From the Department of Clinical Science, Intervention and Technology
(CLINTEC), Division of Surgery
Karolinska Institutet, Stockholm, Sweden

Is it all about the Money?
The Effects of low and high cost Simulator training scenarios in Surgical training

Ninos Oussi

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Is it all about the Money?
The Effects of low and high cost Simulator training scenarios in Surgical training

THESIS FOR DOCTORAL DEGREE (Ph.D.)

By

Ninos Oussi
M.D.

Principal Supervisor:
Professor Lars Enochsson
M.D., Ph.D.
Karolinska Institutet
Department of Surgical and Perioperative Sciences,
Umeå University, Umeå
Division of Surgery

Co-supervisor(s):
Associate Professor Lars Henningsohn
M.D., Ph.D.
Karolinska Institutet
Department of Clinical Science,
Intervention and Technology (CLINTEC)
Division of Urology

M.D., Ph.D., Markus Castegren
Karolinska Institutet
Department of Clinical Science,
Intervention and Technology (CLINTEC),
Institution of Physiology and Pharmacology (FyFa)
Division of Anesthesia and Intensive Care

M.D., Ph.D., Ann Kjellin
Karolinska Institutet
Department of Clinical Science,
Intervention and Technology (CLINTEC)
Division of Surgery

External Reviewer:
Associate Professor Martin G. Tolsgaard
M.D., Ph.D., D.M.Sc.
University of Copenhagen
Copenhagen Academy for Medical Education and
Simulation (CAMES)
Division of Obstetrics, Copenhagen University
Hospital, Rigshospitalet, Copenhagen, Denmark

Examination Board:
Associate Professor Ib Christian Rasmussen
M.D., Ph.D.
Uppsala University
Department of Surgical Sciences
Division of Gastrointestinal Surgery,
Uppsala University, Uppsala, Sweden

Associate Professor Mirna Abraham Nordling
M.D., Ph.D.
Karolinska Institutet
Department of Molecular Medicine and Surgery
Division of Colorectal Surgery, Karolinska
University Hospital, Stockholm, Sweden

Professor Hans Hjelmqvist
M.D., Ph.D.
Örebro University
Department of Medical Sciences
Division of Anesthesia, Örebro University,
Örebro, Sweden

To you,

knowledge,

and whom it may concern.

“Let books be your dining table,	ܟܬܒ̈ܐ ܢܗܘܘܢ ܦܬܘܪܟ :
and you shall be full of delights.	ܕܒܗܘܢ ܬܬܒܣܡ ܒܒܘܣ̈ܡܐ.
Let them be your mattress,	ܘܗܘܢ ܢܗܘܘܢ ܬܫܘܝܬܟ :
and you shall sleep restful nights.”	ܘܬܕܡܟ ܫܢܬܐ ܕܢܝܚܐ ❖

A poem in Assyrian (Syriac language) by Ephrem of Nisibis c. 303-373 A.D.,

the most prominent and famous teacher of the world’s first university;

the School of Nisibis, situated in northern Mesopotamia.

ABSTRACT

Background

The learning process is complex and dependent on several factors such as for instance, the environment to learn, prior knowledge and distinct abilities, motivation, goal-orientation as well as the effects of instructor feedback. Medical education, in particular within surgical domains is imperative due to its influence on patient safety. The demand for training surgeons has shifted from the "master-apprentice/practice on patients", towards a safer modality, involving simulators. The positive effects laparoscopic simulator training has on laparoscopic performance is extensive, as well as its impact on operating room performance. Nonetheless, the difference in learning effect using either low-cost or high-fidelity laparoscopic simulators were not totally clear prior to study start.

Aims

1. To examine whether laparoscopic surgical training may be offered at a lower cost, with maintained equivalent level of training and effect in knowledge/learning using a low-cost laparoscopic Blackbox (Paper I).
2. To study the impact of PC-gaming experience, visuospatial ability and gender on the various parameters of the MIST-VR simulator and its effect on the score (Paper II).
3. To further investigate the Blackbox, and if different adjuncts (video analysis) could provide more information regarding the effects of training (Paper III).
4. To study the effects on time to learn laparoscopic knot- and suturing skills in novices using two different laparoscopic needle holders in a more advanced Blackbox, evaluate outcomes regarding performance, ergonomic discomfort and time to perform laparoscopic knot- and suturing skills, as well as to evaluate an objective video evaluation scoring table (OVEST) (Paper IV).

