invasive and robotic surgery continue to spawn novel surgical procedures, which increases the training load for aspiring surgeons while reducing the time available for such training. This is further aggravated by the (rightly) increased attention for the role of non-technical skills in surgical technical performance. As a consequence, surgical training too had to change.

The integration of technology, particularly simulation-based training, has revolutionized surgical training [1-3]. High-fidelity simulators, virtual reality platforms, and computer-based programs have become essential tools. These offer trainees an immersive and controlled environment in which to practice and refine their surgical skills. Also, competency-based training has (partly) replaced traditional time-based training approaches [4-6]. Trainees are no longer required to complete a fixed duration of training but must instead demonstrate specific skills and competencies, allowing surgeons to acquire skills in a logical, stepwise approach [5]. This shift emphasizes the mastery of essential skills and can ensure that trainees are well-prepared for surgical practice.

Continuous efforts are still made to improve efficiency of training. Improving training efficiency and effectiveness in surgical training is crucial for various reasons. First, it directly impacts patient safety. Ineffective training can lead to longer procedure times and an increased risk of complications, potentially jeopardizing patient well-being. Streamlining training processes and enhancing skill acquisition can result in more competent and safer surgeons [7, 8]. Second, improving training efficiency reduces the time required for trainees to become fully competent surgeons. Traditional surgical training is often lengthy, causing delays in the entry of trainees into practice. By making training more efficient, aspirant surgeons can enter the workforce sooner, helping to address workforce shortages [9, 10] and providing timely care to patients. Third, efficiency in surgical training optimizes resource allocation. Surgical training is resource-intensive, involving costly equipment, operating room time and supervision by experienced surgeons. More efficient training ensures that these resources are used effectively, reducing the financial burden on healthcare systems and enabling serving larger number of patients. Fourth, the integration of advanced technologies in modern surgery, such as robotic surgery and laparoscopic

techniques, requires efficient training to ensure that surgeons are well-prepared to use these technologies effectively, maximizing benefits for patient care.

This all has led to a transition from traditional surgical training to a more adaptive training approach [11-13]. Traditional surgical training often follows a one-size-fits-all approach, where all trainees progress through the same curriculum at the same pace. Adaptive training, on the other hand, tailors the learning experience to individual trainees. It assesses each individual skills, knowledge, and progress and provides a personalized curriculum, ensuring focus on areas where improvement is most needed [14]. This personalization can lead to more efficient skill development and a shorter learning curve [15]. Adaptive training continually assesses performance of a trainee and adjusts the difficulty of tasks and content accordingly. This means that trainees are consistently challenged at an appropriate level, preventing boredom from overly easy tasks and reducing frustration from tasks that are too difficult [16]. This dynamic assessment ensures that trainees stay engaged in their learning. Also, one of the strengths of adaptive training is its ability to provide immediate feedback and targeted remediation. If a trainee struggles with a particular aspect of a surgical procedure, an adaptive system can offer additional practice, resources, or guidance to address the issue. This real-time support helps trainees overcome challenges effectively. Adaptive training systems generate extensive data on trainee performance. Educators and institutions can use this data to gain valuable insights into each trainee's strengths and weaknesses, areas of improvement, and overall proficiency. These insights can inform curriculum development and teaching strategies, enabling continuous improvement in surgical training.

Another transformation in surgical training came with the development of Virtual reality (VR) simulators [17, 18]. Their importance lies in their ability to provide a realistic and risk-free training environment for surgical trainees. Trainees can interact with virtual tissues and instruments, gaining an accurate feel for surgical techniques and sensations. Safety (avoiding mistakes) is paramount in surgery and surgical training, and VR simulators offer a safe environment for trainees to learn and make mistakes without jeopardizing patient well-being. This error-tolerant environment is invaluable for skill development and confidence building. Also, repetition is a cornerstone of surgical proficiency, and VR simulators facilitate repetitive and deliberate practice. Trainees can perform procedures as often as necessary, honing their skills, developing muscle memory, and improving dexterity and speed [18, 19]. Objective performance assessment is another beneficial aspect. VR simulators generate data on accuracy, speed, precision, and technique. Educators can use this data to provide personalized feedback, identify areas for improvement, and track trainee progress. Customized

learning paths are a hallmark of VR simulators, making them ideal for adaptive training. Adaptive learning within VR simulators adjusts the difficulty of simulations based on trainee performance, promoting individualized growth. This dynamic adaptation keeps trainees optimally challenged. Furthermore, VR simulators can play a pivotal role in objective certification and credentialing processes, ensuring that surgeons meet predefined competency standards before practicing on real patients. Lastly, these simulators serve as innovative platforms for surgical research and experimentation. They offer a controlled environment for testing new techniques or instruments, and offer objective measurements of performance.

The transformative impact of VR simulators on surgical training extends to the wealth of data they provide, offering a unique opportunity to analyze the intricate interplay between surgical performance, cognition, and individual differences. Through this platform, we can possible research how trainees think, make decisions, and execute surgical tasks in a virtual setting, providing invaluable insights into the cognitive processes integral to surgical skill development. In essence, VR in surgical training not only enhances practical skills but emerges as a powerful tool for in-depth study, enabling a nuanced exploration of the complex relationship between surgical performance, cognitive abilities, and the distinctive attributes of aspiring surgeons.

INDIVIDUAL DIFFERENCES IN SURGICAL TRAINING

The journey to becoming a skilled surgeon is difficult, characterized by years of rigorous education, hands-on training, and the mastery of complex surgical techniques. The path to surgical excellence, however, is not a uniform one. It is profoundly influenced by the unique qualities and characteristics of individual surgeons. Surgeons are often described as decisive, organized, and hardworking individuals with a can-do and extravert attitude [20, 21], yet the relationship between personality traits and surgical performance remains a relatively unexplored area of research. Understanding how cognitive abilities, personality traits, and their interactions with feedback mechanisms shape the journey of aspirant surgeons is crucial in the quest for improved surgical training, enhanced patient outcomes, and the ongoing advancement of surgical practice.

Current training curricula mostly focus on a generic surgical trainee instead of focusing on individuals [22], ignoring the known factual differences between surgical trainees [23, 24]. These individual characteristics have proved to lead to differences in performance between surgical residents [25]. This is why it is not strange that when experienced surgeons are asked about important predictors of performance

for surgical trainees, most agree that individual characteristics are important, with the top three attributes being cognitive ability, dexterity, and personality [26]. However, which elements of these individual characteristics contribute to differences in surgical performance parameters and to what extent is not yet exactly known, as research into this topic has been limited.

In this thesis we investigate several instances of individual differences among surgical interns, surgical residents and surgeons, and their effect on laparoscopic performance and the acquisition of laparoscopic skills. Elements of personality, cognitive ability, and their interactions with different types of feedback will be investigated. The acquired knowledge can be used to create more personalized training which focuses on the strengths and weaknesses associated with these individual characteristics. Switching from a general training program to personalized adaptive training could further improve training efficiency and effectiveness of surgical residents and interns.

COGNITIVE ABILITY: VISUOSPATIAL ABILITY AND THE OPTICAL ANGLE

The relationship between cognition and surgical performance is an important aspect of surgical practice. As surgery is a complex task, surgeons rely on a diverse set of cognitive processes to excel in their profession. The cognitive abilities that support these processes are essential for various aspects of surgical practice, including decision-making, skill execution, problem-solving, and patient care [26, 27]. These cognitive processes allow surgeons to evaluate information, recognize patterns, and make informed judgments to optimize patient outcomes.

During medical school, students are primarily assessed for cognitive skills such as memory and analytical reasoning, with less emphasis on visuospatial ability. Visuospatial ability, the ability to mentally apprehend, rotate, and manipulate three-dimensional objects, is involved however in important surgical skills such as accurately visualizing anatomical structures, planning surgical approaches, and coordinating precise instrument movements [28]. When medical students specialize in a medical track that relies heavily on visuospatial skills, they are expected to perform relatively uniform in aspects of that track that rely on academic cognitive skills but more variable in aspects that rely on visuospatial ability.

In minimally invasive procedures, such as laparoscopy, strong visuospatial skills are especially essential [25, 29]. This is thought among others to be caused by the fulcrum

effect and deviated optical angles [30-32]. The optical angle is the angle between the path taken by the surgical instrument (line of action) and the direct line of sight from the surgeon to the target area (line of vision)(figure 1). It represents the deviation between the actual instrument path and the surgeon's direct line of sight, which becomes significant when interpreting the visual information on the monitor during laparoscopic procedures. The surgeon must mentally adjust for this deviated optical angle to maintain precision, especially in situations where indirect visualization is common. Surgeons with proficient visuospatial ability tend to perform procedures more efficiently, reduce surgical errors, and enhance patient safety, especially for minimally invasive procedures such as laparoscopy compared to peers with limited visuospatial ability [25, 29].

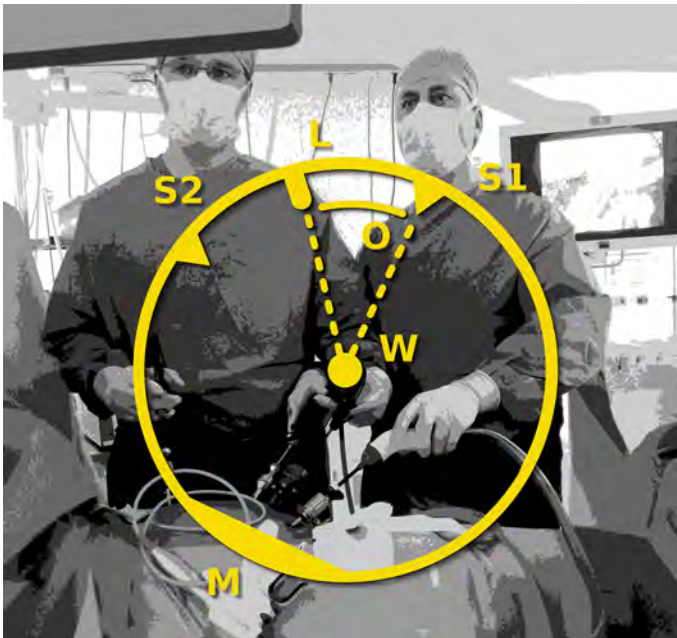


Figure 1. A side view of a laparoscopic procedure in the operating room with a corresponding schematic top-down view in yellow to show the variables relevant to the challenges of laparoscopic indirect vision and optical angle (the angle between the line of action and the line of vision). O = optical angle, S1 = operating surgeon 1, S2 = assisting surgeon 2, L = Laparoscope, W = operating area, M = monitor, L-W = line of scope, S1-W = line of sight.

A larger optical angle requires more ‘mental rotation’, which is performed faster and with less error by an individual of high visuospatial ability [33]. While previous research demonstrated longer task duration for deviated optical angles during the performance of simulated laparoscopic tasks [34-36], there have been no previous studies exploring the

combined effects of both visuospatial ability and optical angles on surgical performance. Hence, one of the objectives of this thesis is to examine the influence of visuospatial ability on surgical performance in conjunction with the impact of optical angles.

PERSONALITY: IMPULSIVENESS

While the concept of the surgical personality has attracted attention from researchers [20, 37-39], very few studies are dedicated to the relation between personality and surgical performance. A stereotype of the surgeon's personality still exists among the general public and medical professionals, describing a surgeon as decisive, well organized, hardworking, but also dominant, (overly) extraverted, and a poor listener [40-42]. However, this is mostly anecdotal, and it is essential to recognize that these stereotypes are generalizations and do not capture the diversity of personalities within the surgical profession. A previous study investigated the relation between surgical VR performance-parameters and personality, based on the results of the personality test NEO-Five Factor Inventory [43]. The NEO-FIVE Factor Inventory is a personality inventory that examines a person's Big Five personality traits (openness to experience, conscientiousness, extraversion, agreeableness, and neuroticism). The authors did not find any significant association. When testing personality among surgeons, one study discovered that surgeons scored significantly higher in Agreeableness, Conscientiousness, Neuroticism, and Openness than their non-surgical counterparts [44], while another study indicated that surgeons had higher Conscientiousness but lower Agreeableness scores compared to non-surgical MD's [45]. In general, surgeons score higher in Conscientiousness and Agreeableness and lower in Neuroticism when compared to the general population [46]. Furthermore, residents in surgery also display variations from the general population, exhibiting higher scores in Extraversion, Openness, and Conscientiousness [21]. In summary, surgeons and surgical residents tend to possess a unique personality profile, primarily characterized by elevated Conscientiousness relative to their counterparts in other medical specialties and the general population. However, the evidence regarding the presence of other personality traits that could define a distinctive surgical personality remains inconclusive.

It would therefore be insightful to see if differences in surgical personality affects training and care outcomes. A previous study demonstrated better patient outcomes for surgeons with low extraversion [46]. Related to the personality trait of extraversion is impulsiveness [47, 48], a personality trait which is well investigated in other areas and associated with negative outcomes. In driving, multiple studies have provided evidence for the link between impulsiveness and dangerous driving and

traffic accidents [49-52]. Impulsiveness is associated with negative choice behavior in drugs and alcohol [51, 53], it increases likelihood of vandalism and theft [51], and is negatively correlated to job performance [54]. In aviation, the Federal Aviation Administration has recognized five hazardous personality traits which contribute to errors, including impulsiveness [55]. Possibly, similar to these other areas, impulsiveness also contributes to errors in surgery. However, we did not find any studies which investigated this relation. In this thesis we aim to explore the relation between impulsiveness and error making within the context of surgical practice.

THE USE OF FEEDBACK IN TRAINING

The use of feedback in surgical training is integral to the development of surgical skills and the improvement of surgical performance. Feedback mechanisms provide learners with information about their performance, helping them identify strengths, weaknesses, and areas for improvement. Various types of feedback are known. In the context of a master-apprentice relationship, a traditional form of feedback involves an experienced surgeon providing guidance and support to the apprentice. This mentorship approach fosters skill development, with the level of guidance gradually decreasing as learners become more proficient. As proficiency grows, learners gain increased responsibility and independence in performing surgical tasks [56-58]. Over the years proficiency based training became more and more popular, among others with the advent of virtual reality trainers, which allows for unbiased and quantitative feedback. With proficiency based training a student needs to train until a predefined level of skills is reached [6]. This approach is effective because it allows for individualized learning, accelerates learning curves, ensures consistent skill development, and leads to improved operating performance [6]. Performance of the trainee can be compared to either peer standards or to expert standards. Setting training goals aligned with expert standards accelerates the learning process, tailoring the educational experience to the learner's specific needs [59, 60]. This approach has proven effective in cultivating consistent skills and enhancing overall operating performance [61, 62]. Despite its efficacy, there is no universally accepted method for establishing training standards, leading to ongoing challenges related to validity and reliability [63-65]. Moreover, the process of generating standards based on expert performance is time-consuming and labor-intensive, posing difficulties in aligning with the busy schedules of surgeons [66]. In contrast, peer standards aim to motivate novices to achieve or surpass the performance levels of their peers [67]. Von Websky et al. demonstrated the superiority of peer standards with external assessment over self-controlled training [68]. Notably, peer standards are

not only effective but also more easily generated, as simulator performance data from students are readily collectible throughout their training. While proficiency-based training aligned with expert standards has demonstrated efficacy in feedback, there is a notable gap in research concerning the validity and reliability of peer standards.

Feedback can also be used in adaptive training, which as mentioned before, has proved to be an effective training method which takes into account individual differences. A form of feedback suitable for implementing adaptive training could be targeted feedback. Targeted feedback, also known as focused or specific feedback, is feedback that is directed toward specific aspects of a learner's performance. Instead of providing broad or general feedback, it focuses on particular strengths or weaknesses. In surgical training, targeted feedback can be delivered through various means, such as direct observation, video review, or simulator assessments. The integration of adaptive training and targeted feedback could possibly improve training efficiency. Adaptive training systems can provide targeted feedback in real time, addressing specific skill deficiencies as they are identified during the training process. It has been proven effective in a variety of domains [15, 16, 69-71], including virtual reality-based training [13].

The interaction between feedback and personality is an intriguing aspect of surgical training. Each trainee comes with their own unique personality traits, which can significantly influence how they perceive and respond to feedback. For instance, individuals with a high level of openness to experience may be more receptive to feedback that encourages them to explore new techniques and alternative approaches. They might see feedback as an opportunity for creative problem-solving and be more willing to experiment with different strategies to enhance their surgical skills. Therefore, to create a form of adaptive training with the use of feedback, it is essential to understand the interplay between the personality traits of a trainee and the type of feedback they receive.

The overarching aim of this thesis is to work towards a comprehensive understanding of individual differences and their impact on surgical skills acquisition and surgical performance, with the potential to inform and improve surgical training methods and feedback systems.

THESIS OUTLINE

In **Chapter 2** we assess the relation between visual-spatial ability and (simulated) surgical performance under different optical angles. Knowing that higher

visuospatial ability is associated with better surgical performance and that surgical performance decreases under non-zero optical angles, the next step is to investigate the interaction between these variables on performance in a laparoscopic task.

In **Chapter 3** we investigate the trainability of working under deviated optical angles. Knowing that performance under a non-zero optical angle may be impaired questions are: Is it possible to train the skills needed to operate under such non-zero optical angles, or is it better to avoid these deviated optical angles and aim for a 0° optical angle?

In the following two chapters we take a closer look at the relation between impulsiveness and surgical performance. In **Chapter 4** we investigate if, similar to other areas, a (negative) relation exists between impulsiveness and surgical performance. To this end we compare performance on a laparoscopic simulator between low and high impulsive subjects.

In **Chapter 5** we again investigate the relation between impulsiveness and surgical performance, however in this study participants with different experience levels are included to examine how professional experience affects the relation between impulsiveness and surgical performance.

As we are interested in how we can use feedback to establish adaptive training, we aim to determine how trainees respond to feedback. This is described in **Chapter 6**, where we compare different types of feedback. Participants in a laparoscopic basic skills simulator training course receive one of three forms of feedback: feedback comparing their results to peer standards, expert standards, or no standards. We compare the improvement in performance among these feedback groups in relation to impulsiveness.

Chapter 7 explores the potential use of targeted feedback to modulate performance, which could be integrated into an adaptive training framework. We provide targeted feedback on either speed or damage/errors in a laparoscopic training course to examine whether this form of performance feedback can guide learners to emphasize specific aspects of their performance.

Chapter 8 contains a comprehensive discussion of our results and offers insights into further research and new skills training possibilities.

In **Chapter 9**, we provide a Dutch summary of the thesis.

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CHAPTER 2

Optical angle and visuospatial ability affect basic laparoscopic simulator task performance

Bas Kengen, Willem Verwey, Harry van Goor, Jan-Maarten Luursema

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ABSTRACT

Background

Surgical trainees show decreased performance during laparoscopic surgery when the laparoscope (camera) is not aligned with their line of sight towards the operating area. In this study we investigate the influence of visuospatial ability on laparoscopic simulator performance under such non-zero optical angles.

Methods

Novices were invited to participate in a laparoscopic training session. After completing a visuospatial ability assessment, they performed a simplified laparoscopic task on an in-house developed laparoscopic simulator under eight different optical angles ranging between 0° and 315° in steps of 45°.

Results

Data-analysis showed decreased performance under all non-zero optical angles for task duration (mean difference between 1506-5049 ms, standard error between 499-507, $p < .05$) and for accuracy under optical angles greater than $\pm 45^\circ$ (mean difference between 1.48-2.11, standard error 0.32, $p < .01$). Performance-zones were identified for various optical angle ranges and differed for task duration and accuracy. Participants of high visuospatial ability performed significantly better under non-zero angles for accuracy compared to participants of low visuospatial ability (mean difference 0.95, standard error .34, $p < .01$), except for the 180° optical angle (no difference).

Conclusion

Performance on a simplified laparoscopic task degrades with increasing optical angle, with the exception of the 180° optical angle. Optical angles can be grouped in performance zones, which differ for task duration and accuracy. High visuospatial ability was linked to better performance for accuracy under all optical angles other than the 0° and 180° optical angle. Visuospatial ability did not impact task duration.

INTRODUCTION

To perform laparoscopic procedures, surgeons have to learn to operate under indirect vision, as the *laparoscope* (a thin, rigid, cylindrical instrument that contains a camera) is inserted through a small incision in the abdomen of the patient and the surgeon receives visual feedback on their actions through a monitor. In this setting, *line of sight* refers to the horizontal projection of the line connecting the surgeon to the operating area. Whenever possible, the monitor is placed in an extension of this line of sight. *Line of scope* refers to the horizontal projection of the line connecting the laparoscope to the operating field when the laparoscope has the operating area in view. The spatial challenge of working under indirect vision increases when the line of sight differs from the line of scope, i.e. when these two lines form a non-zero angle, the *optical angle* (figure 1). Previous research in laparoscopic training and the operating room showed decreasing performance and reaction time (measured in terms of task duration and error rates) and an increase in mental work load under increasing optical angles [1-5]. The maximum optical angle of 180° however is a special case, with some previous studies in laparoscopic performance reporting the worst performance under an 180° optical angle [1-3], and another showing better performance under an 180° optical angle compared to optical angles of ± 90 - 135° [6]. Surgical educators and cognitive psychologists alike are interested in the mitigating role of cognitive abilities in training and performance of spatially challenging psychomotor tasks. In this study we investigate how visuospatial ability modulates performance in laparoscopic training under different optical angles.

Because the capacity to mentally rotate improves with increasing visuospatial ability [7], visuospatial ability likely influences surgical performance under non-zero optical angles. Visuospatial ability refers to the ability to mentally apprehend, encode, rotate, and manipulate three-dimensional objects [8]. Visuospatial ability is important in predicting success in various psychomotor skills such as piloting aircrafts, mechanical drawing [9, 10], and academically in mathematics and science [11]. High visuospatial ability also correlates with better performance in minimally invasive surgery, as an earlier meta-analysis demonstrated improved laparoscopic performance for novices and more experienced surgeons with higher spatial ability (optical angle however was not taken into account as a separate variable) [12]. Also, visuospatial ability predicted surgical skill acquisition rate and can probably be used as criterion for assessing candidates for surgical training [13].

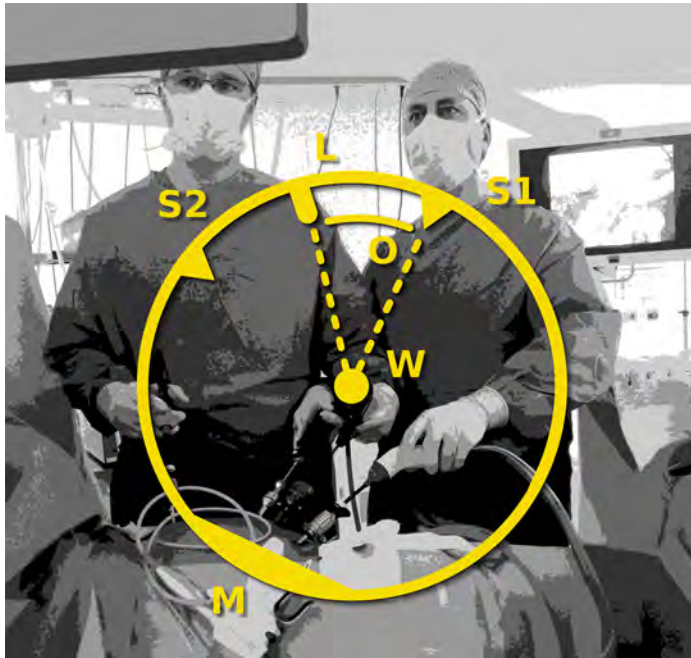


Figure 1. A side view of a laparoscopic procedure in the operating room with a corresponding schematic top-down view in yellow to show the variables relevant to the challenges of laparoscopic indirect vision and optical angle (the angle between the line of scope and the line of sight). O = optical angle, S1 = operating surgeon 1, S2 = assisting surgeon 2, L = Laparoscope, W = operating area, M = monitor, L-W = line of scope, S1-W = line of sight.

Because the capacity to mentally rotate improves with increasing visuospatial ability [7], visuospatial ability likely influences surgical performance under non-zero optical angles. Visuospatial ability refers to the ability to mentally apprehend, encode, rotate, and manipulate three-dimensional objects [8]. Visuospatial ability is important in predicting success in various psychomotor skills such as piloting aircrafts, mechanical drawing [9, 10], and academically in mathematics and science [11]. High visuospatial ability also correlates with better performance in minimally invasive surgery, as an earlier meta-analysis demonstrated improved laparoscopic performance for novices and more experienced surgeons with higher spatial ability (optical angle however was not taken into account as a separate variable) [12]. Also, visuospatial ability predicted surgical skill acquisition rate and can probably be used as criterion for assessing candidates for surgical training [13].

Earlier studies either investigated the effect of non-zero optical angles on surgical performance, or how visuospatial ability modulated surgical performance under a zero degrees optical angle. As far as we know, we are the first to report a study investigating

the effect of both these variables on performance in a laparoscopic task. For practical reasons of training course design and instrument placement in the operating room, we wanted to know whether different optical angles with similar performance levels can be grouped into *zones of performance* for speed or accuracy. Speed and accuracy are associated with different training goals, accuracy being the more relevant proxy measure for clinical safety. Based on previous research we hypothesized that an increasing optical angle would result in a decrease in performance until an optical angle of 180° , after which it would similarly improve until 360° . As discussed above, performance at the 180° optical angle itself may be better than performance at the angles immediately before or after it, which would represent an exception to this pattern. A larger optical angle requires more mental rotation, which is performed faster and with less error by people of high visuospatial ability [7]. Therefore, we expected that this association between optical angle and performance would be affected by level of visuospatial ability, where performance for participants with low visuospatial ability would deteriorate more when switching from the 0° optical angle to the non-zero optical angles compared to participants with high visuospatial ability. If these hypotheses would be correct the results of this study would be a step towards individualized training programs that focus on training with non-zero optical angles in participants with reduced visuospatial ability, and visuospatial ability could be used as a selection criterion for admission to residency programs. Additionally, the results of this study could help indicate which non-zero optical angles should be avoided.

MATERIALS AND METHODS

Subjects

This study was performed at the University of Twente, The Netherlands. Participants were students of the bachelor's program in Psychology. This group was selected to represent a demographic similar to medical students but without medical or laparoscopic experience, to maximize the effect of individual differences in visuospatial ability and minimize the effects of relevant experience. Students could sign up for this study via a digital environment developed for participant recruitment [14]. Participation as a subject in research studies is mandatory for students of Psychology at the University of Twente, who earn study credits for their time. The study protocol was not submitted to an ethical board, as this was not required for this type of research under Dutch law at the time of data collection [15]. Based on a meta-analysis of Kramp et al (2016), who found a medium to strong correlation between surgical performance in the operating room and visuospatial ability ($r = 0.50$) [12], we expected an effect size between 0.5 and 0.8. To detect the lower limit of this expected

effect size (0.5) power calculations with use of G*Power [16] revealed that a total of 28 participants were needed to achieve a power of 0.8 with an α error probability of 0.05.

Apparatus

An in-house designed simulator box was built with a round, rotatable camera lid (figure 2A-B). The round lid of this box was 270 mm in diameter, the dimensions of the box were 390x390x190 mm. The camera was a mini CMOS CCTV security camera with a 640x480 pixel resolution, wired with an RCA connector to a standard 22 inch LCD monitor. We opted for analog connectivity to avoid the latency of USB cameras. The camera was mounted on the edge of the underside of the lid and pointed to the center of the floor of the box, which was the location where the tasks had to be completed. This configuration allowed us to keep the experimental task in focus, while systematically varying the optical angle. The camera image was presented at a monitor in front of the participant and over the working area, a configuration that is typical for laparoscopic surgery. The tasks were performed with a modified laparoscopic single-use Maryland grasper from Johnson and Johnson, in which the grasping end was replaced by a capacitive touch pen for operating the touch sensitive screen of a tablet (figure 2C). OpenSesame 3.0.7 was used to program the tasks on the Samsung Galaxy Note 10.1 GT-N8000 touchscreen tablet running Android 4.1.2. To test visuospatial ability, participants completed the Mental Rotations Test [17] and the Surface Development Test [18], two standard tests to assess visuospatial ability most commonly used in medical learning and training studies. These tests were digitized with the use of OpenSesame 3.0.7 and performed on a desktop PC running Windows 7. Data was analyzed by using SPSS Statistics for Windows, Version 25.0 (IBM SPSS Statistics for Windows, Version 25.0. Armonk, NY: IBM Corp).