Materials and Methods

The participants were medical students from the surgical semester at Karolinska Institutet, Stockholm (Studies I-III) and medical students at Athens University Medical School in Athens, Athens, Greece (Study IV). The studies were conducted at CAMST (Center for Advanced

Medical Simulation and Training), Karolinska University Hospital, Stockholm (Studies I-III), and at MPLSC (Medical Physics-Lab Simulation Center), Athens University Medical School, Athens, Greece (Study IV).

In conjunction with inclusion, the students (Studies I-II) performed a test (MRT-A; Mental Rotation Test – A) for the assessment of their visuospatial ability, and questionnaires including baseline questions (Studies I-IV). The simulator training/tests were done using different laparoscopic simulators; Blackbox (Studies I and III); LapMentor (Study I); MIST-VR (Studies I-III); Simball box (Study IV). The participants' simulator performance analyzed; time to completion and economy of movement (Studies I-IV); optical flow metrics (*path-length* and *total number of particles*) as displayed by the automated video analysis software (Study III); knot- and suturing skills (Study IV).

Results

Studies I and II showed, as previous studies, that the visuospatial ability correlated with the initial simulator training sessions. Study I showed no significant difference in performance between laparoscopic basic skills training regardless of simulator used; low-cost or high-fidelity laparoscopy simulator. Studies I, II and III showed discrepancies between prior PC-gaming experience and the simulator performance, as well as some gender-specific differences. Study III also showed that the use of a low-cost automated video analysis software may be feasibly comparable to the build-in software of the MIST-VR simulator. Study IV presented a shortened time to learn for novices performing laparoscopic knot- and suturing tasks in a simulated environment when using the newly designed laparoscopic needle holder compared to a conventional market needle holder.

Conclusions

Laparoscopic simulator training clearly facilitates laparoscopic skills performance. Improved prerequisites of training opportunities for surgeons could potentiate patient safety, especially since enhanced surgical performance improves patient safety. Subsequently, as depicted in this thesis, there is not one single truth or solution, rather different angles and several factors that affect learning in general and surgical performance in particular. Therefore, considerations of for instance individual differences, gender, and motivation, should all be included when producing laparoscopic skills training curriculum for future surgical trainees.

POPULÄRVETENSKAPLIG SAMMANFATTNING

Bakgrund

Så långt vi kan se tillbaka i mänsklighetens historia finns spår av åtgärder i ett försök att läka skador och sjukdomar. Vissa av dessa åtgärder har utgjorts av kirurgiska interventioner. Redan under de gamla assyriska och egyptiska kungadömena finns beskrivet trepanation (att skapa hål i skallbenet), underlättande av förlossningsarbete, m.m. Med åren har de kirurgiska metoderna långsamt förfinats och under de senaste 60 åren har utvecklingen snabbt gått framåt, där den tekniska utvecklingen varit en starkt bidragande orsak till detta.

Till den moderna kirurgiska utvecklingen hör den minimalinvasiva kirurgin. Där en kamera förs in genom naturliga kroppsöppningar, alternativt genom små hål i huden in i olika hålrum som kan utgöras av tex blodkärl, bröstkorgshåla, bukhåla, ledhåla, m.m., vilka samtliga underlättat genomförandet av vissa operationer. En av anledningarna till införandet av den minimalinvasiva kirurgin har bland annat varit att minska traumat mot kroppen i samband med kirurgi med snabbare återhämtning efter operation, förkortad vårdtid och färre infektioner och smärta. Införandet av denna relativt nya teknik kräver också en modifierad utbildning. Tiden då kirurgyrket bestod i att som Dr Halsted myntade i början på 1900-talet; ”see one, do one, teach one” delvis förknippat med en del patientskador, är sedan länge förbi. Kraven på ökad patientsäkerhet har medfört att kirurger behöver träna mer effektivt och mer patientsäkert. Enklare, tillika mer avancerade minimalinvasiva simulatorer har introducerats på marknaden i allt större grad och utgör idag ett viktigt komplement till den traditionella kirurgiska utbildningen. Precis som flygindustrins krav på piloter att träna i flygsimulatorer har numera även kirurgin börjat anamma detta. Flera länder har infört som krav för att uppnå specialistkompetens i kirurgi; obligatorisk laparoskopisimulatorträning. En av bakgrunderna till detta är de höga kostnaderna relaterade till undvikbara felbehandlingar av patienter, inte minst inom kirurgiska specialiteter som står för en majoritet av dessa. Ökad kirurgisk simulatorträning har visat sig minska risken för fel och skador och därmed ökad patientsäkerhet.