Task and procedure

The participants performed the same series of tasks in the simulator box under eight different optical angles. Participants used a laparoscopic stylus to tap targets on a tablet which was located on the bottom of the simulator box. To initiate a task, participants were instructed to tap and hold a red fixation target on the middle of the screen (figure 2D1), to standardize the starting point of the stylus and its distance to the targets. After the fixation target disappeared, two differently colored (red and blue), circular target areas appeared in opposition of each other (figure 2D2). This marked the start of the actual task, in which participants had to first tap the red target and then the blue target. The circular targets were of a standardized size, with a diameter of 17 mm. These targets were positioned at opposite ends of the tablet screen, ensuring a consistent distance of 80 mm between the centers of the two targets. For programming reasons, the target areas sensitive to clicking

had to be square (17×17 mm) and were consequently slightly larger than the visible targets. When the target area was touched by the stylus it counted as a hit, but if the touchscreen was touched anywhere else than the target it counted as a miss. An audio signal informed the participant whether their attempt was successful or not. After this, the next task would start with a differently located pair of opposite dots (the location of the eight opposite pairs is indicated in figure 2D3). The order of appearance of a total of eight of such pairs of targets was randomized for each of the eight optical angles of the experiment.

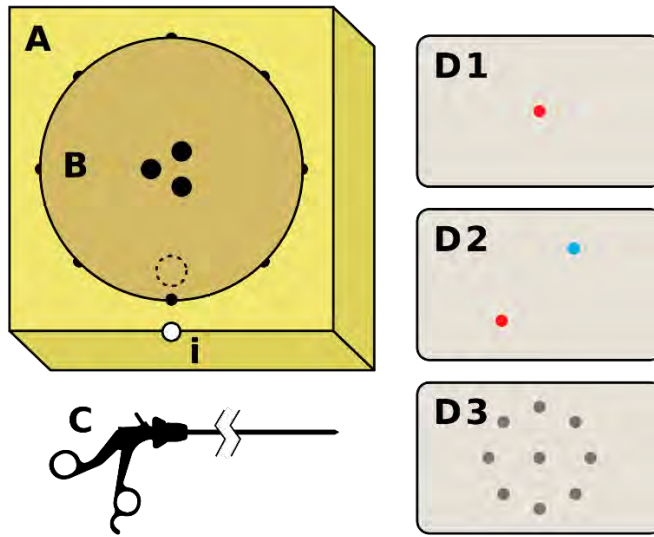


Figure 2. Schematic representation of the experimental task setup. Tasks were performed in a simulator box (A) with a camera (dotted circle) attached to the underside of a rotatable lid (B). The camera was aimed at the center of the floor of the box where a tablet was located. By rotation of the lid the angle of this camera towards the tablet could be altered. Participants inserted a customized laparoscopic instrument that was altered to end in a capacitive stylus instead of a grasper (C) through a laparoscopic port, i.e. a small opening on the front of the box (i) with which they could operate the tablet. To initiate a task, the participant had to tap a red fixation target on a tablet which was located inside the simulator box (D1). This was followed by the actual task of hitting the two differently colored target areas positioned in opposition from each other (D2). For each camera position, eight pairs of targets needed to be tapped as shown in D3.

After a trial run under the 0° optical angle to allow students to familiarize themselves with the apparatus and the procedure, the above-mentioned laparoscopic series of tasks was performed under 8 different optical angles (of 0°, 45°, 90°, 135°, 180°, -135°, -90°, and -45°). Under these different optical angles participants would see and do the same tasks, however seen from a different angle. Therefore, the representation of movements from the participant on the screen deviates increasingly from what

the participant expects to see. Participants were instructed to adjust the camera to the requested angle by lifting, rotating, and repositioning the lid of the simulator box, which would reposition the camera fixed to the underside of this lid. A visual aid was incorporated on the box and the lid to guide the positioning (participants could match small half circles on the box with a small half circle on the lid to form a full circle). The order of the blocks and of the trials within the blocks were randomized in order to compensate for learning effects. Participants were asked to perform to the best of their ability on both accuracy and duration, but to prioritize accuracy.

These tasks were performed during a single 60-minute session. Every participant was individually supervised during this entire session. At the start of the session but before performing the tasks, the participant was informed about the study and was given the opportunity to ask questions, after which an informed consent form was signed. After this, participants completed digitized versions of the Mental Rotations Test [17] and the Surface Development Test [18], two standard tests to assess visuospatial ability most commonly used in medical learning and training studies.

Data preparation

The number of targets hit (accuracy) and the time needed to tap all 8 pairs of targets (duration) were automatically recorded for every individual optical angle by the Open Sesame script running on the tablet. We did not expect differences between the left or right optical angles, i.e. between -45° and 45° , -90° and 90° or -135° and 135° . To confirm this, we performed TOST procedures to assess the differences between the left and right optical angles, with a predefined smallest absolute difference of interest set at 1 second for duration and 1 point in score for accuracy. The choice of a smallest absolute difference of interest in the TOST procedures was informed by a small pilot study conducted prior to the main experiment. One point for accuracy and 1 second for duration emerged as meaningful and detectable units in our study's context. The TOST procedure demonstrated equivalence for both accuracy and duration. To improve statistical reliability, these optical angles were therefore clustered into a single outcome measure for 45° , 90° , and 135° by averaging the scores of the left and right optical angles, which was done separately for accuracy and duration. To investigate the influence of visuospatial ability on performance without taking into account the effect of the optical angle, we calculated grand totals for accuracy and duration by adding the averaged values for all eight optical angles, separately for accuracy and duration.

To evaluate the effect of visuospatial ability on task performance, a visuospatial ability score was calculated for each participant. The number of correct answers

for both visuospatial tests were first scored for each participant. Both the Mental Rotation Test and the Surface Development Test measure the same visuospatial ability factor (i.e., *Visualization*, 'The ability to apprehend a spatial form, object, or scene and match it with another spatial object, form, or scene with the requirement to rotate it (one or more times) in two or three dimensions.' [19]). Both tests have good reliability scores of respectively .83 and .90 [17, 18]. The results of both tests were normalized and averaged to improve robustness.

A 'decrease in performance' variable between the 0° optical angle and the optical angle with the worst performance (assessed per individual participant) was calculated post-hoc after analyzing performance to assess if performance of participants with low visuospatial ability decreased more with a non-zero angle compared to participants with high visuospatial ability.

Statistical analysis

Shapiro-Wilk tests were used to determine if data followed a normal distribution. For most variables this was not the case and non-parametric tests were used to analyze the data.

The statistical analysis employed a linear mixed-effects model, with optical angle and visuospatial ability as fixed effects, and participants included as random effects. Given the discrete and predetermined nature of the optical angles tested (i.e., 0°, 45°, 90°, 135°, 180°, -135°, -90°, and -45°), we opted to treat optical angle and visuospatial ability as fixed effects to explore their direct influence on laparoscopic performance. Including participants as random effects was deemed essential to account for individual variability and enhance the robustness of our findings.

Hence, the model employed in our analysis was as follows:

$$\text{Performance}_{ij} = \beta_0 + \beta_1 \times \text{Optical Angle}_{ij} + \beta_2 \times \text{Visuospatial Ability}_i + \gamma_{oi} + \epsilon_{ij}$$

Where:

Performance_{ij} = Performance (duration or score) of subject i at optical angle j .

$\text{Optical Angle}_{ij}$ = The optical angle during a specific measurement or observation for individual i .

$\text{Visuospatial Ability}_i$ = Visuospatial ability of individual i .

Coefficients β_0 , β_1 and β_2 = Coefficients representing the intercept, the effect of optical angle, and the effect of visuospatial ability, respectively (fixed effects).

Coefficient γ_{oi} = Random intercept for individual i (random effect).

Coefficient ϵ_{ij} = Residual error term.

We compared the main effects of optical angle and visuospatial ability, with Bonferroni corrections for multiplicity. Additionally, when no difference was found in performance under two specific optical angles, TOST procedures were performed to test for equivalence, with a predefined smallest absolute difference of interest of 1 second for duration and 1 point for accuracy.

Mann Whitney U tests were used to compare high and low visuospatial ability groups for the decrease in performance variable between the 0° angle and the non-zero optical angles. For all tests a *p* value equal to- or below .05 was considered significant.

RESULTS

Participants

A total of 37 students participated in the experimental session. However, due to software problems data from only 33 participants were analyzed. Of the participants analyzed, 20 participants were male and 13 participants were female. Age ranged from 19 to 33 years. Mean age was 22.9 years with a standard deviation of 3.2 years. One participant was left-handed. None of the participants reported previous experience with laparoscopy or uncorrected substandard visual acuity. The participants were post-hoc divided in a low visuospatial ability group (n=17) and a high visuospatial ability group (n=16) by a mean split (table 1).

Table 1. Characteristics of all participants and of the two groups of low- and high visuospatial ability

	Total	Low visuospatial ability	High visuospatial ability
Participants	33	17	16
Mean age	22.9	23.1	22.6
Female/Male	13/20	8/9	4/12

Duration

TOST procedures confirmed equivalence for task duration (mean differences of -1.33s and 0.67s, *p* < .01) between opposite right and left optical angles. To improve statistical reliability, these optical angles were therefore clustered into a single outcome measure for 45°, 90°, and 135° by averaging the scores of the left and right optical angles. Participants performed significantly faster under the 0° optical angle task compared to all non-zero optical angles (mean difference between 1506-5049 ms, standard error between 499-507, *p* < .05)(Figure 5A). Performance under the 45° optical angle was significantly faster compared to the optical angles of 90°, 135° and 180° (mean difference between 1581-3543 ms,

standard error between 495-496, $p < .05$). Task duration under an 180° optical angle was significantly shorter than duration under 90° and 135° (mean difference between 1759-1962 ms, standard error between 499-503, $p < .01$). Task duration under optical angles of 90° and 135° did not differ significantly from each other. TOST procedures did not demonstrate equivalence between 90° and 135° (mean duration 90° = 8128 ms, mean duration 135° = 7925 ms, maximum $p = .15$ with $t = -1.48$). Therefore, it was not possible to cluster performance of different optical angles in performance zones for duration.

Task accuracy

TOST procedures confirmed equivalence for accuracy scores (mean differences of 0.69 and -1.31, $p < .05$) between opposite right and left optical angles. To improve statistical reliability, these optical angles were therefore clustered into a single outcome measure for 45°, 90°, and 135° by averaging the scores of the left and right optical angles. The results demonstrated that a 0° optical angle did not differ significantly for accuracy compared to the 45° optical angle, but showed significantly higher accuracy compared to the 90°, 135° and 180° optical angles (figure 5B) (mean difference between 1.48-2.11, standard error 0.32, $p < 0.01$). There were no significant differences in accuracy between the optical angles of 90°, 135° and 180°. TOST procedures demonstrated equivalence between 0°-45° (mean differences of -.88 and 1.12, $p < .01$), 90°-135° (mean differences of -.56 and 1.44, $p < .01$) and 90°-180° (mean differences of -1.21 and 0.79, $p < .01$). No equivalence could be demonstrated between the 135° optical angle and 180° (mean score 135° = 4.86, mean score 180° = 5.49, maximum $p = .21$ with $t = 1.30$). Based on these results optical angles were clustered in three performance-zones (figure 6).

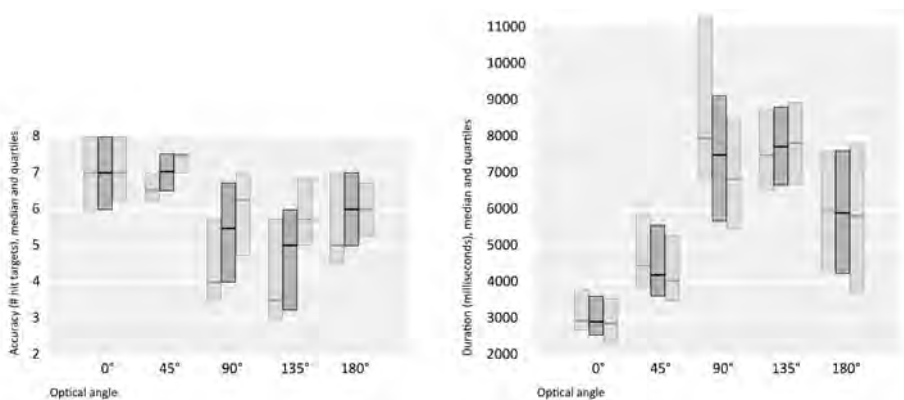


Figure 5. Task performance under systematically varied optical angles. In each cluster of boxes, left boxes represents performance of the group of the low visuospatial ability, and right boxes the group of high visuospatial ability. Middle boxes represent performance of both groups combined. (left) Accuracy under varying optical angles. (right) Task duration under systematically varied optical angles.

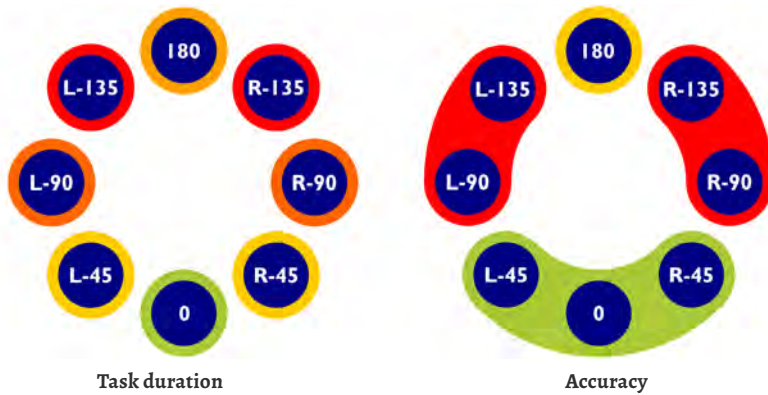


Figure 6. Performance-zones were defined for accuracy but not duration, based on performance under different optical angles. Performance degrades under increasing optical angles, with the exception of the 180° angle, which sits between the 90°-135° and 45° clusters in terms of performance for both duration and accuracy.

Influence of visuospatial ability

Performance in duration and accuracy for both groups of low and high visuospatial ability under each optical angle is visualized in figure 5. There was no significant difference between the low and high visuospatial ability group for total task duration across the trials (mean difference -236 ms, standard error 847, $p = .78$). For the individual optical angles also no differences in duration were found between the low and high visuospatial ability group (table 2).

When comparing total session accuracy score between the two groups, the results demonstrated a significant difference, where accuracy was higher for the group of high visuospatial ability (mean difference 0.95, standard error .34, $p < .01$). When comparing accuracy between the groups for every optical angle individually, the results did not demonstrate a significant difference between the two groups under the 0° and 180° optical angle (table 2). Under all the other optical angles (45°, 90° and 135°) there was a significant difference in accuracy between the two groups, with the high visuospatial group outperforming the low visuospatial group.

To investigate if visuospatial ability modulates the effect of optical angle, we compared difference in accuracy (delta accuracy) and difference in duration (delta duration) between the 0° optical angle and the optical angle with the worst performance for the high- and low visuospatial ability groups. We found no differences in delta duration ($z = -.216$, $p = .829$). For delta accuracy however we did find such an effect, performance breakdown appeared significantly higher for the low visuospatial ability group ($z = -2.36$, $p = .02$).

Table 2. Linear mixed models for duration and accuracy between the groups of low visuospatial and high visuospatial ability for every optical angle individually. * = significant at or below the .01 level.

Duration	0°	45°	90°	135°	180°
Estimate effect	131.93	484.53	1624.88	-485.78	-236.04
Standard error	308.89	394.62	999.59	733.54	846.68
t value	0.427	1.23	1.63	-0.66	-0.28
p value	0.67	0.23	0.12	0.51	0.78
Accuracy	0°	45°	90°	135°	180°
Estimate effect	-0.06	-0.96	-1.41	-1.90	-0.39
Standard error	0.34	0.30	0.53	0.50	0.56
t value	-0.18	-3.20	-2.64	-3.80	-0.70
p value	0.86	<.01*	0.01*	<.01*	0.48

DISCUSSION

Participants showed increased performance degradation for both duration and accuracy when the optical angle deviated further from zero, with the exception of the 180° optical angle (where performance was between those of the 45° and 90° angle). Optical angles that did not differ significantly from each other and were statistically equivalent were clustered in performance zones, which could only be done for accuracy, as performance in duration was not equivalent between any optical angle. Low visuospatial ability increased the negative effect of optical angle on accuracy, except for the 0° and 180° optical angles.

Some previous studies described an increase in task duration with increasing optical angle [1-3]. Rhee et al. reported a linear trend between task duration and an increase in optical angle, however all three studies omitted a direct comparison between the 180° angle to other optical angles. Klein and colleagues did study performance under a wider range of optical angles, and our results confirmed their results [6]. They found that the 180° optical angle was an exception to the linear trend between an increasing optical angle and increasing task duration. An explanation for this finding could be that under a camera alignment of 180° the fulcrum effect is no longer present [20]. Inverted image condition under an 180° optical angle therefore may facilitate learning among novices due to a natural and expected representation of movement [21]. Previous research in psychomotor tasks performance under different visual perspectives without a fulcrum effect however also demonstrated better performance

under an 180° optical angle compared to a 90° and 135° optical angle [22, 23]. This is in line with the idea that different strategies can be adopted for spatial problems [24, 25]. Two strategies suggested (Schultz, 1991) consist of mental rotation of either the working field or subject movement (mental self-movement) [24]. The third strategy he suggested is an analytic strategy which does not require mental rotation, but uses key features of a spatial problem. An analytic strategy previously suggested is that a reversed direction of movement is used under an 180° optical angle compared to a 0° optical angle (mirroring) [22], thus mental rotation is no longer needed. This interpretation is supported by the finding that performance under 180° is not affected by visuospatial ability. The performance zones we identified are also in line with the idea of strategy selection, as earlier results (Kozhevnikov and Hegarty, 2001) suggested an object rotation strategy (mentally rotating an object) between the 45-70° optical angles but a perspective taking strategy (imagining your body in a different position relative to the object) for 90-150° optical angles [25]. In their study, perspective taking but not object rotation was associated with visuospatial ability. It would be interesting to research whether our low-angle performances zones correspond with an object rotation strategy and our high-angle performance zones with a perspective taking strategy. Training specific visuospatial problem-solving strategies may support the acquisition of a wide range of visuospatial challenging skills.

A previous meta-analysis by Kramp et al. showed an overall significant correlation between laparoscopic skills and VSA [12]. Cochrane Q tests showed substantial heterogeneity in the results of the used studies in this meta-analysis, as not all studies demonstrated a significant correlation between visuospatial ability and laparoscopic performance. In this meta-analysis optical angle was not taken into account as a separate variable. The studies included in this meta-analysis used varying methodology to assess the impact of camera angle, and camera angles differed between studies. The heterogeneity of these earlier studies as to the impact of visuospatial ability on laparoscopic performance could be explained by our finding that this impact depends on optical angle.

In this study, students were instructed to prioritize accuracy over duration as this corresponds to actual surgery. In surgery, like in other fields, there is a trade-off between duration and accuracy [26] and this could explain the differences between the performance zones for task duration and accuracy. We found significant better performance on accuracy for participants with high visuospatial ability, however equal performance on task duration. This might imply that accuracy is more affected by visuospatial ability. As task duration has often been used as the main performance

result in studies on surgical performance development, this could mean that the impact of visuospatial ability on surgical performance is underestimated.

Limitations

The results of this research are based on simulated laparoscopy with strongly simplified exercises. Actual surgery differs in many ways, including task complexity, complexity of the environment, and professional experience of the practitioner. To be relevant to laparoscopic surgery, more work is needed to confirm our findings in environments of greater ecological validity, such as the surgical skills lab and the operating room.

Further limiting the ecological validity of our study is the choice for non-medical students as participants. This was done to utilize a similar demographic as medical students, but without confounding variables such as differences in laparoscopic experience.

The performance zones as defined in this study will need additional verification, as factors such as ecological validity and power of the study may greatly impact the specifics of such zones. However, the support of different visuospatial task execution strategies corresponding to our performance zones [25] suggests this is a valuable path to explore.

Impact

Current training programs are often focused on training laparoscopic skills under a 0° optical angle. Implementing non-zero optical angle training could move part of the learning back from the operating room to the skills lab. The modulation of performance under non-zero and non-180° optical angles by visuospatial ability can inform adaptive training design, for example by more extensive training for these angles for trainees of low visuospatial ability. Another option to stop the negative effects of non-zero optical angles is to prevent the use of such angles. This could possibly be achieved by adapting the procedure design or investing more time pre-procedural to create a laparoscopic port for a 0° optical angle.

The concept of different performance zones as demonstrated in this study can be used as an aid for future studies about laparoscopic skills development and the optical angle. Performance zones could be used to optimize *trocar*- and team placement. The *trocar* is the port of entry for the laparoscopic instruments and camera, placed through the skin of the patient's abdomen. During a laparoscopic procedure the introduction of an extra *trocar* is sometimes considered to obtain a better view of the operating field.

The concept of performance zones can help guide extra trocar placement in terms of a trade-off between visibility of the surgical anatomy and performance penalty.

Future Research

For practical purposes, the results of this study need to be extended to the medical domain, for instance in similar studies with medical students/surgeons located in the skills lab or the operating room. For example, are similar performance zones present in such setting? It is also important to learn more about the learning curves for different optical angles and their interaction with visuospatial ability. Is there a lasting performance penalty for difficult optical angles and people of low visuospatial ability? What kind of training effort is needed to perform comfortably under which optical angle? Answering these questions will help us implement adaptive training in which course design and duration depends on individual abilities, competencies and experience [27-29]. Other questions to be answered in future research have to do with transfer of skills, e.g. to which degree does training a task under a specific optical angle transfer to performance under adjacent angles? Does training one skill under a specific optical angle provide an advantage for learning the next skill under that angle? It would also be useful to learn more about the possible strategies which are used to cope with different optical angles and how these strategies can be used to increase training efficiency. For example, are some strategies more effective or efficient than others? Is it useful to guide learners of different visuospatial ability towards different visuospatial problem solving strategies?

Conclusions

Performance on a simplified laparoscopic task degrades with increasing optical angle, with the exception of the 180° optical angle. Optical angles can be grouped in performance zones, which differ for task duration and accuracy. High visuospatial ability was linked to better performance for accuracy under all optical angles other than the 0° and 180° optical angle. Visuospatial ability did not impact task duration.

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CHAPTER 3

Laparoscopic simulator performance and learning curves under different optical angles

Bas Kengen, Harry van Goor, Jan-Maarten Luursema.

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ABSTRACT

Background

Deviated optical angles create visuospatial and psychomotor challenges during laparoscopic procedures, resulting in delayed operative time and possibly adverse events. If it is possible to train the skills needed to work under these deviated optical angles, this could benefit procedure time and patient safety. This study investigates the influence of the optical angle on development of basic laparoscopic surgical skills.

Methods

A total of 58 medical students performed a four-session laparoscopic training course on a Virtual Reality Simulator. During each session, they performed an identical task under optical angles of 0°, 45° and -45°. Performance parameters of task duration and damage were compared between the optical angles to investigate the effect of optical angle on performance development. The 4th session performance was compared to the 2nd session performance for each angle to determine improvement.

Results

Participants performed the task significantly faster under the 0° optical angle compared to the plus and minus 45° optical angles during the last three sessions (z between -2.95 and -2.09, $p < .05$). Participants improved significantly and similarly for task duration during the training course under all optical angles. At the end of the training course however significant performance differences between the zero and plus/minus 45 optical angles remained. Performance for damage did not improve and was not affected by optical angle throughout the course.

Conclusion

Dedicated virtual reality training improves laparoscopic basic skills performance under deviated optical angles as it leads to shorter task duration, however a lasting performance impairment compared to the 0° optical angle remained. Training for performing under deviating optical angles can potentially shorten the learning curve in the operating room.

INTRODUCTION

Laparoscopic surgery is relatively hard to learn, which is demonstrated by studies that show longer learning curves for laparoscopic procedures compared to open surgery [1, 2]. Visuospatial and psychomotor challenges inherent in working with indirect vision and over a fulcrum are important contributors to this extended learning curve [3-5], especially when working under deviated optical angles [6-8]. This latter challenge has not been structurally addressed in laparoscopic simulator training courses.

The optical angle is defined as the angle between the line of action (the horizontal projection of the line connecting the trocar for the laparoscope to the anatomical target) and the line of vision (the horizontal projection of the line connecting the central axis of the surgeon with the anatomical target) (Figure 1) [9]. For reasons of anatomy, pathology, team placement, and procedural techniques such as switching the camera to a different trocar, it is not always possible to maintain the optimal optical angle of 0°. To reduce the risks and effort of placing an extra trocar, a deviated angle is sometimes deemed acceptable. Previous research demonstrated longer task duration for deviated optical angles during the performance of simulated laparoscopic tasks [9-11]. In these studies, with both novices and experts, all participants showed a decrease in performance under deviated optical angles. However, experienced participants showed better adaption to deviated optical angles, as their performance was both relatively and absolutely less affected by a deviated optical angle compared to novice participants. To our knowledge no previous studies have investigated the learning curves for (simulated) laparoscopic performance under deviated optical angles.

During actual laparoscopic surgery, performance on both time and damage for inexperienced surgeons is likely to be impacted more negatively by non-zero optical angles compared to more experienced surgeons. Yet, many current simulation curricula do not include training skills under non-zero optical angles. This is reflected in the design of videobox trainers and virtual reality simulators, most of which do not have features to facilitate such training. The question arises how we could better prepare laparoscopic novices for their first encounter with deviated optical angles in the operating room, i.e. could this be realized with simulation training and how would these laparoscopic skills develop. With effective simulation training the learning curve for non-zero laparoscopic optical angles in the operating room could possibly be shortened, improving patient safety, as most complications occur during the first 30-50 laparoscopic procedures of a surgeon [12-15].

In this study we compare the development of laparoscopic skills under a standard zero optical angle to optical angles of plus and minus 45 degrees. Primary endpoints were damage and task duration. Based on previous research, we hypothesize better performance for working under an optical angle of 0° in comparison to deviated optical angles. We also expect working under deviated optical angles can be trained and that differences in performance under different optical angles will attenuate with training.

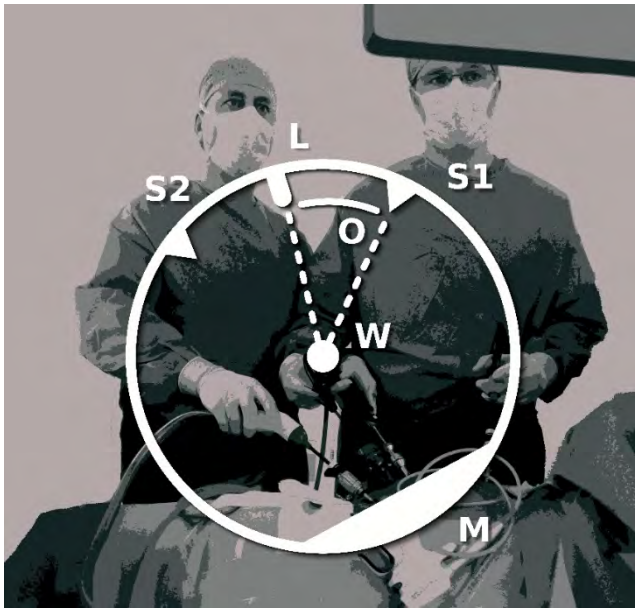


Figure 1. A laparoscopic procedure in the operating room with a corresponding schematic helicopter view to show the variables relevant to the challenges of laparoscopic indirect vision and optical angle (the angle between the laparoscope and the line vision of the surgeon towards the working field). O = optical angle, S1 = surgeon 1, S2 = surgeon 2, L = Laparoscope, W = working field, M = monitor.

MATERIAL AND METHODS

Subjects and course design

Data for this study was collected over a period of 4 months at the Surgical department of the Radboud University Medical Center, the Netherlands. Here, every month a new cohort of first year master students of Medicine starts the surgical internship. At the time of data collection, students could opt to take a voluntary, four-session basic skills laparoscopic simulator training course as part of a 3-week preparatory course for this internship. Every month, between 19 and 29 students enrolled in

this training course. Power calculations based on effect sizes reported by Haveran and colleagues for differences in performance for task duration between a 0° optical angle and 60° optical angle revealed that 34 participants were needed to achieve a power of 0.8 [9]. Four cohorts were included with a total of 58 participants, to ensure sufficient participants who completed all four sessions, as we saw a high drop-out percentage during previous studies [16]. Written informed consent was obtained from all participants and it was made clear to the participants that their data would be analyzed anonymously for scientific purposes only, within our research group. We also made it clear that not consenting to our using their training data would in no way impact their training course experience or any assessments later. All methods were carried out in accordance with relevant guidelines and regulations. No formal ethics review was sought, as this was not required under Dutch law for this type of research at the time of data collection [17].

To take part in the course, students could register themselves online in groups of three for a preferred time and date. Only one session per day was allowed to maintain a distributed practice schedule, as it is known that this leads to better retention of psychomotor skills [18, 19]. Training sessions were always finished within a 60-minute time-frame.

Training session

During the first session, each subject completed a digital demographics and laparoscopic experience questionnaire. Also, a short instruction was given during the first session to introduce students to the skillslab, simulators, and the various training tasks. Supervision was given throughout the whole first session. On request, supervision was available for the last three sessions. This opportunity was not used.

At the LapSim, students started every session with a warming-up exercise under a 0°, 45° and -45° optical angle (Camera Navigation). During this exercise students are in control of the laparoscope and have to focus the camera centrally on multiple digital gallstones spread throughout a virtual abdominal cavity. After this they performed the task 'Grasping' three times under different optical angles: 0°, 45° and -45°. The task was always performed in this order of optical angles. We chose this order because a pilot study showed us that it was too hard for most students to start learning the tasks with an optical angle of 45° or -45°, and they could not finish the task within an acceptable time window (data not shown). We chose the exercise 'Grasping' because it is moderately complex, so we expected the students to cause damage, but still show a (nearly) complete learning curve after completing the course. During this task participants use a virtual laparoscopic grasper with actual handles alternating

between the left and right hand, to retract tubular structures and place these into a retrieval bag in a simulated abdominal cavity. More information about the performed tasks can be found on the website of Surgical Science [20].

In the skillslab participants also had access to an in-house developed videobox trainer. On this trainer students could use standard laparoscopic instruments to perform simple psychomotor tasks. Training activity on this videobox trainer was not monitored.

Apparatus/materials:

The training station consisted of a desktop running windows, a laparoscopic interface consisting of the Simball hardware (G-coder Systems, Västra Frölunda, Sweden) and Surgical Science's LapSim v3.0 training software (Surgical Science, Göteborg, Sweden)(figure 2). This software contained multiple exercises, but the students could only use the exercise 'Grasping' in the three optical angles. Questionnaires were created and completed with LimeSurvey v1.92+, a web-based application to create surveys and collect responses. The questionnaires were completed on-site, on an Asus Laptop running Windows 7. The IBM SPSS Statistics v.23 package was used for data analysis.



Figure 2. Picture of the training station, consisting of Surgical Science's LapSim.

Data preparation

During the performance of laparoscopic tasks, the LapSim simulator automatically records performance parameters such as task duration, instrument path length, angular path, tissue damage, and maximum damage. Since our primary endpoints were task duration and damage, the parameters of task duration, tissue damage, and maximum damage were included in the data analysis. Task duration was recorded in milliseconds. Tissue damage reports the number of times damage was caused by injuring the virtual abdominal cavity, while maximum damage represents the depth of damage created in millimeters for the most severe collision of instrument and virtual tissue. In the current available literature, there is still uncertainty regarding the interpretation of increased path length or angular path. On one hand, they could be negatively associated with less efficient movement. On the other hand, they could be positively associated with additional safety measures, such as avoiding critical anatomy and ensuring visibility of laparoscopic instruments. Furthermore, we expected these parameters to correlate with task duration, suggesting potential redundancy. Consequently, these parameters were not included in the data analysis. Extreme outliers (data points that exceeded the 90th percentile) were removed from the dataset. This led to a data loss of 5,7%.

To compare improvement in performance during the course between the different optical angles, we created 'improvement variables' by subtracting performance at the 4th session from performance at the 2nd session. We chose the second rather than the first session to create these new variables, reasoning that during the first session performance is slowed by adapting to a novel training environment (rather than reflecting laparoscopic performance per se).

Data Analysis

Shapiro-Wilk tests showed that not all parameters followed a normal distribution because of a floor effect for damage. Wilcoxon signed-rank tests were therefore used to analyze the data.

To assess the effect of optical angle on performance, we used pairwise comparisons for performance under the 0°, 45° and -45° optical angles for task duration, tissue damage, and maximum damage, respectively. This was done for every session separately. We also compared performance at the 4th session to performance at the 2nd session for every optical angle to see if participants improved during the course. To assess if this improvement in performance differed between the optical angles, we additionally compared improvement variables between the different optical angles. A level of $p < .05$ was considered statistically significant for all tests.

RESULTS

Participants

All 58 students who participated to the training course volunteered to participate in the research. The 43 students who completed the (voluntary) course were included for data analysis (34 female and 9 male, average age of 24 years ranging from 21 to 30 years). None of the participants reported any previous laparoscopic experience.

Performance

A summary of all performance parameters is shown in figure 3. Students performed faster at the 0° optical angle compared to either the 45° or -45° optical angle for all but the first sessions (z between -2.95 and -2.09, $p < .05$). We found no significant performance difference for task duration between 45° and -45° (table 1). Comparison between the 4th and 2nd training session demonstrated that individuals significantly improved (z between -0.40 and -0.17, $p < .05$) in task duration under all three optical angles (table 1).

Both tissue damage and maximum damage did not differ significantly in performance between the three optical angles any of the sessions (figure 3). The participants did not perform significantly better for both tissue damage or maximum damage during the 4th session compared to the 2nd session under any optical angle (figure 3). Also, no differences in improvement between the 2nd and 4th session between the different optical angles were found.

Table 1. Median task duration in seconds per session in paired comparisons between the three optical angles. The last row demonstrates the median difference in task duration in seconds between the 2nd and 4th session, reflecting improvement in performance during the course. Wilcoxon Signed Ranks tests were performed to compare task duration between the different optical angles, z values and p values are shown. Also, Wilcoxon Signed Ranks tests were performed to compare improvement in task duration during the course between the optical angles, shown in the last row. * = Significant.

Session	0°	45°	z value	p value	0°	-45°	z value	p value	45°	-45°	p value	z value
1	193.4	188.4	-0.16	.88	193.4	189.2	-0.75	.45	188.4	189.2	.66	-0.45
2	122.0	127.1	-2.09	.04*	122.0	134.0	-2.36	.02*	127.1	134.0	.71	-0.37
3	103.6	107.7	-2.17	.03*	103.6	105.5	-2.54	.01*	107.7	105.5	.60	-0.53
4	85.2	90.2	-2.38	.02*	85.2	92.3	-2.95	.00*	90.2	92.3	.67	-0.42
Difference Session 2-4	-31.5	-38.9	-0.40	.69	-31.5	-28.8	-0.17	.87	-38.9	-28.8	.79	-0.27

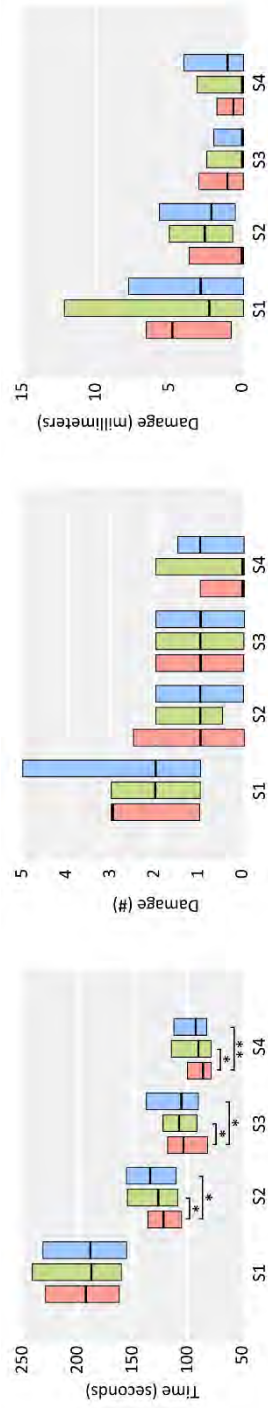


Figure 3. Boxplots showing median and interquartile range for performance for each session, for the 0° optical angle (red), 45° optical angle (green) and -45° optical angle (blue). From left to right: task duration (in seconds), frequency of tissue damage, and maximum damage in millimeters. * = $p < .05$, ** = $p < .01$.

DISCUSSION

During a four-session basic skills laparoscopic training course to support medical students prepare for their surgical rotations, better performance was demonstrated for duration but not for damage under a 0° optical angle compared to 45° and -45° optical angles. For duration, performance improved for all three angles. However, we found no attenuation for the performance differences between the angles over the sessions. No significant improvements for the damage variables were found.

The lack of attenuation of performance differences over time surprised us, as we initially expected that with sufficient training, performance under non-zero optical angles would eventually match that of the zero degree angle. While more experienced surgeons demonstrated relatively better performance under deviated optical angles compared to inexperienced surgeons ([9-11]), they still fell short when compared to the performance under the zero degree angle. It remains uncertain whether these more experienced surgeons, like our study participants, simply did not reach the end of the learning curve, and if differences in performance only emerge at a later stage of the curve. To gain further insights into the development of spatial skills associated with laparoscopic surgery, it will be necessary to study longer segments of the learning curve. Understanding the extent to which spatial skills can be trained is crucial for surgical education and the design of laparoscopic procedures. If spatial skills can be adequately trained, it should be incorporated as an explicit component of the curriculum. However, if not, additional efforts should be made to minimize the use of optical angles that deviate from zero during laparoscopic surgery.

Our lack of findings with regards to the effect of training and optical angle on damage parameters reflects a floor effect. This may have been caused by students taking extra time to complete the task to avoid creating extra damage during these tasks [18]. For future research, tasks and task settings that make it harder to avoid creating damage would be necessary to gain more insight in the learning curve of these clinically relevant parameters.

Our results partly confirm previous single-session studies that compared optical angle with surgical simulator performance. These studies found progressive deterioration in performance on time and accuracy for simulated laparoscopic tasks under increasing optical angles [9-11]. To our knowledge no previous studies have investigated the learning curve of laparoscopic skills under non-zero optical angles. However, in a two-session dentistry study the development of psychomotor skills in a simulated environment was evaluated with indirect vision under a 180° mirrored

image [21]. They found significant performance improvements, demonstrating the possibility to train the skills needed to work under a deviated optical angle. They did not compare the improvement to a 0° optical angle. Also, the procedures in dentistry lack a fulcrum effect which is present in laparoscopic surgery, which impedes direct comparison.

Previous studies in laparoscopic surgery demonstrated that even for experienced surgeons performance decreases under non-zero optical angles, however experienced surgeons showed better adaptation compared to novices [9-11]. This suggests a learning effect for surgeons for working under non-zero optical angles, although with a persisting performance penalty, which is in accordance with our findings. To optimize training course length for clinically relevant optical angles and to learn more about spatial skills development in general, we need more medium- and long-term studies into performance development under these angles. Given the relevance of visuospatial ability for learning and performing highly spatial skills such as those needed for laparoscopy [4, 22, 23], we would advise visuospatial ability testing to become a standard feature of such research.

Strengths and Limitations

Using performance of simulated laparoscopic tasks on a well validated virtual reality simulator allowed for objective and standardized measurements. Implementing multiple training sessions in our study protocol enabled us to monitor the learning curve under different optical angles. Study participants were inexperienced, which provided us an unbiased visualization of this learning curve. These factors made it possible to compare laparoscopic basic skills development between the 0° and (+/-) 45° optical angles.

During our study, participants always performed the task first under a 0° optical angle before performing it under deviated angles. Since learning is expected to occur during the exercise, the performance difference between the 0° and deviated optical angles may have been smaller compared to a truly randomized design. This effect is expected to be at its largest during the first session, because students still had to learn how to execute the task and how to work with the simulator. Despite this disadvantage, the participants still performed significantly better for time under a 0° optical angle during the last three sessions, demonstrating the relevance of the effect of optical angle.

During this basic skills laparoscopic training course, students were free to train on an in-house developed laparoscopic videobox trainer. This trainer was not part of the

study and activity was not monitored, however could have affected the performance on the LapSim, as the tasks for this simulator are designed to train similar skills. Some transfer of skills may have occurred however which could have led to improved performance on the LapSim tasks. This effect is expected to be equal for the 0° , 45° and -45° optical angle and thus unlikely to affect our conclusions.

We specifically concentrated on the parameters related to task duration and damage to assess their impact on laparoscopic performance. While there may be additional parameters that could also influence performance, the power calculation and group size limitations prevented us from conducting subgroup analysis for those factors.

Impact

Our results confirm that performing laparoscopic tasks under non-zero degree optical angles is more challenging compared to a zero degree optical angle ([9-11]). New in comparison to previous studies is that while it is possible to train and improve the necessary skills for such tasks, a performance gap remains between zero- and non-zero angled laparoscopic simulator performance. Currently, training curricula often focus on a zero degree optical angle, while neglecting non-zero degree angles. While questions remain regarding skill transfer and the learning curve, we recommend the implementation of laparoscopic skills training for non-zero optical angles in basic skills simulation training courses. This will better prepare young surgeons for the inevitable encounters with these angles during real surgeries. Training laparoscopic performance under non-zero optical angles in a safe environment could reduce the learning curve, and improve performance in the operating room.

Future research

To be able to fully recommend training for relevant non-zero optical angles we need to answer a number of additional questions. One has to do with transfer of optical angle skills; if you train one task under, say, a 45° optical angle, does this shorten your learning curve for a novel task under the same 45° optical angle? Another has to do with transfer of training under one optical angle to other optical angles; if you train under 45° , do you shorten the learning curve for optical angles of 90° , or 50° , or 46° , or -45° ? In a separate study we found evidence for 'zones of performance' (optical angles with a similar performance penalty) that may translate to 'zones of training' (unpublished data). We would also like to study longer segments of the learning curve for a larger number of optical angles to optimize training efforts for these spatial skills, and to learn more about the extent to which these skills can be trained to match performance under a reference optical angle of 0° .

The spatial complexity of laparoscopy is not just dependent on optical angle, but also on the angle of the laparoscope's lens system (compared to the laparoscope's central axis). Interactions between optical angle and lens angle can further complicate laparoscopic performance. A variable of interest for all the studies proposed above is visuospatial ability, which may greatly impact the speed and end level of learning and performance for these spatial skills. We also recommend where possible to go beyond duration as primary outcome measure and study proxies for complications and damage, which are a more direct measure of skill and ultimately are likely to be more relevant to patient outcomes. This should give a better handle at both the training effort needed for learning to perform under non-zero optical angles, and for the performance penalties associated with different optical angles in a clinical setting.

Conclusion

Performing a laparoscopic task under a deviated optical angle of (+/-) 45° induces a significant and lasting increase in task duration compared to a 0° optical angle in early basic skills training. However, novices are able to improve performance under deviated angles, therefore implementing training under deviated optical angles into basic training courses could help prepare young surgeons for real surgery and potentially shorten learning curves in the operating room.

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CHAPTER 4

Fast or safe? The role of impulsiveness in laparoscopic simulator performance

Bas Kengen, Wouter IJgosse, Harry van Goor, Jan-Maarten Luursema.

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ABSTRACT

Background

Little is known about the relation between impulsiveness and surgical performance even though research in similar high-risk/high-skills shows evidence of more hazardous behavior by impulsive professionals. We investigated the impact of impulsiveness on laparoscopic simulator performance.

Methods

Eighty-three subjects participated in a four-session laparoscopic training course. Based on the Eysenck Personality test, we created equal sized high- and low impulsiveness groups and compared task duration and errors on tasks for two laparoscopic simulators.

Results

The low impulsiveness group outperformed the high impulsiveness group on damage on the LapSim virtual reality trainer ($U = 459$, $p < .049$), and showed a trend towards better error performance on the FLS videotrainer. We found no differences on task duration.

Conclusion

In surgical simulation training, high impulsiveness is associated with creating more damage, but not with faster performance. Time needed to correct errors may have obscured faster performance in the high impulsiveness group.

INTRODUCTION

Some surgeons are safer than others. However, research into individual differences between surgeons in relation to operating room performance has been limited. Two sources of individual differences have been considered in relation to surgical performance: cognitive abilities and personality. Cognitive abilities such as visuospatial ability and psychomotor ability (responsible for eye-hand coordination) are known to be somewhat related to operating room performance, especially for minimally invasive procedures such as laparoscopy [1]. While the concept of the surgical personality has attracted attention from researchers [2-5], we found only two studies that specifically investigated the relation between personality and surgical performance.

Rosenthal et al. investigated the relation between surgical VR performance-parameters and personality, based on the results of the personality test NEO-Five Factor Inventory [6]. The NEO-FIVE Factor Inventory is a personality inventory that examines a person's Big Five personality traits (openness to experience, conscientiousness, extraversion, agreeableness, and neuroticism). Rosenthal et al. did not find any significant association [6]. Lovejoy et al. however showed that surgeons with low extraversion (i.e. introverted surgeons) tended to have better outcomes which is interesting given the consistent reports of higher extraversion in surgeons compared with the general population. The trend of more introvert trainees selected for a surgical specialty in recent years than in the past [7] may reflect a selection process for trainees that will produce better outcomes [8]. Related to the personality trait of extraversion is impulsiveness which in other fields such as traffic and aviation is associated with dangerous behavior and might play an important role in surgical performance [9-13]. The effects of impulsiveness on surgical performance however have so far received little attention from the research community.

Anecdotal evidence and OR-observations support the relevance of impulsiveness-like traits in the operating room: some surgeons are bold while others are hesitant, impacting the quality of the procedure being performed. Excessively bold surgeons may be fast, but more prone to cause intra-operative damage and complications, while extremely careful surgeons may work securely, but hesitant and slow. The psychological construct of impulsiveness is a good fit for this phenomenon, and basic research in psychology has demonstrated that high impulsiveness correlates with faster reaction times but more errors [10].

To investigate the relation between impulsiveness and surgical performance, we adopted a between group design in which we compared laparoscopic simulator

performance of students of high- and low impulsiveness. Students were selected as research subjects because having identical laparoscopic experience levels (namely none), either laparoscopic experience or differences in laparoscopic experience cannot bias the results. We expected that students of high impulsiveness would perform faster, but inflict more damage compared to students of low impulsiveness.

MATERIAL AND METHODS

Subjects and course design

The study was performed at the skills training facility of the surgical department of the Radboud University Medical Center, Nijmegen, the Netherlands. Study participants were fourth-year medical students with no or minimal experience in laparoscopy. They voluntarily signed up for a simulator-based, four-session basic skills laparoscopic training course, offered as part of their surgical rotation preparation. This simulator-based setup allowed us to use standardized tasks and collect quantified performance data. Every month a new cohort starts with this course, and data was collected for six cohorts. Voluntary informed consent was obtained from all participating students. The study design was not reviewed by an ethical board, as this is not required for this type of research under Dutch law.

Training session

Self-selected groups of three students scheduled their sessions in an online calendar. The first training session took around 90 min, as besides the training exercises it included two questionnaires and an explanation of the course setup. Sessions 2–4 took around 60 min. No more than one training session per day was allowed to maintain a distributed practice schedule for better retention of skills [14, 15]. All training sessions had to be scheduled within a three-week period due to the temporal constraints of the internship.

During the first session the students had to complete two questionnaires: a digital demographics questionnaire including questions about previous laparoscopic (simulator) experience, and a digital version of the Eysenck Impulsivity Inventory to collect information about impulsiveness (see ‘Eysenck Impulsivity Inventory’ below). In addition to these questionnaires the students received a brief introduction to the course, which included a demonstration of the principles of laparoscopic basic skills such as instrument- and camera handling. The first session was supervised, no attendant was present during the remaining three sessions.

Two training stations and one observation station were prepared for this training course. The training stations had different training hardware with different tasks. Students at the observation station assisted students at one of the training stations by collecting performance data. At the other training station performance data were automatically collected. Students started at the same station every session, and after completing all tasks of that training station they rotated to the next station. Every student completed all stations in every session (Figure 1).

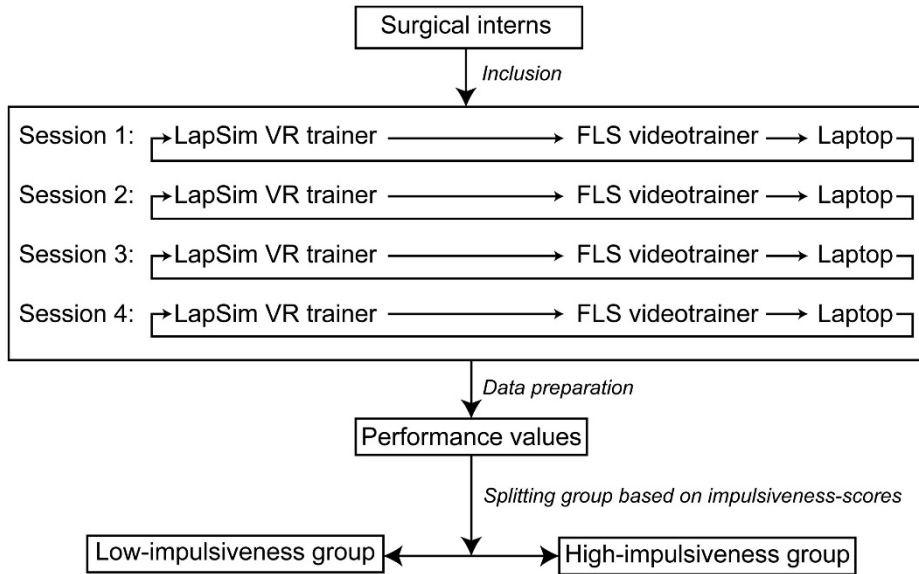


Figure 1. Flow chart of the training course and study design.

Training stations: The LapSim VR trainer and the FLS videotrainer

LapSim VR trainer station

At the LapSim VR trainer station students performed four exercises twice on the well-validated LapSim Virtual Reality trainer (Figure 2) [9, 11-13]. The four exercises were 'camera navigation', 'instrument navigation', 'cutting' and 'lifting and grasping'. In these tasks the student operates the camera or uses instruments such as a grasper or a ligation device in a simulated abdominal cavity to complete simple, non-procedural exercises such as ligation of blood vessels, picking up dropped gall stones, and retrieving dropped suturing needles. Detailed descriptions of the tasks can be found at the website of Surgical Science [16].



Figure 2. Pictures of the three training stations from left to right: observation station, LapSim VR trainer and the FLS videotrainer.

FLS videotrainer station

Students completed three laparoscopic tasks on the FLS videotrainer: ‘Peg Transfer’, ‘Precision Cutting’ and ‘Labyrinth drawing’ (Figure 2). The FLS videotrainer is a validated videobox trainer [17-19], where students use actual laparoscopic instruments to perform simple psychomotor tasks, such as moving plastic beads from peg to peg (Peg Transfer), or use laparoscopic scissors to cut a printed shape from folded gauze (Precision Cutting). These two tasks are described on the website of Fundamentals of Laparoscopic Surgery [20]. ‘Labyrinth drawing’ is a self-developed task where students have to trace a path through a labyrinth using a marker attached to a laparoscopic instrument, to learn how to mitigate the effects of amplification of movement caused by working over a fulcrum. They had to perform this task both right-handed and left-handed.

Observation station

The observation station consisted of a laptop running a self-developed program named ‘CurveSurfer’ [21]. The student at this station assisted the student training on the FLS videotrainer by keeping track of their performance and enter their scores in the software (Figure 2). This program provides the student working on the FLS videotrainer with learning-curve feedback about his or her performance over time, contextualized by learning curves of peers and expert values.

Eysenck Impulsivity Inventory

To assess impulsiveness each student had to complete the Eysenck Impulsivity Inventory. This well validated questionnaire consists of 63 yes-no questions and was developed for the measurement of three personality traits: impulsiveness, venturesomeness, and empathy [22, 23]. We were primarily interested in impulsiveness because of its known relation to damage and risky behavior in other fields, and did not further investigate venturesomeness or empathy. Impulsiveness

scores were calculated after complete data collection to prevent information bias for both students and researchers during data collection.

Apparatus

The LapSim VR trainer station consisted of a desktop computer running Windows with Surgical Science's LapSim v.3.0 training software (Surgical Science, Göteborg, Sweden). Simball hardware (G-coder Systems, Västra Frölunda, Sweden) was connected to the desktop to simulate laparoscopic instruments.

The FLS videotrainer station used a videobox trainer developed by SAGES and ACS for surgical residents, fellows and practicing physicians to learn and maintain laparoscopic skills. The FLS videotrainer was connected to a 17-inch LCD monitor.

The observation station consisted of a laptop running Windows and our self-developed program 'CurveSurfer'. This is a Microsoft Excel based program, designed to create learning curve feedback for students training on the FLS videotrainer [21]. Also, a digital form of the Eysenck Impulsivity Inventory was available at this station. This questionnaire was digitized with LimeSurvey version 1.92+, a web application to create surveys and collect responses [24].

Data preparation/analysis

After all performance data was collected, the participants were split into two groups based on the results of the impulsiveness scores of the Eysenck questionnaire. If their score for impulsiveness was below or equal to the median they were assigned to the low-impulsiveness group, if their score was higher they were assigned to the high-impulsiveness group.

LapSim simulator

Performance on the LapSim Simulator was automatically registered by the simulator. Data was exported from the simulator as an Excel file. The task 'camera navigation' was used as a warming-up exercise, and was not included in the analysis. Registered performance parameters were overall score, instrument path length, angular path, tissue damage, maximum damage, and instrument time. As we were interested in differences in speed and damage control, only parameters representing these aspects were analyzed: instrument time, tissue damage and maximum damage. Tissue damage represents the number of incidents, maximum damage the deepest 'wound' inflicted in mm.

To analyze the differences between the two experimental groups over the whole course rather than over individual training sessions, we averaged ranked performance data

for each parameter of the three individual sessions. To achieve one overall parameter for damage, the parameters 'tissue damage' and 'maximum damage' were combined by calculating the average of these ranks.

This resulted in two parameters per exercise: time and damage. In addition, the time and damage parameters were averaged over all three exercises to create overall LapSim performance parameters for time and damage. Mann-Whitney U tests were done to compare time and damage per exercise and for all exercises combined between the high- and low impulsiveness groups.

FLS videotrainer

The FLS videotrainer does not automatically register performance, therefore all exercises of this training station were video recorded and performance was afterwards manually scored by two authors (BK and WIJ), who were blinded for the results of the impulsiveness test. Tasks were scored for total time and errors made (bead drops during peg transfer). Only data of the task 'peg-transfer' was used, as the task 'labyrinth drawing' is not yet validated and for the task 'precision cutting' the videos did not allow for scoring errors objectively.

To cluster the four sessions, we followed the same procedure as described for the LapSim Simulator above, where we converted the interval data to ordinal data by ranking the parameters and calculated the average ranks over four sessions for time and errors made. We performed Mann-Whitney U tests for total time and total errors made over the four sessions to compare the two experimental groups.

The alpha level was set at 0.05 for all tests.

RESULTS

Participants

Eighty-three students of six cohorts (51.0% of the total amount of students preparing for their surgical rotation) signed up for the voluntary laparoscopic basic skills training course and were eligible for this study. Seventy-three participants completed a minimum of three sessions which was considered mandatory for inclusion in the study. Lost data due to technical problems occurred for two subjects, data of both were excluded. Consequently, data of 71 students were included in the analysis.

Age ranged between 21 and 30 years (mean 23.8 years) and 22 participants were male (31.0%). Two participants reported previous laparoscopic experience, only having operated the camera. Their performance was between the first and third quartile for both damage and speed. Both impulsiveness groups were comparable regarding age, gender and laparoscopic experience (Table 1).

Table 1. Summary of characteristics of study participants.

	Low-impulsiveness group n = 36	High-impulsiveness group n = 35
Sex (male, n)	10 (27.8%)	12 (34.3%)
Age (mean)	23.5 years (22-30 years)	24.0 years (21-29 years)
Laparoscopic experience (n)	1 (2.8%)	1 (2.9%)
Impulsiveness-score	1.64 (0.46 – 2.81)	4.25 (2.83 – 7.15)

Influence of impulsiveness on laparoscopic performance

LapSim simulator

A summary of the results of the LapSim Simulator is shown in Figure 3. Subjects of low impulsiveness had lower scores for damage on every task, which means they caused less damage. This reached significance only when performance of all tasks was averaged ($U = 148$, $p = .049$). Total time did not differ significantly between the two groups for any task individually, nor did it for all tasks combined. Neither did one group structurally outperform the other on time.

FLS videotrainer

Figure 4 shows similar trends of performance regarding the FLS videotrainer data. The low impulsiveness group made fewer errors over four sessions. The low impulsiveness group was marginally faster compared to the high impulsiveness group. The differences for time and errors, however, were not significant.

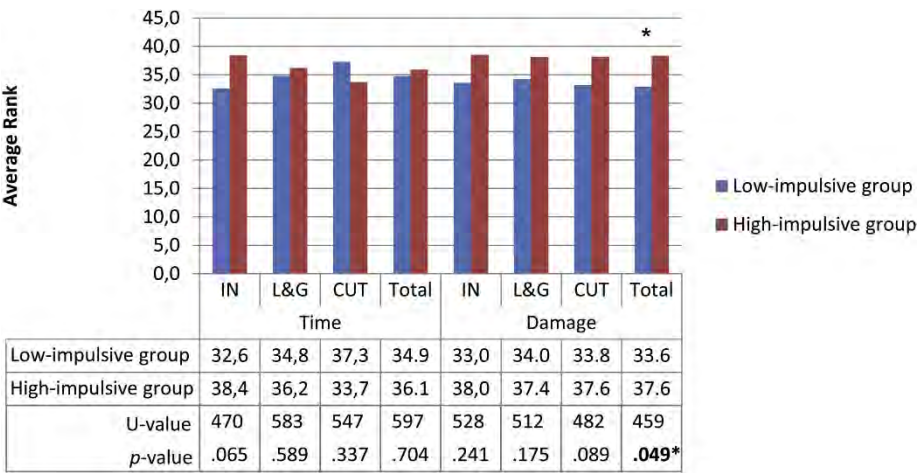


Figure 3. Display of performance (shown as average ranks for time and damage) of the three LapSim VR trainer tasks individually and combined (total). Low ranks mean less time was used and fewer errors were made compared to high ranks. All four training sessions are combined. Blue bars represent performance of the low impulsiveness group, red bars represent performance of the high impulsiveness group. U-values and p-values of Mann-Whitney U tests are shown per exercise and for the total score. Abbreviations of exercises: IN = instrument navigation, L&G = lifting and grasping, CUT = Cutting. * = $p < .05$.

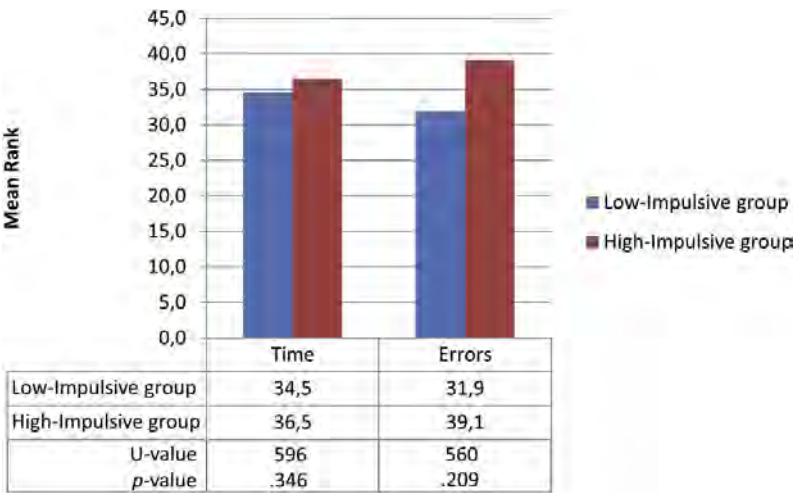


Figure 4. Performance (time and errors) of both experimental groups on the FLS videotrainer. Low ranks mean less time and fewer errors made compared to high ranks. All four training sessions are combined. The blue bars represent the performance of the low impulsiveness group, red bars represent performance of the high impulsiveness group. U-values and p-values of Mann-Whitney U tests are shown per parameter.

DISCUSSION

Students of low impulsiveness outperformed students of high impulsiveness on all damage and error measures collected during a basic skills laparoscopic training course. However, this only reached significance for the averaged damage variables on the LapSim VR trainer. In contrast to our expectations, we found no differences in performance for duration variables. A possible explanation is that faster performance may have been obscured by the extra time needed to correct errors. Also, the exercises were both simple and predictable and students of low impulsiveness may not have needed extra time to carefully assess the situation, which would have slowed them down compared to students of high impulsiveness. In the operating room surgery is complex and unpredictable, which could slow down low-impulsiveness surgeons who need more time for premeditation, which would lead to our expected time/damage trade-off.

When we compare our results to earlier studies in other sectors we see similar results. In traffic, studies show that young drivers who score high on the Barratt impulsiveness scale, another validated test that measures impulsiveness [25, 26], are more likely to drive risky, drive aggressively, lose concentration, lose car control, cause traffic violations and make mistakes [27, 28]. In 2013, Pearson used a five-factor model of impulsiveness-like traits to investigate a possible correlation of these traits with four risky driving behaviors [29]. All correlations showed the same trend: impulsiveness-like traits increase risky driving behavior.

The Federal Aviation Administration suggests a relation between attitudes and incidents in aviation as well [30]. Anti-authority, impulsiveness, invulnerability, machoism and resignation are recognized by this organization as hazardous attitudes. They believe, however, that good judgment can be taught. Therefore, they have created a structured, systematic model to analyze changes during a flight to decrease the probability of human error and increase the probability of a safe flight [30]. Pilots are trained to recognize and counteract hazardous attitudes like impulsiveness via this model (Figure 5). When tested, pilots who received this kind of decision-making training made fewer in-flight errors than those who had not [30]. For laparoscopic simulation training applying this systematic model may be beneficial decreasing error and increasing safety.

As a thought exercise, we apply the six-step FAA model to a situation where a resident is stopping a bleeding. The first step is recognizing the personal hazards e.g. an impulsive attitude of 'quickly do something' meaning directly taking actions trying to control the bleeding. Instead the resident determines the risk of the bleeding e.g.

which vessel is bleeding, what are the consequences? Third step is considering the options to fix the problem e.g. ligating the vessel, closing the hole in the vessel or put digital pressure on the vessel. During the fourth step a decision is made about the mode of action after quickly weighing pros and cons of the options e.g. it is an important artery or vein that need to be saved and thus need to be repaired. After performing the repair (the fifth step), the last step is monitoring the main results of the decision, the bleeding has stopped and the blood flow is successfully restored. To implement this model in a training course, the procedures to be trained would need to be subjected to safety critical task analysis or cognitive task analysis with an emphasis on errors and damage control [31]. Potential errors, damage, complications, their origins and their consequences are defined as main outcomes of the training course. In this way, trainees of known levels of impulsiveness can be steered towards appropriate steps through the training environment.

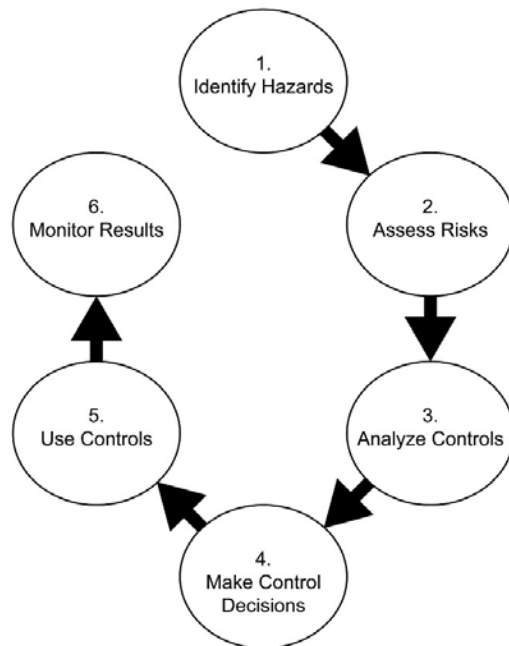


Figure 5. Schematic display of the steps of the risk management decision-making process as introduced by the FAA.

Besides counteracting hazardous attitudes, knowledge on the relation between impulsiveness and adverse incidents also offers an opportunity to design personalized adaptive training programs. For students of high-impulsiveness for example this could mean focusing training on damage control, possibly by creating

a training that steers the students' emphasis to one specific outcome parameter, a method we are currently testing.

Limitations

The results of this research are based on simulated laparoscopy, which differs from real world laparoscopy in a number of ways. Laparoscopy as performed in the OR is more complex, unpredictable, and harbors risk of (life threatening) complications. All these differences might interact with the personality trait impulsiveness. Simulators, however, allow for objective, quantified measurement of damage, which is much harder to do in the operating room.

During the first session of the LapSim Simulator task 'instrument navigation' 20.0% of the high impulsiveness group and 16.7% of low impulsiveness group reached the time limit for this exercise. During the remaining sessions this limit was reached by less than 2% of the students. We may have underestimated differences in time between the two experimental groups in the first session for this simulator. This difference however would have worked against our hypotheses, and has not changed our results.

Another limitation is that students differ from attending surgeons in professional experience. With experience psychomotor skills improve and automate. As a consequence, performance differences attenuate over time and become less sensitive to individual differences [32]. Working with 4th year medical students however ensured identical experience levels for all participants, reducing the risk for confounding variables.

Future research

Having established a negative impact of impulsiveness on student performance in a simplified surgical simulation environment, research is needed to extrapolate these findings to surgeons of different experience levels, preferably in a real-world setting.

Another line of research would be in personalized training. Is it for instance possible to counteract the effects of high impulsiveness by changing assessment variables? We are currently analyzing data from a study where students get feedback on either speed or damage control during simulator training, taking into account differences in impulsiveness.

Conclusion

The personality trait impulsiveness influences laparoscopic simulator performance; low impulsiveness students create less damage, yet are as fast as high impulsiveness

students. More research is needed to learn about the relevance of impulsiveness for performance in the OR and for surgeons of different experience levels. If such studies corroborate our findings, the personality trait of impulsiveness may have implications for professional selection and the design of surgical training programs.

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CHAPTER 5

Professional experience modulates the effect of impulsiveness on laparoscopic simulator performance

Bas Kengen, Harry van Goor, Jan-Maarten Luursema.

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ABSTRACT

Background

High impulsiveness is associated with adverse outcomes, such as dangerous driving leading to traffic accidents and decreased job performance in general. In surgery, high impulsiveness is associated with increased damage during simulated laparoscopy training. In this study we investigate the impact of professional experience on the relation between impulsiveness and simulated laparoscopy.

Methods

A total of 120 participants, of whom 78 inexperienced and 42 experienced in laparoscopy, performed four different, standardized laparoscopic tasks on the LapSim Virtual Reality trainer. Based on the UPPSP impulsive behavior scale, we divided participants into equal sized high- and low impulsiveness groups for both experience groups. We used Mann-Whitney U tests to compare task duration and damage parameters between the low and high impulsiveness group, separately for inexperienced and experienced participants. Spearman's rank correlation tests were used to investigate the correlation of different facets of impulsiveness on performance.

Results

Inexperienced participants with high impulsiveness demonstrated significantly faster task completion ($z = 2.74, p < .01$). Inexperienced participants of very high-impulsiveness (upper quartile) also caused significantly more tissue damage ($z = 2.27, p = .02$). Conversely, experienced surgeons exhibited no discernible performance variations based on impulsiveness for time ($z = 1.42, p = .16$) or tissue damage ($z = -0.19, p = .85$). For inexperienced participants the impulsiveness facets (lack of) premeditation and sensation seeking correlated with shorter task duration, while negative urgency, positive urgency, and (lack of) perseverance were associated with increased tissue damage. For the experienced participants no significant correlations were found between impulsiveness facets and simulator outcomes.

Conclusion

High impulsiveness results in shorter task duration but tend to increase tissue damage for laparoscopic simulator performance of inexperienced trainees. The performance of experienced surgeons remained unaffected by impulsiveness, indicating that professional experience may play a role in mitigating its influence.

INTRODUCTION

Surgeons as a group are often associated with impulsiveness-related traits such as extraversion and a can-do attitude [1, 2]. In several non-surgical domains high impulsiveness has been associated with adverse outcomes. For example, impulsiveness is negatively correlated to professional performance in general [3], and a highly impulsive personality is associated with dangerous driving and traffic accidents [4-8]. Surgeons with high extraversion have shown relatively worse performance outcomes [9]. As impulsiveness is strongly related to extraversion [10-12], impulsiveness might also affect surgical performance. A negative relation between impulsiveness and performance has been demonstrated in our previous research, in which inexperienced students of high impulsiveness caused more damage during simulated laparoscopic tasks compared to their peers of low impulsiveness [13]. However, as skilled performance develops, individual differences in personality may become less important for outcomes. In traffic, Xu et al. demonstrated that increased driving experience results in more sensitiveness to situational cues, and leads to a decreased effect of personality traits such as impulsiveness [14]. In the present study we investigate the relation between impulsiveness and surgical performance to better understand the individual differences that impact surgical skills' development and the potentially mitigating effect of professional experience.

From a psychological perspective the trait of impulsiveness is a broad and multifaceted concept [15]. It received various definitions such as 'swift action without forethought or conscious judgment' [16], 'behavior without adequate thought' [17], and 'the tendency to act with less forethought than do most individuals of equal ability and knowledge' [18]. As these definitions suggest, impulsiveness is essentially related to the control of thoughts and behavior [19]. Whiteside and his colleagues subdivided the trait impulsiveness in five different facets, namely positive urgency, negative urgency, premeditation, perseverance and sensation seeking [20]. Negative and positive urgency refer to the tendency to engage in impulsive behaviors under conditions of negative or positive affect respectively. Lack of premeditation refers to a difficulty in thinking and reflecting on the consequences of an act before engaging in that act. Lack of perseverance relates to the inability to remain focused on a task. Lastly, sensation seeking refers to a tendency to enjoy and pursue activities that are exciting.

To investigate the impact of professional experience on the relation between impulsiveness and surgical performance, we compare laparoscopic simulator performance between subjects of below average and above average impulsiveness,

separately for inexperienced and experienced participants. As the personality construct of impulsiveness is based on the five facets mentioned in the previous paragraph, we will use values for these facets to contextualize our main findings. Based on our prior research into impulsiveness and simulated surgical performance under students [13], we hypothesize faster performance for high impulsiveness surgeons at the expense of increased errors. Additionally, drawing on the work of Xu et al. who found a decreased effect of impulsiveness on safe driving behaviors for experienced drivers [14], we anticipate a more pronounced impact of impulsiveness on the performance of the inexperienced group compared to their more experienced counterparts.

MATERIALS AND METHODS

Participants

This research was conducted at the Radboud University Medical Center, Nijmegen, the Netherlands which includes an academic hospital and (bio)medical and dentist schools. To form two study groups that contrast in surgical experience, first-year medical master students (year 4 of 6 years of medical school), surgical residents and attending surgeons were approached for participation through presentations, posters, email and direct contact. The latter two groups were employed at the departments of Surgery, Urology, and Gynecology of the hospital. Participants were informed about the goals and methods of the study and the use of the collected information and were given the opportunity to ask questions. All participants were informed about the study and signed an informed consent form to allow the use of their anonymized performance data. Participation was voluntary and without compensation. No IRB approval was needed for this study under Dutch law for this type of data collection, processing and analysis [21]. Based on the results of our previous study [13] which demonstrated an effect size of .45 for impulsiveness on tissue damage, power calculations revealed that a minimum of 26 participants were needed per experience group to achieve a power of 0.80 with an α error probability of .05.

Study Design

The experiment consisted of a single session for each individual participant and was conducted in a designated small room in the staff quarters of the Department of Surgery with minimal audiovisual distraction. At the start of the session participants completed a digital demographics questionnaire which include questions about previous experience with laparoscopy. They also completed a digital

version of the UPPSP Impulsive Behavior Scale. Thereafter, participants performed four standardized laparoscopic tasks on a Virtual Reality trainer. A research team member was present during the entire session for technical support and procedural questions. A session lasted between 60 and 90 minutes. The four tasks performed on this simulator were 'Grasping', 'Cutting', 'Coordination' and 'Lifting and Grasping'. These are basic tasks developed to learn fundamental skills in laparoscopic surgery by improving manual dexterity. During these tasks the participant used laparoscopic instruments such as a grasper or ligation device in a simulated abdominal cavity to complete simple, non-procedural exercises such as the ligation of blood vessels, picking up dropped gall stones, and retrieving dropped suturing needles. More detailed descriptions of these exercises can be found at the website of Surgical Science Ltd. [22].

Apparatus

The training station consists of the LapSim® (version 2015), a virtual reality laparoscopic trainer, purchased from Surgical Science Ltd., Gothenburg, Sweden (figure 1). It consists of haptic hardware platform 'LapCam', a 27-inch LCD monitor (AOC International, Taiwan), a touchscreen, and a Windows 10 desktop. Input devices consist of a grasper instrument on the left- and right sides and a camera instrument in the center. This simulator is widely used and extensively validated [23-25].



Figure 1. Pictures of the LapSim Virtual Reality Simulator on which the participants performed four different standardized laparoscopic tasks.

Digital questionnaires were completed on an MSI Laptop running windows 10. Questionnaires were created with Limesurvey version 1.92+, a web application to create surveys and collect responses. Microsoft Excel 2019 was used to save and store data. The software package SPSS Statistics for Windows, Version 27.0 (IBM SPSS Statistics for Windows, Version 27.0. Armonk, NY: IBM Corp) was used to analyze data. Data was saved and stored in Microsoft Excel 2019. The power analysis was conducted using G*power, a statistical software program specifically designed for this purpose [26].

UPPSP Impulsive Behavior Scale

To assess impulsiveness, participants completed a digitized version of the UPPSP Impulsive Behavior Scale. The original UPPS scale was developed by Whiteside and Lynam in 2001 [15]. This team conceptualized impulsiveness by four facets: negative urgency, (lack of) premeditation, (lack of) perseverance and sensation seeking [20]. The scale was validated in multiple studies [15, 27, 28]. Later, to improve construct validity, the UPPS was revised by adding an additional facet: positive urgency [29]. The sum of these facets provides a proxy measurement of impulsiveness. The scale consists of 59 questions which have to be responded to on a four-point Likert scale, for example “My thinking is usually careful and purposeful”, “I’ll try everything once”, and “I tend to lose control when I am in a great mood”. For this study, the scale was computerized. Internal consistency for this scale is strong with a Cronbach's alpha of .93. The individual facets show strong coefficients as well: sensation seeking .79, negative urgency .87, positive urgency .87, premeditation .80 and lack of perseverance .79 [30]. The scores of premeditation and perseverance are inverted in the UPPSP scale, so a high score for premeditation and perseverance actually means a lack of premeditation and a lack of perseverance respectively.

Data preparation

The LapSim virtual reality simulator automatically registers a variety of parameters, including task duration, tissue damage, maximum damage, and path length. These data were exported for all tasks performed by the participants from the simulator as an Excel file and converted to an SPSS datasheet. Data from the completed questionnaires was added to this file. As speed and damage control were our primary endpoints, the simulator parameters task duration, tissue damage, and maximum damage were selected for analysis. Tissue damage represents the number of incidents and maximum damage the deepest ‘wound’ inflicted in millimeters. We created total simulator scores for task duration and tissue damage by adding the values for these parameters from all four individual tasks. For maximum damage we used the most extreme damage value of the four tasks.

Participants were post-hoc divided in an inexperienced group and an experienced group. Prior research has commonly employed a threshold of 10 procedures to distinguish between inexperienced and experienced surgeons, based on the observation of the steepest learning curve occurring within the initial 10 procedures [31-38]. Therefore, participants who had performed as primary operator 10 laparoscopic procedures or less were classified as inexperienced and participants with more than 10 or more laparoscopic procedures as primary surgeon were classified as experienced.

Impulsiveness scores were calculated after data-collection to prevent information bias for both participants and researchers. Based on the results of the UPPSP scale both the experience and inexperienced group was further divided into subgroups of low- and high impulsiveness. If the score of the participant was below the median the participant was assigned to the low-impulsiveness subgroup, if the score was higher than the median the participant was assigned to the high-impulsiveness subgroup.

Data analysis

Shapiro-Wilk tests demonstrated that not all of the outcome parameters were normally distributed, therefore non-parametric tests were used to analyze the data. A p value of $< .05$ was considered significant. To compare demographics for the two experience groups, we performed Mann-Whitney U tests to compare age, gender and UPPSP-scores.

We utilized Mann-Whitney U tests to compare the performance of the inexperienced and experienced groups in terms of total task duration, total tissue damage, and maximum damage. This comparative examination served as a means to evaluate the validity of the chosen performance measures for effectively distinguishing the skill levels of inexperienced and experienced participants.

To analyze differences in performance between the low-impulsiveness group and the high-impulsiveness subjects for each experience group we performed Mann-Whitney U tests for total task duration, total tissue damage, and maximum damage. Also, performance of the participants of the lowest quartile of the UPPSP scores were compared to those of the highest quartile of the UPPSP scores for both experience groups to further investigate the relation between impulsiveness and performance.

To investigate the influence of the different facets of the UPPSP scale (negative urgency, positive urgency, premeditation, perseverance, and sensation seeking), we performed a Spearman's rank correlation test between the impulsiveness facets and selected simulator outcomes, separately for both experience groups.

In addition to the primary data analysis, a post hoc analysis of gender effect on outcomes was performed using Mann-Whitney U tests evaluating any differences in outcomes between males and females within each group.

RESULTS

Participants

A total of 121 participants participated in the study. One participant of the experienced group had to abort halfway through the training session due to an emergency call. Data of this participant was removed from the dataset. Data of 120 participants were included in the analysis. From the 120 participants 78 were classified as inexperienced and 42 as experienced. In the inexperienced group 26 out of 78 participants were male (33%), and in the experienced group 29 out of 42 participants were male (69%) ($z = -3.73, p < .01$). The median age for the inexperienced group was 24 years and for the experienced group 37 years ($z = 2.80, p < .01$). There were no differences in impulsiveness between the experience groups; the median score for the UPPSP scale for the inexperienced group was 119.5 and for the experienced group 120.0 (table 1).

Table 1. Demographics of the two groups (inexperienced and experienced), including total number of participants, sex, median age in years, median UPPSP score, experience with more than 10 procedures as assistant, experience with more than 10 or 50 procedures as main operator, and number of MD's.

	Inexperienced group	Experienced group
Number of participants	78	42
Male / female (%)	26 / 52 (33% / 67%)	29 / 13 (69% / 31%)
Age	24	37
Median UPPSP score	120	120
Experience with assisting laparoscopic procedure (> 10)	10 / 78 (13%)	42 / 42 (100%)
Experience as operator laparoscopic procedure (> 10)	0 / 78 (0%)	42 / 42 (100%)
Experience as operator laparoscopic procedure (> 50)	0 / 78 (0%)	33 / 42 (79%)
Degree Doctor of Medicine	14 / 78 (18%)	42 / 42 (100%)

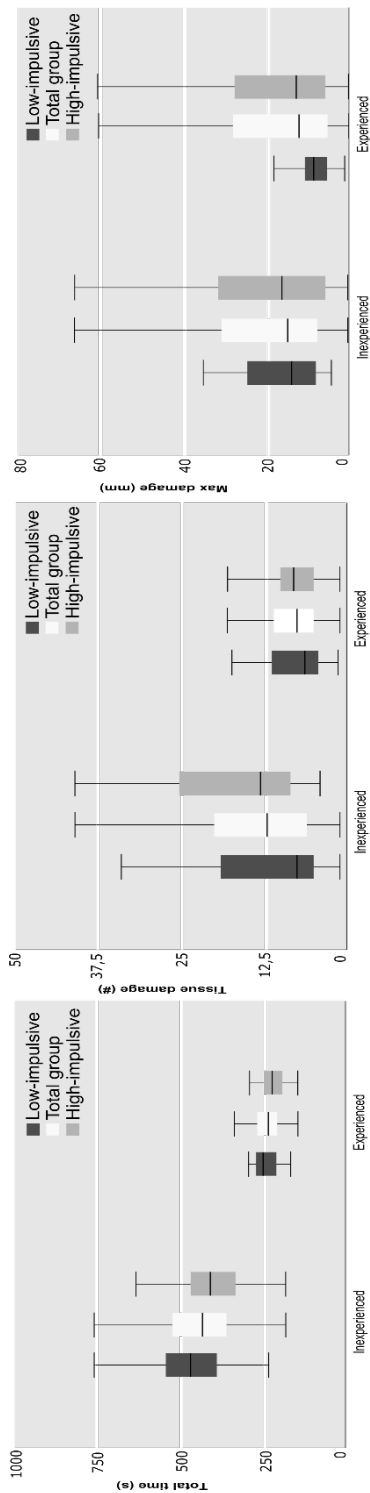


Figure 2. Boxplots illustrating performance comparisons among the inexperienced and experienced groups, as well as between low- and high-impulsiveness groups within the two experience categories. The left side (dark) represents low-impulsiveness groups, the right side (grey) high-impulsiveness groups, and the center (white) depicts total performance. Outliers are not shown.

Inexperienced versus experienced

To confirm the validity of our outcome measures, we first compared performance on these measures between our two experience groups. There were notable differences in performance between the inexperienced and experienced groups (figure 2). Specifically, the experienced group outperformed the inexperienced group in both total task duration ($z = -8.01, p < .01$) and total tissue damage ($z = -2.63, p < .01$). However, when evaluating maximum damage ($z = -.87, p = .386$), no significant difference emerged between the two experience groups.

Influence of impulsiveness on performance

Figure 2 contrasts the performance of the groups of low- and high impulsiveness for the two experience groups. In the inexperienced group, high-impulsive participants were significantly faster ($z = 2.74, p < .01$). For the other performance outcomes, no significant differences in performance were found within either experience group (table 2).

When comparing inexperienced participants in the lowest versus highest UPPSP scale quartiles, the most impulsive individuals were faster ($z = 2.27, p = .02$). However, this was now counterbalanced by a notable increase in tissue damage ($z = -2.00, p < .05$). The experienced group did not show any significant differences in performance when comparing the highest and lowest quartile (table 2).

Table 2. Results of Mann-Whitney U tests comparing performance between the low- and high-impulsiveness groups for inexperienced and experienced participants. The entire groups were compared and also the lowest quartile versus the highest quartile of impulsiveness. Tis. Dmg. = Tissue Damage, Max. Dmg. = Maximum damage, * = $p < .05$.

		Median split			Lowest vs. highest quartile		
		Time (s)	Tis. Dmg. (#)	Max. Dmg. (mm)	Time (s)	Tis. Dmg. (#)	Max. Dmg. (mm)
Inexperienced	z value	2.74	-1.62	-0.30	2.27	-2.00	0.00
	p value	0.01*	0.11	0.77	0.02*	0.05*	1.00
Experienced	z value	1.42	-0.19	-0.05	1.74	-0.65	-0.53
	p value	0.16	0.85	0.97	0.08	0.52	0.63

There were no significant differences in performance between men and women across both inexperienced and experienced groups.

Individual facets of impulsiveness

In the analysis of impulsiveness facets (table 3), the Spearman's rank correlation test revealed that inexperienced participants who lacked premeditation were faster ($r = -.30, p = .01$). Inexperienced participants who scored high on sensation seeking also were faster ($r = -.23, p = .05$). Inexperienced participants who scored high on the facets negative urgency, lack of perseverance, or positive urgency created more tissue damage ($r = .29, p = .01$; $r = .28, p = .01$; and $r = .23, p = .04$ respectively). Again, for the inexperienced group, we found no correlation between impulsiveness facets and maximum damage.

For the experienced group we found no significant correlations between any of the individual facets of the UPPSP and task duration, tissue damage, or maximum damage.

Table 3. Results of the Spearman's rank correlation coefficient between the individual facets of the UPPSP and performance outcomes for the inexperienced group. The scores of premeditation and perseverance are inverted in the UPPSP test, so a high score for premeditation and perseverance implies a lack of premeditation and a lack of perseverance respectively. An urge for sensation seeking and a lack of premeditation is correlated to shorter task duration. A tendency to engage in impulsive behaviors under conditions of negative or positive affect and a lack of perseverance is correlated to more tissue damage. r = Correlation coefficient, p = significance, $*$ = $p < .05$.

	Time (s)		Tissue Damage (#)		Maximum Damage (mm)	
	<i>r</i> value	<i>p</i> value	<i>r</i> value	<i>p</i> value	<i>r</i> value	<i>p</i> value
Negative urgency	-.02	.85	.29	.01*	.06	.60
(Lack of) Premeditation	-.30	.01*	.20	.08	.08	.50
(Lack of) Perseverance	.04	.71	.28	.01*	.11	.35
Sensation seeking	-.23	.05*	-.12	.30	-.14	.22
Positive urgency	-.10	.41	.23	.04*	.02	.86

DISCUSSION

This study investigated the impact of impulsiveness on laparoscopic simulator performance, and its modulation by professional experience. Mostly confirming our hypotheses, inexperienced participants with high impulsiveness completed tasks faster, and inexperienced participants of very high impulsiveness also caused more tissue damage. This contrasts with an earlier study performed by our group, in which inexperienced high-impulsiveness participants created more damage but were

not faster compared to their low-impulsiveness counterparts [13]. This may reflect differences in simulator settings that we since adopted to create more challenging tasks. A trend towards faster completion times was noted for experienced participants of high impulsiveness, however this failed to reach significance, perhaps caused by their overall faster completion times and resulting smaller standard deviations.

With experience, differences in tissue damage between impulsiveness groups disappeared. The reduced impact of impulsiveness on performance for likely reflects the automation of laparoscopic psychomotor skills [39]. Similar trends have been noted in other domains such as traffic, where the automation of skills enables experienced individuals to allocate more cognitive resources to external situational cues and alerts of potential risks, resulting in decision-making that relies less on intrinsic factors such as personality [14, 40]. Even if this hypothesis is correct, impulsiveness may still remain a risk factor for experienced surgeons, especially in situations where automated skills cannot be relied on, such as during technically challenging or emergency procedures.

Considering in more detail the facets of impulsiveness, we found that all five facets are involved in performance, i.e. (lack of) premeditation and sensation seeking correlate with faster performance, while negative urgency, positive urgency, and (lack of) perseverance correlate with increased damage. Negative urgency and positive urgency refer to the tendency to act impulsively when experiencing negative or positive emotions respectively; lack of perseverance indicates the tendency to quit when a task becomes difficult or boring. Common to these three facets may be a lack of self-discipline under constraints, leading to errors. If this hypothesis bears out in future research, targeted educational interventions stimulating habits that are conducive to better self-discipline may improve damage control of highly impulsive, inexperienced surgeons.

Our study is the first to explore all facets of impulsiveness in surgical performance. However, previous studies in traffic have focused specifically on impulsiveness and its trait-facet sensation seeking, associating it with hazardous driving [41, 42]. These studies have mainly concentrated on the potential negative impacts of impulsivity and sensation seeking. Unlike traffic studies, our findings show that sensation seeking correlates with faster performance but not increased damage in surgery. These differences may reflect differences in outcome measures rather than contradictory findings. The traffic studies did not take into account potential positive outcomes for sensation seeking such as faster task completion, and while both traffic studies reported increased hazardous behavior, they did not find an impact of impulsiveness or sensation seeking on factual

outcomes such as accident involvement or traffic violations. Hazardous behaviors have not been well defined for surgical simulator studies, which may be an omission to be rectified, provided that such behaviors are associated with poor outcomes.

The absence of differences in the maximum damage variable between the inexperienced and experienced groups raises concerns about the validity of this specific damage parameter, which we have noted in earlier studies [13, 43]. Despite these concerns, we opted to analyze maximum damage because of its potential relevance for future studies investigating transfer of skills.

Limitations

While our study employed a specific definition of surgical experience based on the number of performed procedures for our analyses, it is crucial to acknowledge the existence of alternative conceptualizations, which introduces certain limitations to our approach. Although this metric is commonly employed [44], it may not comprehensively capture the diverse aspects of surgical expertise. Alternative definitions and measurements, such as case diversity and complexity [45], clinical outcomes [46], or self-reflection [47], were not explored in this study. Our decision to categorize expertise based on the number of performed procedures provides a practical and widely recognized metric [44], facilitating straightforward comparisons across diverse surgical contexts.

Furthermore, the composition of the inexperienced group, mostly students, and the experienced group, primarily staff members, introduces potential confounds related to their roles, such as time constraints and motivation. Unfortunately, the number of participants was insufficient to allow subgroup analysis for different group compositions. For difference in gender composition of experience groups we were able to perform post hoc analysis demonstrating no performance differences. Despite these limitations, our chosen categorization enabled meaningful exploration of the relationship between experience and surgical proficiency.

Another concern regarding group composition was the different fraction of men and women for the experience groups. However, no performance differences were found between men and women, ruling out biological gender as a source of performance differences.

Impact

For surgical educators, these findings underscore the need to recognize individual differences, including impulsiveness, among trainees. Crafting tailored training

modules that consider how impulsiveness affects task performance holds promise for enhancing the overall effectiveness of laparoscopic training programs. Training programs could be adapted to encourage high-impulsive young surgeons to focus on areas such as damage reduction in relation to recognizing and mitigating tendencies towards impulsive behavior. A similar approach to training is implemented in the education of pilots, as the Federal Aviation Administration recognizes impulsiveness as a dangerous attitude. To prevent errors, pilots learn to recognize this attitude, and counteract it with a structured risk management decision-making process [48]. This might be one of the reasons why safety in aviation has significantly increased over the years [49].

Future research

Understanding the reasons behind the mitigating effect of professional experience on laparoscopic performance is crucial for developing educational strategies to mitigate its negative impact. A potential method to explore strategies to counteract impulsiveness involves think-aloud protocols, where surgeons articulate their thought processes during challenging simulations or surgical procedures. Post-simulation interviews can offer insights into surgeons' reflections, perceived impulsive tendencies, and strategies to maintain control and optimize outcomes. Identifying the mechanisms to counteract the influence of impulsiveness may facilitate knowledge transfer to novice surgeons, potentially expediting their learning curves and enhancing patient safety.

Conclusion

The personality trait of impulsiveness affects laparoscopic simulator performance of inexperienced trainees, in that trainees of high impulsiveness are faster but tend to create more tissue damage. The performance of experienced surgeons remained unaffected by impulsiveness, indicating that professional experience plays a role in mitigating its effects.

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CHAPTER 6

Peers versus Pros: Feedback using standards in simulation training

Wouter IJgosse, Bas Kengen, Harry van Goor, Jan-Maarten Luursema.

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ABSTRACT

Background

Creating and updating expert performance-based standards for simulators is labor intensive and requires the regular availability of expert surgeons. We investigated how peer performance based standards compare to expert performance based standards.

Methods

One hundred medical students took part in a four-session laparoscopic basic skills simulator training course. Performance for the FLS videotrainer tasks were compared between students who received feedback based on either peer standards, expert standards or no feedback at all (control group).

Results

No difference in performance between our feedback groups was found. Compared to the control group, they were 18–36% faster but made 52% more errors for tasks on the FLS video trainer (U range [93.5–957], average $p < .01$).

Conclusion

We demonstrated that feedback based on peer standards is equally effective as feedback based on expert standards. The found trade-off between speed and error is not desirable and warrants further investigation.

INTRODUCTION

Performance feedback is essential to the development of professional skills [1]. As such, it forms the core of current educational approaches such as proficiency-based training and deliberate practice [2,3]. In these approaches, students are stimulated to reflect on their performance by providing them with quantified performance feedback, and by contextualizing their performance using standards. This type of feedback is also known as automated feedback. Hereby standards are automatically displayed when trainees finish their tasks.

Early in laparoscopic simulator training, standards for simulation training were often based on vendor-provided settings but increasingly these standards are replaced by expert derived performance standards [4-6]. Training goals based on expert standards shorten learning curves, tailors the educational experience to the exact needs of the learner [5, 6] and have been demonstrated to produce uniform skills and improve operating performance [2, 3, 7-9]. Accordingly, a FLS videotrainer training program has been developed using expert standards [10, 11] and is now a requirement for American board certification [12, 13]. It is fair to say that contextualizing performance with expert derived performance standards is the gold standard in surgical simulation training. However, there is no universally accepted method to generate standards for training and issues of validity and reliability remain [14,15]. In addition, generating standards based on expert performance is a time consuming, labor intensive process which can be hard to prioritize in the busy schedule of the surgeon [16].

An alternative way to provide learners with automated feedback is by using standards based on averaged peer performance (peer standards). Peer standards are thought to encourage the novice to reach a performance level similar to or exceeding their peers [17]. Von Websky et al. showed that peer standards with external assessment are superior to self-controlled training [18]. In addition to being effective, peer standards are easier to generate since simulator performance data of students are easy to collect in the course of their training.

We compared learning based on peer standards to learning based on the gold standard (expert standards) by comparing student performance in three conditions. Students received automated feedback based on either peer standards [1], expert standards [2] or no feedback at all [3]. Students' performance was analyzed for different tasks on the well validated FLS videotrainer [19]. We expected that both peer standards and expert standards would lead to gains in performance compared to self-directed training without automated feedback. As current research about the value

of peer-derived performance standards is scarce we did not know how peer-derived performance standards would compare to expert-derived performance standards in terms of performance gains. In this study we aim to provide evidence for the validity of laparoscopic simulator standards based on peer performance, rather than the more common expert performance based standards.

MATERIAL AND METHODS

Participants and study design

We conducted this study at the surgical skills facility of the Radboud University Medical Centre for six consecutive months. Every month, a new cohort of medical students in their fourth year (total of six years medical school, 3 years bachelor, 3 years master) was offered a voluntary, four-session laparoscopic basic skills course as part of their (eight-week) surgical rotation preparation. After finishing their Bachelor track, students enter the internships that form the Master track stepwise in monthly groups of around 30 students. This means that at the start of the basic skills laparoscopy course, each cohort has similar knowledge and skills.

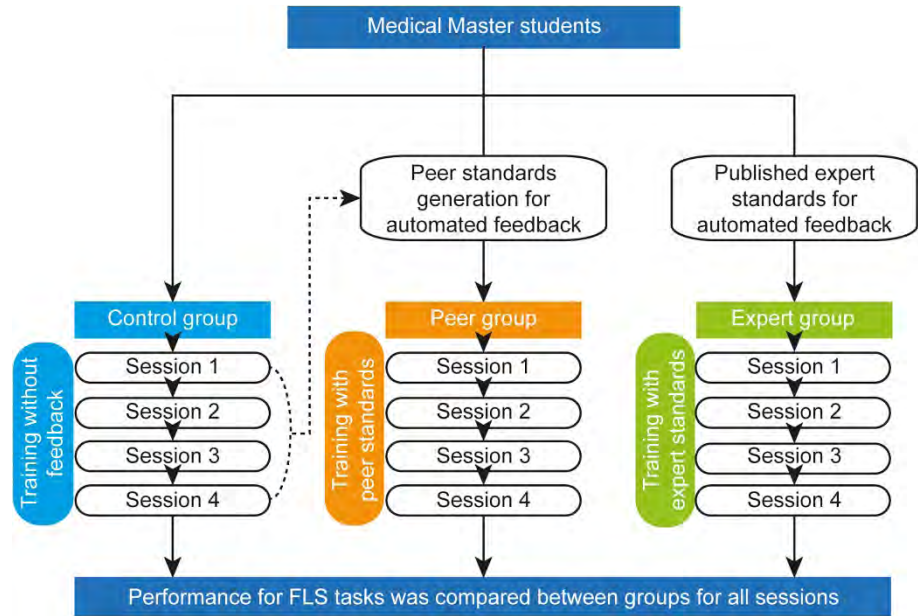


Figure 1. Study flowchart. At each session students rotated along the FLS videotrainer station and the LapSim virtual reality trainer station.

The study consisted of two experimental groups and one control group: Cohort 1 and 2 trained without automated feedback (control group); Cohort 3 and 4 trained with automated feedback based on peer standards (peer group) derived from the control group; Cohort 5 and 6 trained with automated feedback based on expert standards (expert group), see study flowchart (Figure 1). All participants of these six cohorts voluntarily signed an informed consent document allowing us to use their anonymized performance data for scientific study. It was made clear to the students that not signing would in no way affect their participation to this course or the assessment of their rotation. No formal ethics review was sought as this is not required under Dutch law for this type of study.

Training course design

We developed the four-session skills training course by ourselves to help students train psychomotor skills with the FLS videotrainer and the LapSim Virtual Reality (VR) trainer for, among other things, camera manipulation and 3D insights in laparoscopy. Students scheduled their training sessions using an online calendar. Self-selected groups of three scheduled four training sessions of one hour each (except for the first training session of 90 min, in which 30 min was reserved for instruction). During each session, participants rotated along a FLS videotrainer station (which was a combination of a support role and the FLS videotrainer station) and the LapSim VR trainer station, spending on average 20 min at the support role and each station, which allowed them to perform each offered training task once (Figure 2). Every session the same rotation schedule was used and students were not exposed to any form of laparoscopic practice outside this basic skills training course. The four training sessions had to be completed within three weeks, and students were discouraged from completing more than one training session on a single day in order to maximize learning [20]. At the first session of each group, each subject completed a demographics questionnaire. Also, a short instruction on how to perform the different tasks was given. No study coordinator was present during the remaining three sessions.

At the FLS videotrainer subjects performed three different tasks: Laparoscopic Labyrinth, Peg Transfer, and Precision Cutting. During Laparoscopic Labyrinth, first a printed labyrinth was connected on a plastic board by four clips and centered on the Velcro strip in the center of the marked square on the floor/base of the FLS videotrainer. Then a felt marker was placed in an in-house adapted laparoscopic instrument and placed in the left or right hole in the top of the trainer depending on whether the left or right hand was used to control the instrument (Figure 4). The task started when the felt tip touched the first dot. Then the subject had to trace the

path until reaching the second dot. This task was repeated for the other hand with a different color marker. Variables for this task were duration (seconds), number of line crossings, and number of disconnects of felt-tip and paper. We developed this task to help the trainee learn to correct for the amplification of movements (and tremor) due to the fulcrum effect.



Figure 2. Training stations: The FLS videotrainer and the LapSim virtual reality trainer.

Training stations: The LapSim VR trainer and the FLS videotrainer

FLS videotrainer station

This station was a combination of a laptop and a FLS videotrainer. Students used the laptop to monitor the performance of their colleague on the FLS videotrainer and recorded the resulting data in an in-house developed application (CurveSurfer) for generating individual learning curves. Depending on the experimental condition the student's own multi-session learning curves were contextualized by either peer standards or expert standards at the end of each task they performed on the FLS videotrainer. The CurveSurfer software would store task performance from each session, so as the course progressed, students' performance would become visible to them as learning curves (Figure 3). Students in the control group used CurveSurfer to fill out the scores of their colleagues, but no learning curves and standards were displayed.

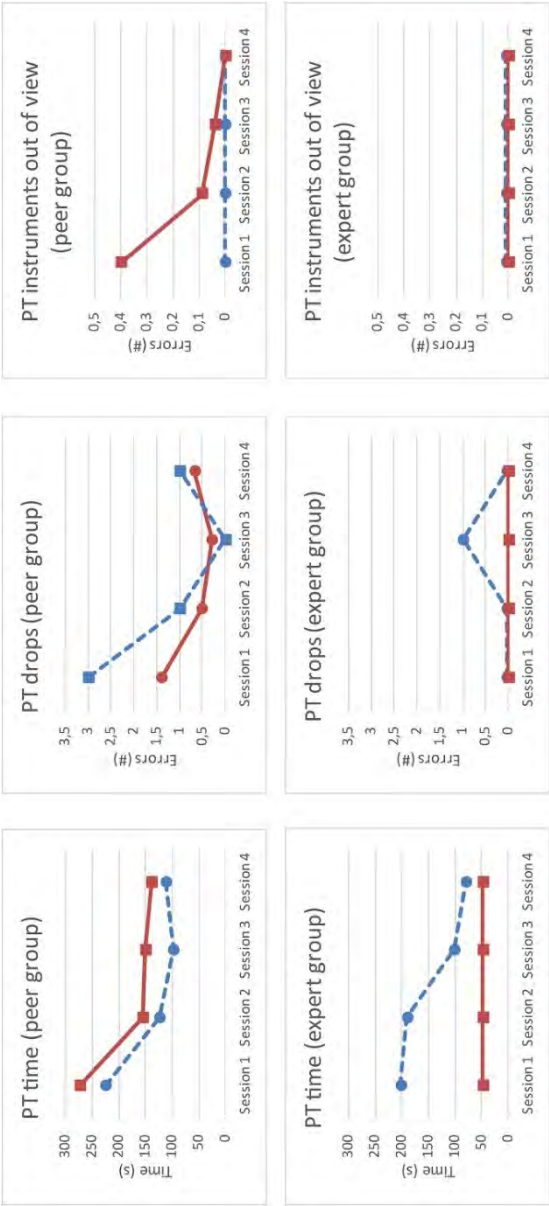


Figure 3. Example feedback windows from the CurveSurfer application. The top row visualizes how performance in the peer group was contextualized, the bottom row for students in the expert group. All graphs show one of the collected variables for the Peg Transfer task as shown in the title. The red straight line in each graph represents the type of feedback which was given, the blue interrupted line the individual learning curve of a random student in either the peer or expert group.



Figure 4. The printed labyrinth inside the FLS videotrainer. This student is showing right handed performance.

Peg Transfer and Precision Cutting are official FLS videotrainer tasks [21]. Quantitative performance measures were collected by their colleague using the laptop and consisted of total duration for each task, and error measures as described in the task descriptions. Precision Cutting was used as an overflow task to help students synchronize their rotations along the stations. Consequently, participants often could not finish this task and data for this task were not analyzed.

LapSim VR trainer station

At the LapSim VR trainer station the subject trained with two training programs, one focused on time, one on damage control. These programs included the following tasks: camera navigation, instrument navigation and coordination [22]. This setup required us to customize LapSim task settings. Consequently, we had no expert settings available that would have allowed us to make the LapSim part of our study and the LapSim data were not analyzed.

Peer standards and expert standards

Peer standards were displayed as learning curves and were based on the data from our first two cohorts, the control group. This means we calculated the mean scores for every variable for each session and these were graphically presented in CurveSurfer as a background learning curve to the individual learning curves for the students in the peer group (Figure 3, top row).

We used published and validated expert values for Peg Transfer and Precision Cutting [11]. Since these expert performance values were collected during a single

session, expert standards were not displayed as a learning curve but as a horizontal line for each variable. For the expert group, these lines were visible as a background to their own learning curves (Figure 3, bottom row).

Because the Labyrinth task is a self-developed task we did not have published expert values available. To derive those from our data, we calculated the ratio at session one between the expert values and control group values for the Peg Transfer and Precision Cutting task. We used the average of those two ratios to extrapolate hypothetical expert values for the Labyrinth task.

Apparatus

Every simulator station had its own setup:

The FLS videotrainer station consisted of an Asus laptop running Windows 7, a König USB 2.0-analogue audio/video converter, iSpy v6.8.2.023 desktop recording software, an in-house developed software application (CurveSurfer) to record performance and provide the participant automated feedback in the form of contextualized learning curves, and a stopwatch. The FLS videotrainer system was connected to a 17-inch video monitor, and all materials needed for the tasks performed on the FLS videotrainer including the materials for the custom task were provided.

The LapSim VR station consisted of the LapSim VR trainer with a desktop computer running Windows, a laparoscopic interface consisting of Simball hardware (G-coder Systems, Västra Frölunda, Sweden) and Surgical Science's LapSim v.3.0 training software (surgical Science, Göteborg, Sweden).

Data were analyzed with the IBM SPSS Statistics v.23 package.

Data preparation

Video was recorded for the FLS videotrainer and data for duration and error were collected for the Peg Transfer task by two blinded observers who each scored half of the recorded videos. Duration for the Labyrinth task was also scored from video, but the error variables for this task were scored from the collected, filled-out Labyrinth papers. Since only objective observations were made by the blinded observers, we chose for a method that reduces workload but does not allow for reporting inter-rater reliability. Because the number of errors was too low for each separate task we could not use this data for analysis. Instead we added the number of errors across both tasks to create a single error measure for each session, for each person. Due to scheduling conflicts and the voluntary nature of this course, data loss for the fourth training

session was high. Therefore, we compared performance at session 1–3 between students with and without participation at session 4 to see if there had been a self-selection bias. Finding no such bias, we included all four sessions in our analysis. We also controlled rotation schedule for performance metrics on the simulators. No performance differences were found between the participants implying that it did not matter at which station the students started and moved on following its scheme.

Data analysis

Some of our variables were not normally distributed (as assessed by a Shapiro-Wilks test), and therefore we used Mann-Whitney U tests for our analyses. To assess the potential of standards for automated feedback during training, we compared performance contextualized by peer standards to performance contextualized by expert standards. To verify the effect of automated feedback, we combined the feedback groups and compared performance of this group with the control group. Effect sizes for these analyses are reported as r [24. 25]. A level of $p \leq .05$ was considered statistically significant.

RESULTS

Participants

A total of 100 participants started with our training course. Due to scheduling constraints, 85 students finished the first three sessions, but only 52 finished all four (dropout rates of 35%, 38% and 65% for the peer, expert and control group respectively). Group size and available demographic data are shown in Table 1. Demographic data were missing for 16 subjects who did not fill out the digital form. There were no demographic differences between groups and none of the demographic variables affected performance. Only two students reported previous laparoscopic experience. Both students did not show any different performance compared to the other students.

Expert standards versus peer standards

The only significant difference between the expert group and the peer group in speed was for the Peg Transfer task during the second training session, where the expert group outperformed the peer group. No differences between the peer group and the expert group were found for error (Table 2).

Table 1. Demographic data for the three groups. a = Demographic data for 6 students were missing in this group. b = Demographic data for 10 students were missing in this group. c = Two students assisted during a laparoscopic procedure, one did this three times, the other five times.

	Peer standards feedback group (<i>n</i> = 23) ^a	Expert standards feedback group (<i>n</i> = 40)	Control group (<i>n</i> = 37) ^b
Male, %	43.5	32.5	24.3
Age, y	24 ± 2	24 ± 2	24 ± 1
Right hand dominance, %	93.8	87.5	72.7
Self-reported game experience, %	31.3	25	15
Laparoscopy experience ^c , <i>n</i>	0	2	0

Table 2. Performance comparison between the peer group and expert group (Mann-Whitney U test results). Performance distributions in the two automated feedback groups did not differ significantly except for the Peg Transfer task at session 2. An asterisk indicates significant performance differences. PTt stands for Peg Transfer time (s); Lt stands for Labyrinth time (s); E stands for number of errors.

Peer standards feedback group				Expert standards feedback group			statistics		
Task	<i>n</i>	<i>M</i>	<i>SD</i>	<i>n</i>	<i>M</i>	<i>SD</i>	<i>U</i>	<i>p</i>	<i>r</i>
PTt1	23	214.74	101.86	40	189.85	56.11	417	.54	-.08
PTt2	23	146.43	27.82	37	121.03	29.08	217	.00*	-.41
PTt3	23	119.61	26.33	38	113.76	26.59	404	.62	-.06
PTt4	15	107.67	17.80	25	99.24	26.22	139	.18	-.21
Lt1	23	145.17	58.78	39	128.77	38.59	355.5	.18	-.17
Lt2	23	110.52	29.10	37	100.81	22.96	337	.18	-.17
Lt3	23	96.91	26.88	39	87.54	20.19	355.5	.18	-.17
Lt4	15	82.93	15.57	25	81.16	21.41	160	.44	-.12
E1	23	12.83	7.29	39	13.41	6.85	409	.56	-.07
E2	23	11.13	5.02	37	11.08	4.74	409	.80	-.03
E3	23	11.26	5.23	38	10.18	5.93	377.5	.38	-.11
E4	15	7.47	4.55	25	9.72	6.56	154	.35	-.15

Feedback versus no feedback

The combined automated feedback groups were significantly faster compared to the control group for Peg Transfer in all sessions. However, the control group significantly outperformed the combined feedback groups on error for the first three sessions. For the Labyrinth task, the combined feedback groups were significantly

faster at session 3 and 4 (Table 3). Performance across all three groups for time and error is graphically presented in Figure 5, Figure 6, Figure 7.

Table 3. Performance comparison between the control group and the automated feedback group (Mann-Whitney U test results). Performance distributions in the control and the combined automated feedback groups differed significantly except for the Labyrinth task at session 1 and 2. An asterisk indicates significant performance differences. PTt stands for Peg Transfer time (s); Lt stands for Labyrinth time (s); E stands for number of errors.

Control group				Automated feedback group			Statistics		
Task	<i>n</i>	<i>M</i>	<i>SD</i>	<i>n</i>	<i>M</i>	<i>SD</i>	<i>U</i>	<i>p</i>	<i>r</i>
PTt1	33	272.97	131.95	63	198.94	76.21	598	.00*	-.35
PTt2	33	155.18	36.55	60	130.77	30.98	577.5	.00*	-.34
PTt3	23	150	37.26	61	115.98	26.43	297.5	.00*	-.44
PTt4	12	138.83	44.78	40	102.40	23.54	93.5	.00*	-.44
Lt1	34	154.94	73.82	62	134.85	47.30	872	.16	-.14
Lt2	32	106.59	33.26	60	104.53	25.70	957	.98	-.00
Lt3	23	105.52	25.61	62	91.02	23.14	474.5	.02*	-.26
Lt4	12	96.92	21.04	40	81.82	19.23	148.5	.05*	-.28
E1	31	8.55	5.93	62	13.19	6.96	563	.00*	-.34
E2	32	5.50	5.57	60	11.10	4.81	375	.00*	-.50
E3	21	4.14	2.78	61	10.59	5.66	195	.00*	-.52
E4	12	5.83	3.90	40	8.88	5.93	174	.15	-.20

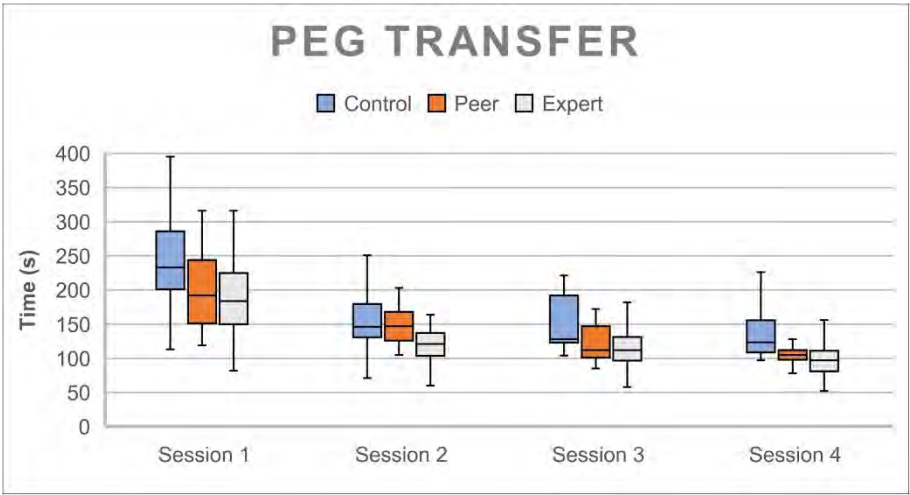


Figure 5. Peg Transfer: performance differences between groups for the variable time.

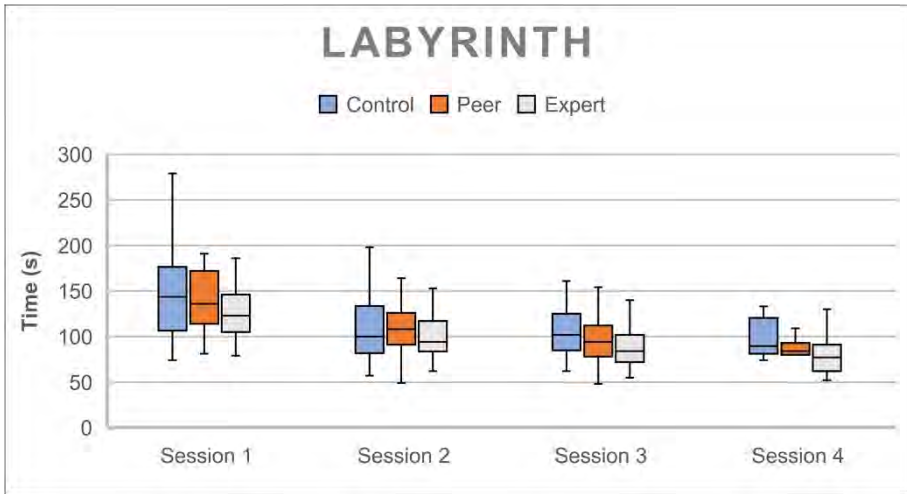


Figure 6. Labyrinth: performance differences between groups for the variable time.

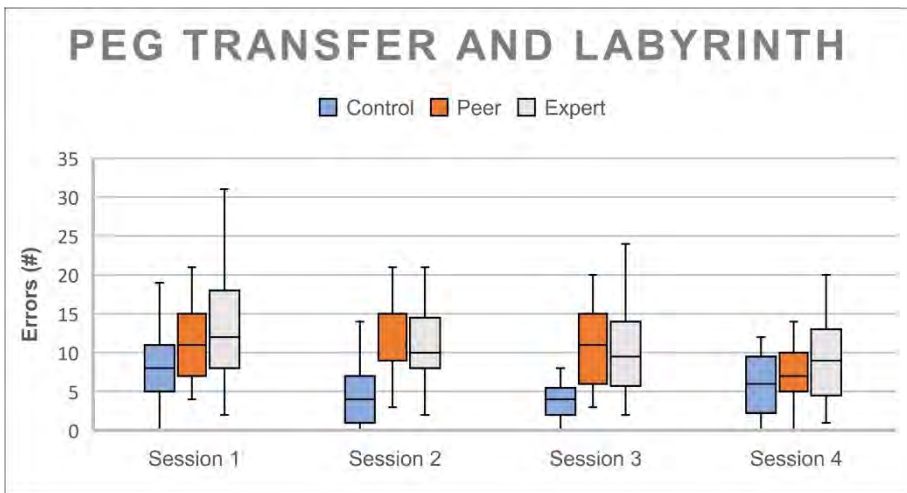


Figure 7. FLS videotrainer task performance for Peg Transfer and Labyrinth. Figure 5 and Figure 6 display the variable time whereas Figure 7 displays the total amount of errors made.

DISCUSSION

Peer standards versus expert standards

We found that peer standards lead to similar learning gains as expert standards. This extends the findings of Websky et al. [18], who found peer performance-based feedback with external assessment to be more effective compared to no feedback.

Using peer performance-based feedback during simulation training provides a welcome alternative to expert-based performance values, due to limited availability of experts to create such values and the diminishing number of experts with little or no simulator experience. Institutions of academic medicine provide simulation training to a steady influx of trainees with no laparoscopic experience, which provides easy and plentiful opportunities to generate peer performance-based standards.

An additional benefit of peer-performance based standards is that they can be provided to the student in the form of learning curves, with different values for each session. Expert performance-based standards typically consist of a single value, which can be represented only as a horizontal bar. Peer performance-based learning curves provide the student with standards for both end goals and session goals, which means more context for comparison.

Feedback induced performance trade-off

Performance feedback is considered essential to learning and to educational approaches such as deliberate practice and proficiency-based training [2, 3, 8]. However, we found that trade-offs between different performance variables may occur as a consequence of this automated feedback and this can have the unwanted consequence of training our students for speed at the cost of safety. We think that having contextualized our students' learning curves with either expert values or peer-performance based learning curves may have stirred a sense of competition that led to faster, but less careful task execution. As training for safe surgery is paramount these trade-offs should be further investigated.

Self-reflection

An interesting observation can be made as to self-reflection based on standards: the performance of both automated feedback groups in our study improved already before any feedback was available to our students. Knowing that their performance will be contextualized using standards is apparently sufficient to improve speed. Such effects will have to be accounted for in future studies assessing the role of automated feedback.

Limitations

Demographics were missing for sixteen of our one-hundred subjects. Since all participants were drawn from a homogenous population we expect no differences between groups if these data were complete.

Dropout rates were high for the fourth session. As our laparoscopic basic skills course at that time was not mandatory, and time available for extracurricular activities was limited, students were not always able to complete the full four sessions of our training course. Since we did not find performance differences on sessions 1–3 between students who performed three versus four sessions, we have no reason to assume a performance bias during session 4, and we analyzed all four sessions.

Since the labyrinth task has not yet been officially validated, we had to extrapolate expert values for this task. We developed this task to help our students anticipate the amplification of movements caused by working over a fulcrum [26, 27]. Given the ecological validity of this task, we felt it would be interesting to include the resulting variables despite its validity status.

Future research

To enhance the usefulness of training methods with automated feedback, we want to find ways to correct the bias students show towards speeded performance at the cost of making more errors. The addition of a theoretical framework that emphasizes damage control in combination with targeted supervision and intervention may help the student properly contextualize and prioritize aspects of their performance [1, 28, 29, 30, 31]. This should lead to a more balanced development of skills. The combination of objective, quantified feedback provided by learning curves, the provision of theory and the focused, personal approach of an experienced instructor might make for a powerful combination. Cohort studies such as the one presented here provide a great opportunity to investigate the effectiveness of such additions.

Conclusions

We demonstrated the equivalence of expert standards and peer standards as automated feedback for laparoscopic simulator training. As peer standards are easier to generate, peer performance-based training may become a valuable addition for our training courses. We unexpectedly identified a feedback induced performance trade-off in which students prioritized speed over error. To optimize the use of standards, future research is needed to assess whether the way in which feedback is displayed and contextualized reduces the amount of errors.

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CHAPTER 7

Speed versus Damage: using selective feedback to modulate laparoscopic simulator performance

Bas Kengen, Wouter IJgosse, Harry van Goor, Jan-Maarten Luursema.

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ABSTRACT

Background

Adaptive training is an approach in which training variables change with the needs and traits of individual trainees. It has potential to mitigate the effect of personality traits such as impulsiveness on surgical performance. Selective performance feedback is one way to implement adaptive training. This paper investigates whether selective feedback can direct performance of trainees of either high- or low impulsiveness.

Methods

A total of 83 inexperienced medical students of known impulsiveness performed a four-session laparoscopic training course on a Virtual Reality Simulator. They performed two identical series of tasks every session. During one series of tasks they received performance feedback on duration and during the other series they received feedback on damage. Performance parameters (duration and damage) were compared between the two series of tasks to assess whether selective performance feedback can be used to steer emphasis in performance. To assess the effectiveness of selective feedback for people of high- or low impulsiveness, the difference in performance between the two series for both duration and damage was also assessed.

Results

Participants were faster when given performance feedback for speed for all exercises in all sessions (average z -value = -4.14 , all p values $< .05$). Also, they performed better on damage control when given performance feedback for damage in all tasks and during all sessions except for one (average z -value = -4.19 , all but one p value $< .05$). Impulsiveness did not impact the effectiveness of selective feedback.

Conclusion

Selective feedback on either duration or damage can be used to improve performance for the variable that the trainee receives feedback on. Trainee impulsiveness did not modulate this effect. Selective feedback can be used to steer training focus in adaptive training systems and can mitigate the negative effects of impulsiveness on damage control.

INTRODUCTION

Personality is a major source of differences in behavior between people [1-3]. Emerging research is highlighting differences in personality between surgeons and controls; in these studies surgeons typically show heightened extraversion [4-6]. In traffic and in high-skilled professions such as pilots, the related personality trait of impulsiveness has been shown to correlate with dangerous behavior [7-12]. Patients may be at risk if a similar association is present in the operating room. In a previous simulator-based laparoscopic training study, we found that high-impulsiveness trainees created more damage in comparison to low-impulsiveness trainees but were equally fast [4]. An adaptive training approach, already used in military medical skills acquisition and retention, to effectively train personnel of different skills levels [13], could potentially counteract the negative effects associated with high impulsiveness.

In adaptive training, variables such as the difficulty level of the training task are varied as a function of trainee performance, to maximize learning and keep the trainee's interest level high [14]. Many different forms of adaptive training have been described [15]. In its simplest form it means adapting the difficulty of the exercise based on the performance of the apprentice. Other examples are adjusting task difficulty to individual differences such as personality or learning styles, or altering perceived difficulty levels by modifying performance standards [16, 17]. Advantages of this type of training are among others: a personalized learning experience, focused remediation of individual weaknesses in skilled performance, and its ability to give teachers a better insight in the students' capabilities. Adaptive training has been proven effective in a variety of novel educational fields[18-22], including virtual reality (VR) based training and serious gaming [23, 24].

VR training is increasingly used for the acquisition of psychomotor skills needed for minimally invasive surgery. One of the advantages of these electronic simulators is the large amount of quantified performance parameters they record. Currently, this information is mostly used to provide feedback to its users to demonstrate their progress. However, this feature provides an opportunity to steer emphasis of a user to a specific aspect of a task, for example speed or errors made. In this way performance parameters could be used to create a form of adaptive training. Such personalized training which steers the student towards improving his or her weaknesses may increase training quality and efficiency. A previous review indicated that different skills benefit from different types of feedback, for example process feedback may be a more effective way to train decision making than outcome feedback [15]. However, little is known about types of feedback in relation to surgical skills training.

The research reported here investigated two questions: Can selective feedback be used to steer student performance towards either damage control or speed in laparoscopic simulator training? If so, does impulsiveness impact these changes? We expected selective feedback to influence performance positively for the targeted performance measure. We did not formulate an expectation as to whether the effect of selective feedback would be impacted by impulsiveness.

MATERIALS AND METHODS

Subjects and study design

Every month, around thirty first-year master students of Medicine with no- or very limited surgical experience start their surgical rotations at the Radboud University Medical Center. These students were given the opportunity to voluntarily sign up for a basic laparoscopic skills simulation training course as part of their rotation. During all training sessions, students performed two series of exercises that only differed in whether feedback was provided on speed or on damage control. We collected data over a period of six months for a total of 83 participants. Students were explicitly told that enrollment in the study was voluntary and declining would not impact their participation to the course or the assessment of their rotation. All students elected to participate, and filled out a digital demographics- and impulsiveness questionnaire. Performance on time and damage was compared for both feedback series, and within each series for students of high- and low impulsiveness. The study design was not submitted to an ethical board, as this was not required for this type of research under Dutch law at the time of data collection [25]. Voluntary informed consent was obtained from all participating students.

Course design

The course consisted of four 60-minute sessions, scheduled on different days to maximize learning [26, 27]. The four training sessions were performed within 3 weeks, with no more than one training session scheduled on a single day (distributed practice). Previous research demonstrated similar retention of a complex surgical motor skill for a weekly and a monthly training schedule [28]. We do not expect different time intervals between sessions to result in significant performance differences. Self-selected groups of three students scheduled their sessions in an online calendar. Participating students were assigned a random login code to the VR simulator to ensure anonymity. During each session, students would rotate along the VR trainer station, the Fundamentals of Laparoscopic Surgery (FLS) trainer station, and a support station to assist the student at the FLS trainer station with collecting performance data (which was not automated for this station as it was for

the VR station)(figure 1). During the first session the students were introduced to the available training stations by one of the researchers. The other training sessions were not supervised. The participants started at the same training station every session.

During the first session students completed two digital questionnaires while they were at the support station: a digital demographics questionnaire including questions for previous laparoscopic (simulator) experience, and a digital version of the Eysenck Impulsiveness Inventory to collect information about impulsiveness.

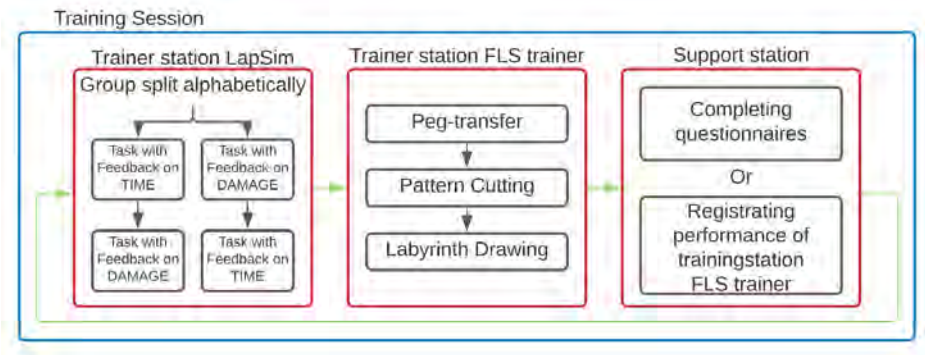


Figure 1. Flowchart for a single training session. Participants always rotated between the stations in the same order and performed at each station once in each session. The total course consisted of four of these training sessions.

Training stations: The LapSim VR trainer and the FLS videotrainer

LapSim VR trainer station

At this station, during each session, students performed two series of the same four tasks on the LapSim VR trainer. The LapSim Virtual Reality trainer is a well-researched simulator and transfer of skills gained from training on the LapSim to operating room performance has been established [29-31]. The series differed only in feedback emphasis: during one series, students received feedback via the simulator on duration only, and for the other they received feedback via the simulator only on damage parameters. Limited feedback for both damage and duration was given during the tasks. The screen glowed red when participants inflicted virtual damage, and in one of the tasks, subtasks would end if the participant acted too slow. Quantitative summary feedback in relation to normative expert values was given at the end of each task for either speed or damage, implementing our experimental conditions. This consisted of time in seconds for duration (time on task), number of damage inflicting incidents (tissue damage), and deepest virtual wound in millimeters (maximum damage).

Students were split alphabetically by their last name into two equal-sized groups to start with either the speed series or damage-control series. Both series were completed during each session by all students. Students were informed of this design, and knew when they were training for speed or for damage control. The four tasks were ‘camera navigation’, ‘instrument navigation’, ‘cutting’ and ‘lifting and grasping’. These are tasks where the student operates the camera or uses instruments such as a grasper or a ligation device in a simulated abdominal cavity to complete simple, non-procedural exercises involving simulated blood vessels, gall stones and suturing needles. Detailed descriptions of the tasks can be found at the website of Surgical Science [32].

FLS videotrainer station

To prepare students for their surgical rotation they also trained on the FLS trainer, but this data was not used for this research. On this videobox trainer students trained basic skills. Performed exercises were ‘peg-transfer’, ‘pattern cutting’ and ‘labyrinth drawing’. A description of the first two tasks can be found at the website of Fundamentals of Laparoscopic Surgery [33]. The last exercise is a self-developed task where students have to trace a path through a labyrinth using a marker attached to a laparoscopic instrument, designed to learn to anticipate the amplification of movement caused by working over a fulcrum with the laparoscopic instruments. The third student who was not training at a training station recorded the performance of the student practicing at the FLS videotrainer station to help them monitor progress.

Simulators and apparatus

The LapSim VR trainer station consisted of a desktop computer connected to Simball Hardware (G-coder Systems, Västra Frölunda, Sweden), running Surgical Science’s LapSim® Virtual Reality Simulator training software v.3.0 (Göteborg, Sweden). This is a validated VR simulator designed to teach basic skills and some laparoscopic procedures[29, 34, 35]. Data was saved and stored in Microsoft Excel 2007 and analyzed with IBM SPSS Statistics for Windows, Version 22.0 (Armonk, NY: IBM Corp).

The FLS videotrainer is a validated box trainer developed by SAGES and ACS [36-38]. This box trainer was connected to a 17-inch Philips LCD monitor.

A laptop running windows 7 was installed for the students to complete the questionnaires. Questionnaires were created with Limesurvey Version 1.92+, a web application to create surveys.

The Eysenck Impulsiveness Inventory consists of 63 yes-no questions and was developed in 1978 by S. B. G. Eysenck and H.J. Eysenck for the measurement of three

primary personality traits; impulsiveness, venturesomeness, and empathy [39-41]. Examples of these questions are “Do you often buy things on impulse?”, “Do you generally do and say things without stopping to think?” and “Do you often change your interests?”. Previous studies demonstrated good scale reliability for impulsiveness for this broadly used test, with a Cronbach's alpha ranging between 0.82-0.84 for impulsiveness [42, 43]. Reliability for venturesomeness and empathy demonstrated questionable to good reliability, with Cronbach's alpha ranging between 0.65-0.85.

Data preparation/ Analysis

Data on the LapSim was automatically registered by the simulator. The parameters instrument time and tissue damage were included in data-analysis, as these are the primary outcome measures of this research. Instrument time records the total duration of an exercise, tissue damage records the number of instances virtual damage was created. The task ‘Camera navigation’ was used as warming-up exercise and not analyzed. A p value of $< .05$ was considered significant.

Shapiro-Wilk tests demonstrated that not all of the data followed a normal distribution. For damage this was caused by a floor effect, as participants did not always create damage, which happened most often during the last training session. For time it was caused by a ceiling effect for the exercise ‘instrument navigation’, as there was a maximum time-limit which was reached by 21.3% of the students during the first session. During the remaining sessions this limit was reached by less than 2% of the students. Wilcoxon signed ranks tests were performed to compare the two training series. This was done for every exercise and session separately.

Two participants had limited laparoscopic camera assistant experience. Their performance however was between the first and third quartile for both damage control and speed, and their performance data was kept in the dataset. The other participants reported no laparoscopic experience, ensuring equal experience levels.

The Eysenck Impulsiveness Inventory measures impulsiveness, venturesomeness, and empathy. Impulsiveness has been shown to correlate with dangerous behavior in traffic, aviation and decision making [7-12]. As far as we know, for empathy and venturesomeness such links have not been demonstrated. Additionally, the locus of this study was a single-user laparoscopic basic skills course with simple, predictable exercises. In contrast to the more socially and technically complex environment of the operating room, we did not expect empathy or venturesomeness to affect training outcomes. To not negatively impact the power of our study by introducing additional variables, we focused on the personality trait of impulsiveness in this

study. Impulsiveness scores were calculated at the end of the data-collection phase to prevent information bias for both students and researchers.

Based on the results of the Eysenck Impulsiveness Inventory the students were divided into two experimental groups after data collection, a group of low impulsiveness and a group of high impulsiveness. The low-impulsiveness group consisted of all the students that scored equal or lower than the median score, the high-impulsiveness group of all students that scored higher. There were no significant differences in the distribution of the impulsiveness-groups between the starting order of the training stations or training series.

To examine if students of high-impulsiveness and low-impulsiveness are equally suitable for this type of adaptive training, we compared the effect of altered feedback between the two groups. To do this, we subtracted performance parameters of the training series with emphasis on damage control from the performance parameters of the training series with emphasis on speed. The resulting differences were then compared between the two impulsiveness-groups with Mann-Whitney U tests. This was done for both speed and damage, for every exercise and session separately.

RESULTS

Participants

A total of 83 students participated (Table 1). Of these students 62.7% completed all four sessions. Due to technical issues, data for two students was lost. Data of the remaining 81 participants were analyzed. Age ranged between 21-30 years (mean 23.6 years) and 26 participants were male (32.1%). The preferred hand was the right hand for 74 participants (91.4%). The groups of high- and low impulsiveness students did not differ for age, sex, preferred hand, and laparoscopic experience.

Table 1. Summary of characteristics of study participants.

Group	Total	Low-impulsive	High-impulsive
Number	n=81	n=41	n=40
Sex	26/81 male (32.1%)	12/41 male (29.2%)	14/40 male (35.0%)
Age	23.9 years (21-30 years)	23.3 years (21-30 years)	23.8 years (21-29 years)
Preferred hand	74/81 right hand (91.4%)	37/41 right hand (90.2%)	37/40 right hand (92.5%)
Laparoscopic experience	2/81 (2.5%)	1/41 (2.4%)	1/40 (2.5%)

Differences in performance between the two training series

Comparisons for performance on speed and on damage, within both the speed and damage feedback series, are shown in Figure 2. Participants were significantly faster when given performance feedback for speed for all exercises in all sessions; Participants performed also significantly safer when given performance feedback for damage, with the exception of the ‘Lifting & Grasping’ exercise during the first session (Table 2).

Table 2. Results of the Wilcoxon signed ranks tests comparing performance of every task between the two training series; speed versus damage control.

Instrument navigation								
Total time					Tissue damage			
	session 1	session 2	session 3	session 4	session 1	session 2	session 3	session 4
Z-value	-4,20	-6,03	-6,57	-5,70	-3,71	-5,50	-6,27	-4,97
Significance	,00	,00	,00	,00	,00	,00	,00	,00
Lifting & Grasping								
Total time					Tissue damage			
	session 1	session 2	session 3	session 4	session 1	session 2	session 3	session 4
Z-value	-3,52	-2,81	-4,01	-4,30	-1,58	-4,59	-5,38	-4,39
Significance	,00	,01	,00	,00	,11	,00	,00	,00
Cutting								
Total time					Tissue damage			
	session 1	session 2	session 3	session 4	session 1	session 2	session 3	session 4
Z-value	-3,73	-3,57	-2,50	-2,72	-2,14	-3,90	-4,03	-3,82
Significance	,00	,00	,01	,01	,03	,00	,00	,00

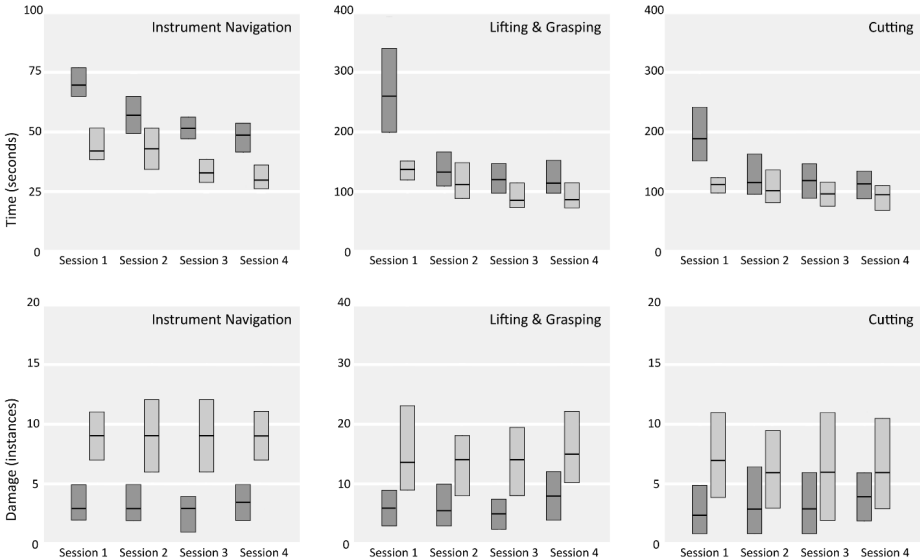


Figure 2. Performance comparison for the speed and damage series, for each session and task. Damage series performance is dark gray, speed series performance is medium gray. The black horizontal stripes indicate median values, the boxes indicate quartiles. All damage series and speeds series pairs are different, with the exception of damage in the first 'Lifting & Grasping' session.

Influence impulsiveness on performance differences between the two training series

Differences in performance between the two training series did not differ between the low and high-impulsiveness group for any task or session (Figure 3). Even when comparing the first quartile of students of low-impulsiveness to the fourth quartile of students of high-impulsiveness no differences were found.

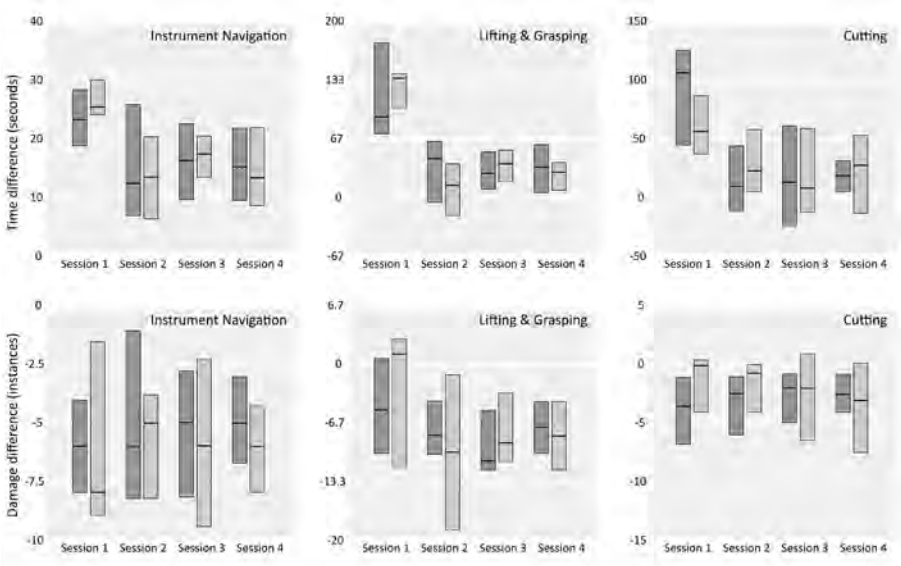


Figure 3. Performance differences between the damage and speed feedback series, compared for students of high and low impulsiveness. Low impulsiveness shown as dark gray, high impulsiveness as medium gray. Black horizontal stripes indicate median values, the boxes indicate quartiles. Feedback for damage and for speed induced the same performance differences for students of low- and high impulsiveness in all sessions of all tasks (and thus was equally effective for both groups).

DISCUSSION

In adaptive training, task variables and task complexity change throughout the training experience to provide the trainee with an optimal challenge. Adaptive training optimizes training effectiveness and efficiency as it can accommodate individual differences between trainees in their path towards competency. Adaptive training systems have been proven effective in areas such as improving memory, rehabilitation, and x-ray screening [18-22]. There are several ways to implement adaptive training; for example, gaming related levels that increase in difficulty based on the player' skills level (seen in serious games [24, 44, 45]), or individual trajectories that steer trainees toward tasks designed to remedy specific lapses in

skills or knowledge. In this study, we have established the potential use of selective performance feedback to implement adaptive training for surgical skills.

In earlier research we established the effect of impulsiveness on laparoscopic simulator performance [4]. High-impulsiveness students created more damage but were not faster in various basic skills tasks. As damage control is a major goal of surgical skills training, adaptive training could optimize training efficiency by emphasizing damage control related feedback for students of high impulsiveness. This could be straightforward to implement, as we found in this study that trainee performance was strongly biased towards either speed or damage control by the type of feedback they received, regardless of trainee impulsiveness status.

Finding that impulsiveness does not impact the effect of selective feedback contrasts with earlier research that found different personalities react differently to adaptive training, with personality traits such as openness to experience and neuroticism correlating positively with adaptive training outcomes [46]. Personality is a multi-faceted construct, as is surgical performance, and more studies are needed understanding the relations between this source of individual differences and surgical performance. Of special interest would be to study the relation between personality and operating room performance, where team functioning is an additional variable likely to be affected by personality. This relation would remain undetected during simulator skills training, which typically happens on an individual basis.

Limitations

Our study has a few limitations. The task ‘instrument navigation’ has a time limit and shuts down if the items of the task are not completed before the limit is reached. During the first training session only, 21.3% of the students were not able to finish this task in the allotted time span. As a consequence, performance differences for this task during this session are smaller than they would have been under unlimited temporal conditions. Despite this limitation we found large and significant differences in performance on this task and session under selective feedback.

Also, we did not exclude students who did not complete all four sessions and this could potentially be a source of bias. Incomplete courses were mostly caused by time constraints of the students and resulting scheduling conflicts. However, we cannot exclude the possibility of self-selection by high-performing, highly motivated students to finish the course. This could potentially cause a bias towards higher performance during session 3 and 4. To assess the likeliness of this scenario, we compared performance during the first two sessions for students who would finish

the course and those who would not. We did not find differences in performance for these groups and thus performance bias caused by self-selection is not likely to have impacted our results.

As this study was performed in an educational setting at the internship stage without proficiency-based criteria, it is not immediately clear what the ramifications are for the operating room, and follow-up translational work is needed. However, studies such as ours show that setting explicit goals followed by summative feedback does impact performance, and this ultimately can contribute to the culture of safety in and out of the operating room.

Students knew whether they were training speed or damage control, which could make it conceivable that performance differences were not caused by the different feedback, but simply because the participant tried to perform faster or with lesser damage. However, in an unpublished pilot study where students were solely instructed to focus on either speed or damage control and feedback did not differ, we did not find differences in performance in the data. Therefore, we expect differences in performance between the two training series in this study to be caused by the different feedback.

Future research

We are only starting to understand the relations between individual differences and surgical performance. We have begun to study impulsiveness, relevant for damage control [4, 7-12, 47], but other individual differences need to be taken into account as well. Personality includes more aspects than just impulsiveness which need to be investigated. Also, for the spatially challenging aspects of minimally invasive surgery for instance visuospatial ability is a relevant individual difference [48]. Team dynamics in the operating room are likely to be impacted by personality, and 'Big Five' personality traits need to be studied in this context (as has been done in fields such as product design and nuclear powerplant operation [49, 50]). The better we can predict surgical performance based on individual differences, the more efficient and effective our adaptive training systems can be.

Research in this area however would be complex, requiring large datasets to address the relations between the many variables of interest. An approach to speed up this effort might be to use digital simulation training and digital testing for relevant individual differences in a multi-institutional effort to collect the required data. Given the dynamic, complex, and incomplete nature of such data, a machine learning approach based on Bayesian network modeling would be necessary to expedite the

analysis of such data [51]. Dynamic, real-time analysis and modeling would open up exciting possibilities for adaptive training, team selection, and case assignment.

Conclusion

Targeted, selective feedback on selected performance measures can be used to alter training focus and performance. Trainee impulsiveness did not modulate this effect, and selective feedback can be used to design adaptive training systems that mitigate the negative effect of impulsiveness on damage.

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CHAPTER 8

General Discussion

Surgical competence encompasses a multifaceted blend of knowledge, patient care, communication skills, professionalism, and surgical technical skills [1]. Achieving and maintaining surgical competence requires extensive and life-long learning. Individual characteristics of young surgeons such as cognitive ability and personality are likely to influence this learning process. Yet, little is known about this relation. Standardized 'one size fits all' laparoscopic training programs pay little attention to individual differences as they offer a single, uniform pathway to reach an 'expert level'. A lack of knowledge pertaining to the relation between individual differences and the development of surgical skills thus risks over-training some, under-training others, and being most effective and efficient only for a generalized, 'standard' trainee.

In this thesis we studied the effects of individual differences between surgical trainees on laparoscopic performance and contemplated how these differences could be harnessed to elevate the standards of surgical skills education. Our investigations included an in-depth analysis of laparoscopic performance among surgical consultants and surgical trainees, both interns and residents, in which we explored the relationship between individual characteristics and laparoscopic skill development, to uncover patterns, strengths, and areas that require improvement. Building on our findings, we aspire to provide insights into how these individual differences can be harnessed to tailor surgical education programs. By recognizing and accommodating these variations, we hope to enhance the overall efficiency and effectiveness of surgical (skills) training and ultimately contribute to the development of more competent and proficient surgeons. Let us delve further in the findings and implications of this thesis, starting with a key aspect of our research: adaptive training.

Adaptive Training

In recent years, the landscape of education and training has evolved significantly, driven by the need to support the diverse personal qualities and abilities of individuals [2]. A key approach that has emerged in this context is adaptive training, which aims to enhance the learning experience by adjusting the instructions to meet the unique needs of each learner. Adaptive training is not a one-size-fits-all solution, but a dynamic and flexible process that continuously evolves as the learner advances. The concept of adaptive training is supported by a growing body of research across various fields. Simulation-based training in medical education, for instance, has been shown to enhance the acquisition of procedural skills [3], particularly when tailored to individual trainee needs [4].

Especially adaptive simulations that respond to real-time trainee performance provide a more engaging and effective learning experience by continuously challenging the trainee at an appropriate level [5]. A comprehensive review by Vaughan et al. (2016) highlights the benefits of adaptive learning technologies that customize educational content based on individual performance and characteristics, ensuring efficient and effective learning outcomes [6]. In adaptive training, variables are adjusted according to the performance of the trainee and to individual differences to enhance learning outcomes and maintain motivation [7]. Adaptive training has shown effectiveness in various domains, such as memory improvement, rehabilitation, and x-ray screening [8-11]. It is already effectively used for military medical skills acquisition and retention [12]. By implementing similar strategies in regular surgical training, unique strengths and weaknesses of each trainee can be addressed more effectively. For instance, a trainee struggling with spatial orientation but excelling in motor skills might receive targeted feedback and exercises designed to enhance their spatial reasoning and ability to manipulate objects in three-dimensional space.

Adaptive training involves the real-time modification of instructional methods based on ongoing assessments of the needs of the learner. This can occur at both micro and macro levels [13]. Microadaptive adjustments are made during the training process and are based on the performance and progress of the trainee [13]. These adjustments can include changing the difficulty of tasks, providing immediate feedback, or altering the pace of instruction to better match the current abilities and learning speed of the trainee. For instance, if a trainee demonstrates proficiency in a particular skill, the system might introduce more complex tasks to keep the trainee challenged and engaged. Conversely, if a trainee struggles with a specific concept, the training program can offer additional resources, practice opportunities, or alternative explanations to facilitate understanding and mastery. Macroadaptive adjustments, on the other hand, are made prior to the training and are based on personal characteristics like cognitive abilities, personality traits, learning styles, and even prior knowledge [13]. These adjustments ensure that the learning environment is initially tailored to the needs of the trainee. For example, a learner with strong verbal abilities but weaker spatial reasoning might receive more verbal explanations and fewer spatial tasks initially, gradually building up their spatial skills as they progress. Similarly, a trainee who exhibits high levels of anxiety might benefit from a training environment that includes stress-reduction techniques and a slower pace of instruction. By considering these stable traits from the outset, macroadaptive strategies create a foundation for a more personalized and effective learning experience from the beginning.

Besides the training tasks themselves, personalized feedback is crucial for effective individualized training, significantly enhancing the learning process [14]. Immediate, specific feedback allows trainees to correct errors in real-time, making it more effective than delayed or generic feedback [68]. This helps reinforce correct techniques and prevents mistakes from becoming ingrained habits. High-quality feedback should provide constructive suggestions for improvement, addressing individual weaknesses and strengths, which facilitates a customized learning experience [15]. Evaluating skills within virtual reality simulators can effectively automate the feedback process for trainees and highlight which aspects of the virtual environment need to be adjusted [18].

By recognizing the potential of adaptive training to address the specific strengths and weaknesses of surgical trainees, we identified a critical area of investigation: the relationship between individual characteristics and laparoscopic skill development. In this thesis, we therefore explored how cognitive abilities and personality traits, specifically visuospatial ability and impulsiveness, and feedback mechanisms influence skill acquisition in laparoscopic surgery. With our studies we aimed to provide insights which can be used to create adaptive surgical training programs, ensuring they are fit to enhance the unique capabilities of each trainee, leading to more effective and efficient learning outcomes.

Main findings

Our research explored various aspects of laparoscopic training, focusing on how individual differences such as visuospatial ability and impulsiveness, as well as the impact of feedback mechanisms, affect surgical performance and learning.

We found that spatial ability plays a crucial role in laparoscopic procedures performance with non-zero optical angles, as participants with higher spatial skills performed significantly better under these conditions. Our studies also indicated that the skills required for laparoscopic procedures under non-zero optical angles are just as trainable as those for a standard 0° optical angle, as training under different angles resulted in comparable performance improvements. This suggests that including deviating angles in training could better prepare surgeons for real-world scenarios where a non-zero optical angle is sometimes inevitable. Additionally, we identified various "performance zones" based on optical angles, indicating suitable and unsuitable zones for optimal performance.

Beside cognitive skills we also investigated the personality trait of impulsiveness. Our studies demonstrated a clear effect of impulsiveness on the surgical performance of inexperienced trainees. In this group, highly impulsive individuals performed laparoscopic tasks faster, but created more damage. In contrast, the performance of experienced surgeons was not significantly affected by impulsiveness, suggesting that experience mitigates the negative effects of impulsive traits.

Our research on individual differences in surgical education also focused on the role of feedback during training. We introduced a peer-performance-based feedback standard and found it to be as effective as expert-based feedback. Both feedback groups performed faster, but made more errors compared to a no-feedback group. This suggests that peer-based training could complement expert-based training by providing achievable session goals and final targets. Lastly, we examined the use of targeted feedback to emphasize focus on specific performance parameters such as speed and damage. Feedback effectively directed practice, highlighting the potential of adaptive training systems to enhance the efficiency and effectiveness of surgical skill acquisition.

Cognitive ability: visuospatial ability and the optical angle

The cognitive ability of visuospatial ability has emerged as a significant factor, affecting the performance of surgeons. Visuospatial ability refers to the ability to mentally apprehend, encode, rotate, and manipulate three-dimensional objects [16]. This ability is especially of importance during minimally invasive procedures such as laparoscopy [17, 18]. These procedures pose unique visuospatial challenges, primarily due to the use of indirect vision and the presence of a fulcrum effect [19-21]. These challenges are aggravated by working under deviated optical angles [22-24].

During minimally invasive surgery, non-zero optical angles require surgeons to perform intricate mental transformations of the surgical field and instruments. The optical angle refers to the angle between the line of action (the horizontal projection of the line connecting the trocar for the laparoscope to the anatomical target) and the line of vision (the horizontal projection of the line connecting the central axis of the surgeon with the anatomical target) (figure 1) [23]. The mental gymnastics needed to perform under non-zero optical angles can be demanding, especially for less experienced trainees of low visuospatial ability [25]. The findings in **chapter 2** of this thesis highlight a noticeable decline in simulated laparoscopic performance when deviated optical angles are introduced. This performance drop is particularly

striking among novice trainees of low visuospatial ability. This suggests that high visuospatial ability facilitates better mental transformations required for adjusting to non-zero optical angles. The significant difference in performance underscores the potential for tailored training programs. Recognizing that trainees with lower visuospatial ability may struggle more with these tasks, educational strategies could include targeted interventions to enhance their spatial skills. For example, virtual reality training programs that simulate various optical angles and provide real-time feedback, which are already available on some simulators, could help these individuals improve their spatial reasoning and adaptability.

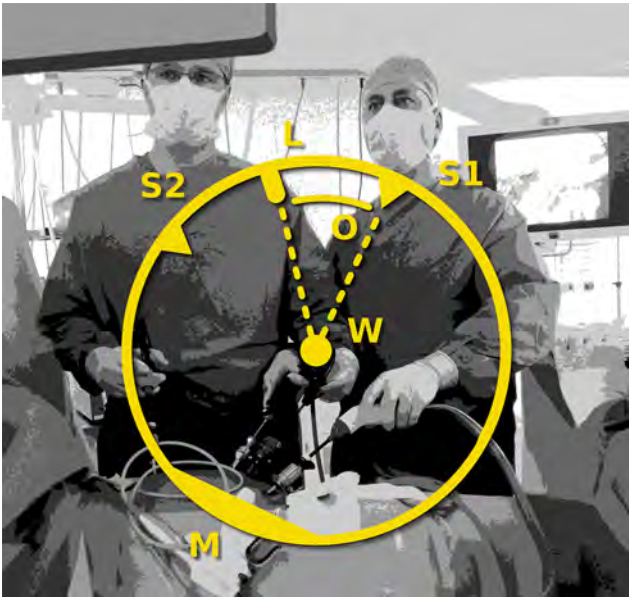


Figure 1. A side view of a laparoscopic procedure in the operating room with a corresponding schematic top-down view in yellow to show the variables relevant to the challenges of laparoscopic indirect vision and optical angle (the angle between the line of action and the line of vision). O = optical angle, S1 = operating surgeon 1, S2 = assisting surgeon 2, L = Laparoscope, W = operating area, M = monitor, L-W = line of scope, S1-W = line of sight.

Traditionally, surgical training programs have primarily focused on training laparoscopic skills under a zero-degree optical angle [25-29]. While this focus addresses a significant portion of laparoscopic cases, it may leave trainees under-prepared to handle the deviated optical angles frequently encountered in real surgical scenarios.

One notable contribution from this thesis, as seen in **chapter 3**, is the demonstration of the effectiveness of dedicated training programs designed to improve performance

under non-zero optical angles. Trainees, through focused training, exhibited the ability to enhance their laparoscopic skills when faced with deviated optical angles. Consequently, we strongly recommend the integration of such specialized training into standard surgical curricula. To facilitate the transition to this integrated approach, more research is needed to understand the transfer of skills between various optical angles. For instance, investigating specific training strategies that enhance performance and skill transfer when working under deviating optical angles is crucial. Questions like whether skills can be transferred to mirrored optical angles and determining the transfer range to nearby optical angles after training under a specific non-zero optical angle are pertinent. Additionally, exploring how professional experience might mitigate the performance penalty associated with working under deviated optical angles is a valuable avenue for research, particularly in long-term learning curve studies.

The evidence presented in this thesis strongly suggests that the 0° optical angle is the safest option, even for experienced surgeons. As there is a trade-off between the risks associated with creating an additional port and the benefits of using a 0° optical angle [30], these trade-offs should be thoroughly evaluated for each surgical procedure. To enhance patient safety, investments in the development of new camera techniques for laparoscopic procedures could minimize the necessity for extra camera ports. One promising approach is multiview synthesis, which can create virtual camera angles using images from one or two camera positions at various viewing angles [31, 32]. This technology has the potential to offer the benefits of optimal viewing angles without the need for additional ports.

This thesis has primarily focused on visuospatial ability, one aspect of the various cognitive skills related to skilled performance [33]. Alongside visuospatial ability, other cognitive functions such as working memory [34], perceptual ability [35], decision-making ability [36] and sustained attention [37], are linked to motor function and have demonstrated to impact surgical performance. Working memory involves holding and manipulating information temporarily, aiding surgeons in retaining critical information and make decisions simultaneously, hereby affecting surgical performance [38, 39]. Perceptual ability is the capacity to interpret sensory information accurately, essential for understanding visual cues and spatial relationships in the surgical field [40]. Decision-making ability enables surgeons to make informed choices, facilitating prompt and effective handling of procedural steps and complications [41]. Sustained attention is the ability to maintain focus over long periods, ensuring that surgeons stay concentrated on complex tasks without becoming distracted [42, 43]. A recent systematic review on individual predictors

for novice surgical trainees' performance revealed that, alongside psychomotor- and visuospatial abilities, perceptual ability is a particularly promising predictor of baseline simulator performance [44]. This emphasizes the critical role of recognizing and understanding individual variations in all the cognitive abilities among trainees, adding valuable insights for surgical education and training.

Personality: Impulsiveness

When looking at individual characteristics in addition to cognitive abilities, personality is a crucial factor in understanding surgical performance and its implications for surgical care. Personality is defined as the set of psychological traits and mechanisms within individuals that influence their interactions with and adaptations to internal psychological processes, physical environments, and social environments [45]. Charting the links between personality and surgical performance can help us better understand why errors and complications occur, and how we can prevent them.

The personality traits of surgeons have been shown to differ from the general population and other medical specialists, with surgical residents often exhibiting high extraversion and high conscientiousness [46-49]. Interestingly, studies have suggested that introverted surgeons may perform better than their extraverted counterparts [48].

We know that the personality trait impulsiveness is closely related to extraversion [50-52]. This personality trait is described as the tendency to act with less forethought than most individuals of equal ability and knowledge do [53]. In other fields such as aviation and traffic, impulsiveness is strongly linked to dangerous behavior and accidents [54-58]. This is why this personality trait also drew our attention. We found that even though its negative association in other fields, it has received little attention in the surgical field. However, research in psychology has demonstrated that for basic reaction time tasks, high impulsiveness correlates with faster reaction times, but also more errors [59].

In line with this study, in **Chapter 4** we demonstrated that highly impulsive, inexperienced trainees make more damage during the performance of simulated laparoscopic tasks compared to their low impulsiveness peers. However, in **Chapter 5** we observed that impulsiveness did not affect performance for more experienced residents and consultants. It would be valuable to delve into the reasons why performance of experienced surgeons is not affected by impulsiveness, as such insights could possibly be used to shorten the learning curve for novices. Existing

psychological research on learning curves indicates that experienced individuals often make accurate and consistent decisions, owing to superior information-gathering strategies and a deeper understanding of the situation [60]. This pattern is evident in domains such as traffic, where novice drivers, with lower situational awareness, are more prone to accidents [61, 62]. Unlike novices, experienced drivers show less susceptibility to personality traits such as impulsiveness [62]. In driving the expectation is that experienced practitioners possess more automated skills, resulting in greater mental reserve capacity. This capacity allows for more effective acquisition of situational information and facilitates decision-making based on this information rather than intrinsic motivations [63]. It is likely that the same principle applies to experience in laparoscopic surgery. The concept of automated skills [64], is essential here. With practice and repetition, surgeons develop a repertoire of automatic responses to common surgical scenarios [65], which frees up cognitive resources for more complex decision-making. When individuals experience high cognitive load, their decision-making processes can be compromised, leading to impulsive actions [66, 67]. By automating routine tasks, surgeons can allocate their cognitive resources more efficiently, allowing them to focus on more complex decision-making without being overwhelmed by excessive mental demands. Therefore, automation serves as a protective mechanism against impulsive actions by lightening the cognitive load and enabling surgeons to maintain better control over their responses.

Moving beyond impulsiveness, it is essential to recognize that personality encompasses a wide array of traits, and each of these traits can wield its distinct influence on both surgical performance and motor skills. Across various domains, specific personality traits have been associated with skills that require motor performance. For instance, within law enforcement, self-control and anxiety have been pinpointed as factors influencing shooting performance [68]. In the field of music, it is known that music enhances motor performance, with a more pronounced improvement observed in individuals with extroverted personalities compared to introverts, depending on the genre of the music [69]. Furthermore, in the realm of sports, there exists a correlation between high extraversion and neuroticism and athleticism [70]. This suggests that many personality factors can play a significant role in motor performance, and possibly also surgical performance.

Additionally, it is worth noting that surgical performance involves a multifaceted skill set, including non-technical skills such as communication, leadership, and concentration [71], which were not investigated in this thesis. Deficiencies in communication, for example, have been identified as a leading cause of adverse events and can significantly impact patient care [72]. Bad communication is

often the leading cause of adverse events and leads to twice as many deaths as clinical inadequacy [73]. Given that interpersonal communication is closely linked to underlying personalities [74], it is likely that personality traits influence the occurrence of errors in surgery and other medical fields beyond technical errors.

The use of feedback in training

In our exploration of the role of individual differences in surgical education, we also were interested in the role of feedback during training. This decision was informed by prior reviews and meta-analyses that consistently underscore the pivotal role of feedback as a major effector on students' learning and overall academic performance [75, 76]. While effective learning heavily relies on the provision of adequate feedback and clearly defined training goals [77], it is noteworthy that feedback often remains retrospective. Feedback for novices, beyond being a mere review of performance, should actively assist students in real-time improvements [78]. This kind of 'just in time' feedback allows individuals to make adjustments and improvements on the spot, enhancing the learning process by addressing issues as they arise, preventing trainees from automatizing incorrect skills and behavior [79, 80]. In traditional operating room training, real-time performance feedback is not always feasible, as the supervising surgeon may experience cognitive overload when trying to assess performance of a trainee, teach new skills, while simultaneously keeping track of the status of patient and procedure [81, 82]. In the context of surgical training, the advent of simulators has revolutionized the way feedback is provided, enabling immediate, objective and quantified assessment of performance. While feedback is pivotal for learning, it has not been (fully) incorporated in surgical curricula [83]. In this thesis we investigated the current use of feedback and its potential for other uses than just a review of performance.

To date, most training curricula embrace proficiency-based training, as such training has proven to be more effective in comparison to training without goals, and results in durable acquisition of laparoscopic skills [27, 84]. In proficiency-based training a trainee trains until a predefined proficiency level is reached instead of focusing on a prescribed task repetition or training sessions. This proficiency level is often based on expert performance. The use of expert-based proficiency levels, although valuable, has its challenges, such as potential discouragement [85]. Another disadvantage of expert values is that these are often hard to require as experts in the field usually are time limited. Furthermore, no standardized methods exist to generate expert values, causing different 'expert' datasets for similar tasks [86]. In a previous

study not included in this thesis, we reported a list of conditions needed for such standardization, including the reporting of relevant participant demographics, simulator type with software version and task settings, and the necessity to perform tasks in a controlled environment with randomization of task order [86]. The use of different proficiency values could otherwise lead to differences in length and focus of proficiency-based training courses, different end-level proficiency of trainees, and can affect training costs. In **chapter 6** we demonstrated a different type of feedback standard with the effective use of peer performance. Feedback based on performance of peers proved to be just as effective in the acquisition of laparoscopic skills as feedback based on expert performance. Using peer performance-based feedback during simulation training provides a welcome alternative to expert-based performance values, especially given the limited availability of experts and the diminishing number of experts with simulator experience. Academic medical institutions regularly train a steady influx of trainees with no laparoscopic experience, providing ample opportunities to generate peer performance-based standards. An additional benefit of peer performance-based standards is their dynamic nature. They can be provided to students in the form of learning curves, with different values for each session, unlike expert performance-based standards, which typically consist of a single value represented as a horizontal bar. Peer performance-based learning curves offer standards for both end goals and session goals, providing more context for comparison and potentially enhancing motivation and engagement. However, our research also revealed a trade-off between different performance variables as a consequence of automated feedback. This trade-off can result in students prioritizing speed over accuracy, leading to faster but less careful task execution. We therefore think it is important to emphasize accuracy and damage control when using feedback standards to ensure safe surgical practices.

Besides expert values, investigating what types of performance variables, and how they should be measured, is important. For example, Surgical Science's LapSim virtual reality simulator records the maximum amount of damage created during exercises in millimeters. We have noticed great variability of this parameter within both inexperienced students and consultants, making us question its reliability for feedback. While data regarding transfer of motor skills from the simulator skillslab to the operating room have shown good results, inconsistencies exist about which simulated parameters align with those observed in real surgical scenarios [87]. This makes the interpretation of simulated performance parameters more difficult. However, more and more assessment tools and methods are developed that aim for the objective measurement of performance in the operating room [88-90]. For example, the Generic Error Rating Tool categorizes errors during laparoscopic

surgeries by defining four error modes related to task execution: inadequate use of force or distance (overshooting a target); inadequate use of force or distance (falling short of a target); inadequate visualization; and wrong orientation of instrument or dissection plane [88]. Correlating simulator parameters with those of such advanced assessment tools would enable more specific evaluation of relevant simulator parameters, and a deeper understanding of the transfer of technical skills.

The use of feedback in adaptive training

As we have demonstrated in **Chapter 7**, feedback can be used to steer trainees towards focusing on their less developed skills. This feedback can be based on performance parameters from previous tasks or expected performance parameters derived from individual characteristics such as personality or cognitive ability. In surgical training, this ensures that each trainee receives the most relevant and beneficial guidance [91, 92], optimizing their learning experience. For example, a trainee struggling with spatial orientation tasks but excelling in motor skills might receive targeted feedback to improve their spatial reasoning, involving specific exercises designed to enhance their ability to visualize and manipulate objects in three-dimensional space. A study among medical students demonstrated that a deliberate practice-based remediation program, which included targeted feedback and reflection on underperformed aspects, significantly improved clinical performance [93]. This suggests that targeted feedback could be effective in addressing individual weaknesses and enhancing overall competence.

Analyzing metrics such as task completion time, accuracy, and error rates provides a concrete basis for identifying areas of weakness. This analytic approach ensures that feedback is both precise and practical, offering a deeper understanding of the nuances of a procedure [85]. Trainees can then focus their efforts on improving these areas, with subsequent training sessions progressively building these competencies [86]. Additionally, understanding individual characteristics, such as personality traits and cognitive abilities, can further refine this process. For instance, trainees with lower visuospatial ability might benefit from more visual aids and practice with spatially complex tasks, while highly impulsive trainees might receive feedback encouraging more deliberate and measured approaches to surgical tasks.

Although more research is needed to validate the effectiveness of targeted training in surgical contexts, existing studies provide promising results. Oian and Lehman demonstrated the efficacy of targeted feedback in a high school programming course,

where students receiving feedback on errors showed significant improvement [94]. Similarly, another study found that students receiving personalized, targeted feedback on their specific weaknesses achieved significantly better improvement in music rhythm reading compared to peers without such guidance [95].

Furthermore, advances in technology may open doors to intelligent simulation systems that can adapt to the unique needs of learners. We envision prospective computer-based training systems that incorporate artificial intelligence, enabling real-time analysis of a trainee's performance and dynamic adjustments to the training scenario. In such a scenario, challenges and guidance would be tailored to the trainee's skill level. For instance, if a trainee excels in one aspect of surgery, but faces challenges in another, the envisioned future system could spontaneously generate scenarios that specifically target the areas requiring improvement.

Further perspectives

Continued technical developments are expected to further elevate the level of (medical) education in the future. An interesting topic which has entered the field in the recent years is “serious gaming”. The gaming industry is more and more interested in developing new content for health care purposes which add a new format of training. Games, such as the laparoscopic serious game *Underground*, have shown promising results [96, 97]. Besides educational value, these games could possibly add entertainment value, thereby increasing training compliance. In gaming, a form of adaptive training is naturally implemented, as most games consist of levels with increasing difficulty. These games also have the potential to use individual characteristics to alter training levels. For example, the game could recognize that the trainee has low visuospatial ability, and therefore create levels which have deviated optical angles.

An interesting feature of new simulators is the option of procedure based training. For more experienced trainees, a shift is desired from basic skills training to more complete surgical procedures. The newest generation of virtual reality simulators can implement real patient data from pre-procedural imaging such as a CT-scan or MRI [98]. Implementing such techniques in laparoscopic training could help surgical residents better prepare themselves for anatomy, procedural steps, procedure specific difficulties, and possible complications. In this way, the resident can explore different options during the procedure without having to worry about the possible consequences. Artificial intelligence is not yet designed for this use, but could

also be a great addition to laparoscopic training. For example, it could generate a virtual patient tailored to the trainee's capabilities and personal characteristics, incorporating insights from past cases. In this way the trainee would be stimulated to train on his or her improvement areas with unseen cases and simultaneously gain experience with a variety of possible difficulties encountered peri-procedurally.

The future of surgical training holds exciting possibilities, thanks to ongoing advancements in technology and innovative approaches, such as serious gaming and procedure-based training. As we move forward, personalized training experiences are becoming increasingly achievable, with the potential to enhance educational outcomes, motivation, and, ultimately, patient safety. Embracing these emerging trends and technologies will be key to further elevating the field of surgical education. The journey towards more individualized, adaptive training is ongoing, and it promises to shape the future of surgical training in a way that benefits both learners and patients alike.

Conclusion

Throughout this thesis, we have explored the dynamics between visuospatial ability, impulsiveness, feedback mechanisms, and laparoscopic skills development. Our key findings reveal that trainees with higher visuospatial abilities perform better under non-zero optical angles. We also found that impulsiveness leads to faster performance but causes more damage among inexperienced trainees, whereas it does not significantly affect the performance of experienced surgeons. Furthermore, feedback, whether peer-based or expert-based, plays a crucial role in guiding training efforts and can be used to create adaptive training systems. These insights suggest that personalized feedback, targeting less developed skills based on individual characteristics, can enhance the efficiency and effectiveness of training programs.

In light of these insights, we firmly believe that the next logical step in the advancement of surgical education is the implementation of more adaptive training programs based on individual differences. Such programs would not only acknowledge the individualized nature of skill progression but also ensure that each trainee attains proficiency at an optimized pace. By integrating personalized elements into surgical training, we can better prepare the next generation of surgeons to become proficient, adaptable, and innovative caregivers, capable of handling a diverse range of surgical challenges, ultimately leading to improved patient outcomes and advancements in the field of surgery.

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CHAPTER 9

Nederlandse samenvatting

In de afgelopen twee decennia heeft de chirurgische opleiding ingrijpende veranderingen ondergaan onder druk van voortdurende veranderingen in de zorg, nieuwe inzichten in onderwijs en technologische vooruitgang. Technologische innovaties, met name op het gebied van minimaal invasieve chirurgie en robotchirurgie, leiden tot nieuwe chirurgische procedures. Dit verhoogt de trainingsbelasting voor aspirant-chirurgen en vermindert de beschikbare tijd voor dergelijke training.

Onder andere om deze reden, maar ook voor het verder verhogen van patiëntveiligheid, wordt er aanzienlijke tijd, geld en moeite geïnvesteerd om de efficiëntie van chirurgische training te verbeteren. Een inefficiënte training kan namelijk leiden tot langere proceduretijden en een verhoogd risico op complicaties. Verbeterde trainingsefficiëntie vermindert de tijd die nodig is voor chirurgen in opleiding om volledig bekwame chirurgen te worden, wat resulteert in kostenbesparingen en zorgt voor een snellere beschikbaarheid van chirurgen in de praktijk.

Een belangrijke ontwikkeling in de verbetering van trainingsefficiëntie is de integratie met technologie, waarbij met name simulatietraining de chirurgische training heeft gerevolutioneerd. Hoogwaardige simulatoren en virtual reality platformen zijn essentiële tools geworden. Ze bieden chirurgen in opleiding de mogelijkheid om interactie te hebben met virtuele weefsels en instrumenten, fouten te maken zonder het welzijn van de patiënt in gevaar te brengen en bieden objectieve prestatiebeoordeling. Doordat deze simulatoren getalsmatig prestatiegegevens kunnen genereren wordt onderzoek naar de relatie tussen individuele verschillen en het aanleren van chirurgische vaardigheden eenvoudiger en aantrekkelijker.

De invloed van deze individuele verschillen op chirurgische prestaties is tot op heden weinig onderzocht. Meestal is gefocust op de chirurgen in opleiding als gehele groep, zonder hierbij aandacht te schenken aan individuele verschillen. Eerdere onderzoeken toonden significante verschillen in persoonlijkheden en cognitieve vaardigheden tussen verschillende chirurgen in opleiding. Het is daarom te verwachten dat deze jonge chirurgen ook verschillende behoeften hebben in training. In dit proefschrift hebben we geprobeerd een aantal vragen met betrekking tot dit onderwerp te beantwoorden. We hebben onder andere onderzocht hoe persoonlijkheid en cognitieve vaardigheden het aanleren van chirurgische vaardigheden beïnvloeden. Daarnaast hebben we onderzocht of feedback op trainingsprestaties kan worden gebruikt om gepersonaliseerde training te creëren.

In **hoofdstuk 2** hebben we de invloed van ruimtelijk inzicht op chirurgische prestaties onderzocht tijdens laparoscopische procedures onder verschillende kijkhoeken.

Laparoscopische procedures vereisen dat chirurgen opereren met indirect zicht, waarbij visuele feedback op een monitor wordt ontvangen via de laparoscoop met een camera die door een kleine incisie in de buik wordt ingebracht. Tijdens deze procedures staat de laparoscoop niet altijd in lijn met de laparoscopische instrumenten van de chirurg, wat resulteert in een afwijkende kijkhoek. Deze afwijkende kijkhoek van de camera leidt tot een onnatuurlijke projectie van het werkveld voor de chirurg op de monitor. Hierdoor wordt de chirurg gedwongen een mentale transformatie uit te voeren om het beeld van de laparoscoop in overeenstemming te brengen met de werkelijke plaatsing van het gereedschap in de buik van de patiënt. Onze verwachting was dat ruimtelijk inzicht een belangrijke rol speelt in deze mentale transformatie en dat daarom prestaties beter zouden zijn voor operateurs met een goed ruimtelijk inzicht. Deelnemers aan dit onderzoek bestonden uit 37 psychologiestudenten zonder ervaring in laparoscopie, welke laparoscopische taken uitvoerden op een zelf ontworpen laparoscopische simulator onder verschillende kijkhoeken (0°, 45°, 90°, 135°, 180°, -135°, -90° en -45°). Ze werden ingedeeld op basis van hun ruimtelijk inzicht in een groep met relatief hoog ruimtelijk inzicht en een groep met relatief laag ruimtelijk inzicht. De resultaten toonden aan dat alle deelnemers over het algemeen minder goed presteren onder afwijkende kijkhoeken in vergelijking met de standaard kijkhoek van 0°. Opmerkelijk was dat de groep met beter ruimtelijk inzicht alleen significant beter presteerde dan de groep met minder ruimtelijk inzicht onder de afwijkende kijkhoeken, terwijl de prestaties tussen de groepen vergelijkbaar waren onder de 0° kijkhoek. Deze bevindingen suggereren dat ruimtelijk inzicht voornamelijk van belang is bij het omgaan met visuele uitdagingen veroorzaakt door afwijkende kijkhoeken. Daarnaast identificeerde de studie verschillende "prestatiezones" op basis van kijkhoeken, oftewel geschikte en ongeschikte zones van kijkhoeken, wat praktische implicaties kan hebben. Bijvoorbeeld kan het overwegen van deze prestatiezones helpen bij het optimaliseren van de plaatsing van *trocars*, de instrumentgeleiders die door de huid van de patiënt worden ingebracht.

Nadat we hadden aangetoond dat afwijkende kijkhoeken een negatieve invloed hebben op (gesimuleerde) chirurgische prestaties, onderzochten we of de vaardigheden die nodig zijn voor het uitvoeren van laparoscopische procedures onder afwijkende kijkhoeken even goed te trainen zijn als onder een 0° graden kijkhoek. Dit onderzoek is beschreven in **hoofdstuk 3**. In totaal hebben 58 medische studenten zonder laparoscopische ervaring een laparoscopie cursus van vier sessies gevolgd op de LapSim virtual reality simulator, waarbij ze bij elke sessie dezelfde taak onder een 0°, 45° en -45° kijkhoek uitvoerden. De verbetering in prestaties tussen de tweede en vierde trainingssessie werd vergeleken tussen de drie verschillende kijkhoeken om zo het leereffect tussen de verschillende kijkhoeken te beoordelen. Zoals verwacht

voerden deelnemers laparoscopische taken sneller uit onder een 0° kijkhoek in vergelijking met afwijkende kijkhoeken. De prestaties tussen de 45° en -45° kijkhoek waren vergelijkbaar. De prestaties tussen de drie kijkhoeken verbeterden evenredig, wat aangeeft dat de vaardigheden voor afwijkende kijkhoeken net zo goed te trainen zijn als voor een 0° kijkhoek. Momenteel ligt de focus in de chirurgische opleiding voornamelijk op training onder 0° kijkhoeken, maar dit onderzoek suggereert dat het ook zinvol is om te trainen met afwijkende kijkhoeken. Zo worden chirurgische assistenten beter voorbereid op procedures met afwijkende kijkhoeken die in de praktijk vaak onvermijdelijk zijn. Interessant zou zijn om in langer lopende studies te kijken of het prestatieverschil tussen moeilijke en makkelijke kijkhoeken verdwijnt of stabiliseert in de loop van de tijd.

Naast cognitieve vaardigheden wilden we ook de invloed van persoonlijkheid op chirurgische prestaties en het aanleren van chirurgische vaardigheden beoordelen. In andere sectoren dan de gezondheidszorg is al bekend dat impulsiviteit gelinkt is aan negatieve resultaten. Zo is impulsiviteit in het verkeer gerelateerd aan gevaarlijk rijgedrag en verkeersongelukken en op de werkvloer is impulsiviteit negatief gecorreleerd aan functie-gerelateerde prestaties. In **hoofdstuk 4** hebben we deze relatie onderzocht binnen de chirurgische laparoscopie training. Onze hypothese was dat hoog-impulsieve operateurs sneller werken, maar hierdoor meer fouten en complicaties maken. Er werden 83 onervaren medische studenten uitgenodigd voor een trainingscursus van vier sessies op de LapSim virtual reality simulator. Op basis van de "Eysenck Impulsiveness Inventory test" werden de deelnemers ingedeeld in een relatief hoog-impulsieve en relatief laag-impulsieve groep. De prestaties op de LapSim simulator gedurende de cursus werden vergeleken tussen deze twee groepen. De hoog-impulsieve groep creëerde significant meer schade gedurende de cursus dan de laag-impulsieve groep. Ze werkten ook sneller dan de laag-impulsieve groep, echter dit verschil was niet significant.

In **hoofdstuk 5** hebben we deze relatie tussen impulsiviteit en chirurgische prestaties verder onderzocht, waarbij we deze keer onervaren en ervaren deelnemers hebben uitgenodigd om zo de invloed van ervaring mee te kunnen nemen. In totaal namen 121 coassistenten, chirurgen in opleiding en snijdend specialisten deel aan het onderzoek. Alle deelnemers voltooiden de UPPSP-test, die verschillende aspecten van impulsiviteit meet om de invloed van deze persoonlijkheidsfactor op chirurgische prestaties te begrijpen. Deelnemers werden op basis van ervaring verdeeld in onervaren en ervaren groepen, waarna ze verder werden onderverdeeld op basis van impulsiviteit in hoog-impulsieve en laag-impulsieve groepen. De deelnemers voerden een reeks laparoscopische oefeningen uit op de LapSim virtual reality

simulator, waarna de prestaties werden vergeleken. De resultaten toonden aan dat in de onervaren groep de hoog-impulsieve deelnemers sneller waren dan de laag-impulsieve deelnemers. Bij de extreem hoog-impulsieve deelnemers werd daarbij ook meer schade vastgesteld in vergelijking met de laag-impulsieve deelnemers. Verschillende aspecten van impulsiviteit correleerden in deze onervaren groep positief met kortere proceduretijd, terwijl andere aspecten positief correleerden met veroorzaakte schade. Opvallend was dat in de ervaren groep geen significante verschillen werden gevonden in snelheid of schade tussen hoog- en laag-impulsieve deelnemers, wat suggereert dat impulsiviteit minder invloed heeft bij ervaren deelnemers. De mechanismen achter deze bevindingen vereisen verdere verkenning.

Ons onderzoek naar individuele verschillen in chirurgisch onderwijs richtte zich tevens op de rol van feedback tijdens training. Eerdere reviews benadrukten consistent de cruciale rol van feedback als belangrijke factor voor het leren van studenten en hun algehele academische prestaties. Momenteel omarmt de meerderheid van de trainingscurricula het concept van *vaardigheidsgerichte training* (proficiency based training), aangezien dit effectiever blijkt dan training zonder specifieke doelen. In vaardigheidsgerichte training streeft een deelnemer naar een vooraf bepaald vaardigheidsniveau, in plaats van zich te richten op voorgeschreven taakherhaling of trainingsduur. Het te behalen vaardigheidsniveau is vaak gebaseerd op expert-waarden en wordt teruggeven als feedback (vaak onder expert niveau). Deze waarden kennen echter enkele nadelen. Zo kunnen aspiranten bijvoorbeeld ontmoedigd raken door te uitdagende trainingsdoelen. Bovendien is het moeilijk om overall expertwaarden voor te verkrijgen vanwege tijdsbeperkingen van experts. Een bijkomend probleem is het ontbreken van een gestandaardiseerde methode om expertwaarden te genereren, wat kan leiden tot verschillende 'expert' standaarden voor vergelijkbare taken. In **hoofdstuk 6** hebben we een daarom een alternatieve vorm van feedbackstandaard geïntroduceerd door effectief gebruik te maken van standaarden gebaseerd op peer-performance. In een vier sessies durende laparoscopische training op de LapSim virtual reality simulator werden 100 medische studenten verdeeld in drie groepen. Eén groep ontving feedback op basis van prestaties van chirurgische experts, een andere groep ontving feedback op basis van prestaties van medestudenten, terwijl een derde groep geen feedback ontving. Resultaten toonden aan dat de groepen met feedback significant sneller presteerden ten opzichte van de groep zonder feedback, hoewel ze hierbij ook meer fouten maakten. De twee feedbackgroepen verschilden qua prestaties niet van elkaar en lijken dus even effectief te zijn. Daarom suggereren we dat peer-performance-gebaseerde training een waardevolle aanvulling zou kunnen zijn op laparoscopische training, mogelijk in combinatie met op expert gebaseerde training.

Een gecombineerde vorm van feedback voegt meer context toe aan aspiranten door zowel haalbare trainingsdoelen voor elke sessie als de uiteindelijke einddoelen te tonen. Het potentieel om deze normen te genereren uit een grotere groep trainees biedt bovendien voordelen op het gebied van beschikbaarheid, betrouwbaarheid en flexibiliteit. Er is aanvullend onderzoek nodig om te onderzoeken waarom de groep zonder feedback minder fouten maakte.

In **hoofdstuk 7** onderzochten we het gebruik van feedback van een laparoscopische trainingssimulator om de aandacht van studenten te richten op specifieke prestatieparameters van gesimuleerde chirurgische taken, in dit specifieke geval snelheid versus schade. Deze kennis kan waardevol zijn bij de ontwikkeling van adaptieve trainingssystemen. Adaptieve training past de moeilijkheidsgraad van de training aan op basis van de eigenschappen en prestaties van de deelnemer, waardoor een gepersonaliseerde leerervaring ontstaat. Dit type training is bewezen effectief in diverse educatieve domeinen, waaronder virtual reality training en serious gaming, en biedt doelgerichte verbetering van individuele zwakke punten. Voor dit onderzoek nodigden we 83 onervaren medische studenten uit om deel te nemen aan een vier sessies durende trainingscursus. Deelnemers voerden twee identieke series laparoscopische taken uit op de LapSim virtual reality simulator, waarbij ze bij één serie enkel feedback kregen over snelheid en bij de andere serie alleen feedback ontvingen over gemaakte schade. De prestaties tussen de twee series werden vergeleken om te beoordelen of de feedback daadwerkelijk leidde tot meer gerichte oefening op een van de twee prestatieparameters. Resultaten toonden aan dat deelnemers significant sneller presteerden wanneer ze feedback kregen over snelheid en significant minder schade veroorzaakten wanneer ze feedback ontvingen over schade. Dit wijst erop dat de feedback effectief kan worden gebruikt om de focus van de training te sturen. Deze bevindingen benadrukken de potentie van adaptieve training in de medische opleiding, waarbij feedback kan worden ingezet om aspiranten gericht te begeleiden naar het verbeteren van specifieke vaardigheden. Adaptieve trainingssystemen kunnen hierdoor de efficiëntie en effectiviteit van chirurgische vaardigheidstraining verder optimaliseren.

In de algemene discussie in **hoofdstuk 8** worden de voornaamste bevindingen en conclusies uit eerdere hoofdstukken samengebracht in een bredere context. De studies van dit proefschrift benadrukken de cruciale rol van individuele verschillen in cognitieve vaardigheden en persoonlijkheid voor laparoscopische prestaties. Een belangrijke aanbeveling is de chirurgische vaardigheidstraining meer te personaliseren, afgestemd op individuele kenmerken en behoeften. In het tweede deel van dit hoofdstuk worden verdere ontwikkelingen in de chirurgische educatie

verkend, met een focus op technologische vooruitgang en innovatieve benaderingen zoals serious gaming en procedure-gebaseerde training. Het proefschrift draagt bij aan het vormgeven van de toekomst van chirurgische training, met als doel voor ieder individu de educatieve resultaten te optimaliseren.



APPENDICES

DANKWOORD (ACKNOWLEDGEMENTS)

CURRICULUM VITAE

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DANKWOORD

Het laatste onderdeel van dit proefschrift, het dankwoord! Waarschijnlijk het meest gelezen, maar ook een van de moeilijkste onderdelen om te schrijven. Zoveel mensen hebben bijgedragen aan de totstandkoming van dit werk en vooral aan het plezier in de periode van mijn promotieonderzoek. Ik wil iedereen van harte bedanken die direct of indirect heeft geholpen. Zonder jullie steun zou dit proefschrift niet mogelijk zijn geweest.

Dr. J-M. Luursema, Beste Jan-Maarten, dankzij jouw vele ideeën en initiatieven ben ik (lang geleden) gestart met dit promotie-onderzoek. De vele gezellige overlegmomenten die we hebben gehad gingen vaak maar weinig over het onderzoek zelf, maar waren altijd inspirerend en leerzaam. Ik heb erg met je gelachen tijdens onze autoreis naar Hamburg en het was leuk om een keer op bezoek te komen bij je thuis in Den Haag. Het was altijd bijzonder om te horen waar je je mee bezig hield, van je hollywoodcarrière met slijmzwam Andy, het 3D-printen van alles wat mogelijk was, tot het creëren van augmented anatomielessen. Bedankt voor je altijd uitgebreide commentaar en hulp al die jaren, en voor de vrijheid die je me hebt gegeven tijdens dit project.

Prof. dr. H. van Goor, Beste Harry, het is bewonderenswaardig hoe je, ondanks onze beperkte overlegmomenten, altijd wist waar ik mee bezig was. Zonder notities herinnerde je je nog wat we zes maanden eerder hadden besproken. Soms begreep ik je commentaar niet meteen, maar er bleek altijd een achterliggende reden voor te zijn waar ik zelf nog niet over had nagedacht. Jij keek altijd vooruit en zag the bigger picture. Bedankt voor je hulp en het mogelijk maken van dit traject als promotor.

Geachte leden van de manuscriptcommissie, **Prof. dr. E.J.M. Tanck**, **Prof. dr. K.M. Stegers-Jager** en **Prof. dr. J.A. van der Hage**, bedankt voor het beoordelen en goedkeuren van mijn thesis. Ook de overige leden van de commissie wil ik hartelijk bedanken voor hun deelname aan de oppositie.

Beste **Wouter**, Bedankt voor de leuke samenwerking die we hebben gehad. De vele dagen die we samen opgesloten zaten in het aquarium op het secretariaat van de heelkunde waren een stuk draaglijker door jouw gezelschap. Heel veel succes met het afronden van je opleiding tot chirurg, we komen elkaar vast nog wel eens tegen op of buiten het werk.

Ook de andere onderzoekers van de afdeling heelkunde en de coauteurs van andere afdelingen en universiteiten waar ik al die jaren mee heb samengewerkt wil ik

bedanken voor de leuke momenten en prettige samenwerking. **Sander**, jou wil ik nog specifiek bij naam noemen. Ik heb veel van je kunnen leren aan het begin van mijn wetenschappelijke carrière en heb altijd genoten van onze lunchmeetings.

Ik wil ook alle coassistenten, AIOS, ANIOS en specialisten van de afdeling heelkunde, urologie en gynaecologie bedanken die hebben meegewerkt aan de onderzoeken. Zonder jullie tijd en inzet zou dit project niet mogelijk zijn geweest.

Beste stafleden, arts-assistenten, laboranten en overige medewerkers van de afdeling Radiologie van het Maastricht UMC+. Ik waardeer enorm de ondersteuning en begeleiding die ik van jullie heb ontvangen aan het begin van mijn loopbaan als arts. Ik ben jullie erg dankbaar voor alle hulp en al het vertrouwen, en natuurlijk ook voor de vele gezellige momenten samen, zowel binnen als buiten het Maastricht UMC+. **Nienke, Geneviève en Max**, ik was erg blij met jullie als jaargenoten en heb ontzettend genoten van onze tijd samen in Maastricht! Ik zal altijd aan jullie denken wanneer ik een nummer van Peter Beense hoor. Ook wil ik mijn collega's van het Rijnstate Ziekenhuis bedanken, waar ik maar kort gewerkt heb, maar wel veel heb geleerd. Verder een hartelijk dankwoord aan mijn nieuwe collega's in het ETZ in Tilburg. Ik kijk uit naar onze samenwerking en ben dankbaar voor de warme ontvangst!

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Elmar, mijn broer uit mentorgroepje 10! Ik ken niemand die er zo uitspringt zowel bij de studie als uitmuntende student, maar ook buiten de opleiding tijdens de late uurtjes in de stad. Ik heb genoten van alle avonden op de Sint Annastraat met goedkope Caneï en herrie van DJ Bl3nd. Je bent een prachtige kerel met het hart op de tong. Tank foar alle moaie mominten!

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Lieve **Loes**, met je prachtige rode haren en je oneindige energie breng je altijd vrolijkheid en levendigheid met je mee. Niemand danst zo enthousiast als jij! Het is zo knap wat jij allemaal bereikt, je reist de hele wereld over, bent huisarts, en vindt daarnaast nog de energie om op zo'n hoog niveau yoga te doen en prachtige retreats in Italië te organiseren. Het was bijzonder en onvergetelijk dat je als BABS op mijn bruiloft aanwezig was, ik ben ontzettend blij met een vriendin als jij!

Ook de andere mul-mullers, **Aron, Dominique, Jiska, Lucas, Vivianne** en de aanhang wil ik bedanken voor de superleuke avonden en weekenden die we hebben gehad. T-Thursday is een begrip geworden welke nog lastig overtroffen kan worden!

Beste **Ton**, de MMA-vechter met een klein hartje. Ik heb een ontzettend leuke tijd met je gehad, onder andere toen je kort mijn huisgenoot was. Ik kon altijd bij je langskomen om knakworsten te eten en om FIFA te spelen. Ik hoop dat je nieuwe bouwproject nog even duurt en je dus nog wat langer in Tilburg blijft wonen!

Kees, mijn buddy, jullie huis in Sittard is lange tijd een tweede thuis voor mij geweest. Wat ben ik blij dat we nog steeds zulke goede vrienden zijn. Jij hebt altijd voor me klaargestaan wanneer dat nodig was. Je bent altijd overal voor in, zelfs als ik je op vrijdagavond bel met de vraag of je binnen een half uur zin hebt om een weekendje naar Parijs te vertrekken. Dat je mijn paranimf bent, is niet voor niets! Fijn dat je nou samen met Loes zo'n leuk huis in Maastricht hebt en binnenkort ook de opleiding gaat afronden!

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Lieve **papa en mama**, waar zou ik zijn zonder die mooie en fijne jeugd die jullie me hebben gegeven? Jullie hebben ons als kinderen altijd alle mogelijkheden geboden en de vrijheid gegeven om te doen en laten waar we zelf zin in hadden. Ontzettend bedankt voor jullie onvoorwaardelijke steun, liefde en vertrouwen. Dankzij jullie ben ik kunnen groeien en bloeien zoals ik ben. Ik hou enorm veel van jullie! Lieve **Petra**, ook jou wil ik bedanken. Je bent een echt onderdeel van de familie geworden. Ik ben blij dat je er altijd voor papa bent en zo'n leuke extra oma bent voor de kleinkinderen.

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CURRICULUM VITAE



Bas Kengen was born on March 5, 1992, in Groningen, the Netherlands, as the second of four siblings, growing up alongside an older sister, a twin brother, and a younger sister. Although his birthplace was in the north, Bas was raised in Sittard, in the southern part of the Netherlands. It was in Sittard that he graduated from Trevianum Scholengroep, completing the Gymnasium program. His strong foundation in the sciences and his desire to help others led him to pursue a career in medicine. That same year, he embarked on his medical studies at Radboud University Nijmegen—a decision that would profoundly shape both his professional and personal life.

During his time at Radboud University, Bas dedicated himself not only to mastering the medical curriculum, but also to engaging in scientific research, marking the beginning of his journey toward doctoral studies.

After earning his medical degree in 2017, Bas began working at the emergency department of Zuyderland Medical Center in Sittard as a resident not in training (ANIOS). This role provided him with hands-on experience in a fast-paced environment, where he practiced his clinical skills. It was here that Bas's interest in radiology deepened, as he recognized the pivotal role that imaging plays in patient diagnosis and treatment.

In September 2018, Bas advanced his career by beginning a radiology residency at Maastricht UMC+ (AIOS). Throughout his residency, he developed a particular focus on interventional radiology and breast radiology—two subspecialties that perfectly align with his passion for procedural work and patient-centered care. Building on the expertise he gained during his residency, Bas began a fellowship in breast and interventional radiology at ETZ Hospital in Tilburg in May 2024. Through this fellowship, he aims to deepen his knowledge and refine his skills in these specialized areas.

Outside of his professional life, Bas is an avid traveler, always eager to explore new destinations with his wife, Noortje. Together, they seek out enriching experiences, whether hiking through nature or immersing themselves in diverse cultures. Bas also maintains an active lifestyle, participating in various sports, with a particular passion for football.

LIST OF PUBLICATIONS

- Kengen, B., van Goor, H., Verwey, W., & Luursema, J. M. (2023). Optical angle and visuospatial ability affect basic laparoscopic simulator task performance. *Applied Ergonomics*, 116, 104210. <https://doi.org/10.1016/j.apergo.2023.104210>
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- Kengen, B., IJgosse, W. M., van Goor, H., & Luursema, J. M. (2021). Speed versus damage: using selective feedback to modulate laparoscopic simulator performance. *BMC Medical Education*, 21(1), 1-9. <https://doi.org/10.1186/s12909-021-02789-3>
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- Luursema, J. M., Rovers, M. M., Alken, A., Kengen, B., & van Goor, H. (2015). When experts are oceans apart: comparing expert performance values for proficiency-based laparoscopic simulator training. *Journal of Surgical Education*, 72(3), 536-541. <https://doi.org/10.1016/j.jsurg.2014.11.005>
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- Kengen, B., van Goor, H., & Luursema, J. M. (2024). Professional experience modulates the effect of impulsiveness on laparoscopic simulator performance. Under review at *The American Journal of Surgery*

RESEARCH DATA MANAGEMENT

Ethics and privacy

All research conducted in this thesis adhered to the ethical standards outlined in the 1964 Helsinki Declaration and local ethical guidelines. Participants provided informed consent, granting permission for the collection and processing of their data within the scope of this research project. To uphold the availability, integrity, and confidentiality of the data, a comprehensive set of technical and organizational measures was implemented. These measures include pseudonymization, access authorization, and secure data storage. Privacy protection is further ensured through the encryption of participant data using individual subject codes.

Data and storage

The data generated throughout this thesis was systematically archived in alignment with the Findable, Accessible, Interoperable, and Reusable (FAIR) principles. Informed consent documents are securely housed in the department archive at Radboud university medical center, specifically in room M608.03.051. Access to the original raw performance data of participants on laparoscopic simulators is strictly controlled, requiring an administrative account managed by the research team. Exclusive access to simulators is granted solely to individuals with specific rights linked to their Radboud university medical center personal card.

The processed data for chapters 2 to 7 of this thesis project, along with associated files such as SPSS files and Excel sheets, is digitally stored in a structured and logical manner on a local server within the Department of Surgery at Radboud university medical center. Regular centralized backups of the servers are conducted to ensure data integrity. Subject codes are stored separately from the study data on the department server. To prevent errors, comprehensive codebooks document all (meta) data in detail, and version numbers are assigned to all saved files. This versioning system allows access to previous versions for error-checking purposes. Change of data storage locations and rules and regulations are subject to Radboud university medical center IT strategy e.g. recent relocating of department maps (e.g. local H-drive to one-drive environment).

Data sharing

Any future use of the data for research purposes requires successful permission from all participants who contributed to the relevant datasets. The datasets analyzed during these studies are available from the corresponding author upon reasonable request. All data collected and generated for this thesis will be retained for 15 years after the termination of the respective studies on the department server of Radboud university medical center with restricted access.

PhD PORTFOLIO

Department: Surgery
PhD period: 01/01/2015 – 30/10/2024
PhD Supervisor(s): Prof. Dr. H. van Goor
PhD Co-supervisor(s): Dr. J-M. Luursema

Training activities	Hours
Courses	
• BGIC Basic Laparoscopy Course Hamburg (2015)	32.00
• RIHS - Introduction course for PhD candidates (2018)	15.00
• Radboudumc - Scientific integrity (2019)	20.00
Conferences	
• Chirurgendagen with poster presentation (2015)	16.00
• Chirurgendagen (2016)	16.00
Other	
• Weekly research meeting, Department of Surgery, Radboudumc. 2-3 per year oral presentation (2015-2017)	120.00
• Member of the Skillslab Working group (2015-2019)	108.00
Teaching activities	
Lecturing	
• Instructor skillslab (2015-2018)	864.00
Supervision of internships / other	
• Supervision of medical student clinical internships (2017)	60.00
Total	1251.00