Syfte

1. Att studera om kirurgisk träning av titthålskirurgi kan erbjudas till en låg kostnad med bibehållen träningseffekt genom användning av lågkostnadssimulator (Blackbox) i jämförelse med högkostnadssimulator (LapMentor) (Studie I).
2. Att närmare studera vilken effekt av tidigare datorspelserfarenhet, visuospatialförmåga och kön har på de ingående parametrarna i MIST-VR simulatorn (Studie II).
3. Att vidare studera huruvida Blackboxen kan potentieras genom tillägg av extra utrustning (videoanalysprogram), samt om detta kan ge mer information om effekten av simulatorträning (Studie III).
4. Att undersöka effekten av inlärning av laparoskopisk knyt- och sutureringsförmåga hos nybörjare vid användning av olika laparoskopiska nålförare i en mer avancerad Blackbox-simulator (Simball box), samt utvärdera skillnaderna i utfall av prestation, belastningsbesvär och tid till genomförande av knyt- och sutureringsövningar, och slutligen att validera en objektiv video-evalueringspoängskala (OVEST) (Studie IV).

Material och Metoder

Studiedeltagarna var studenter på läkarprogrammet under kirurgterminen på Karolinska Institutet i Stockholm (Studier I-III) samt läkarstudenter på läkarprogrammet på Athens University Medical School in Athens, Athen, Grekland (Studie IV). Studierna genomfördes på CAMST (Center for Advanced Medical Simulation and Training), Karolinska Universitetssjukhuset, Stockholm (Studier I-III), respektive MPLSC (Medical Physics-Lab Simulation Center), Athens University Medical School, Athen, Grekland (Studie IV).

I samband med inkludering av studenterna (Studier I-II) genomfördes ett test (MRT-A; Mental Rotation Test – A) för bedömning av visuospatialförmågan, samt en enkät för besvarande av bakgrundsfrågor (Studier I-IV). Simulatorträning/-tester utfördes i olika simulatorer; Blackbox (Studie I och III), LapMentor (Studie I), MIST-VR (Studier I-III), Simball box (Studie IV). Studenternas prestation i simulatorerna (simulator performance) analyserades utifrån mätning av bland annat; tid (genomförande av övningen/testet) och rörelseekonomi (instrumentens förflyttning i rymden) (Studier I-IV), antalet rörelsepunkter i det automatiserade videoprogrammet (Studie III), samt knyt- och sutureringsförmåga (Studie IV).

Resultat

Studie I och II visade, likt tidigare studier, att visuospatialförmågan korrelerade med de initiala simulatorövningarna. Vidare demonstrerade Studie I ingen signifikant skillnad beträffande kirurgisk laparoskopiträning av basala färdigheter oberoende av simulator som använts; låg- respektive högkostnadssimulator. Studierna I, II och III visade på skillnader i tidigare datorspelserfarenhet och simulatorprestationen, men även vissa könsskillnader. Studie III visade vidare att ett lågkostnads automatiserat videoanalysprogram kan vara fördelaktigt jämförbart med det inbyggda analysprogrammet i simulatorn (MIST-VR), vilket talar för att bedömning av basal kirurgisk laparoskopiträning med låg kostnad är möjlig. Studie IV visade en förbättrad inlärningskurva hos nybörjare som genomförde laparoskopiska knyt- och sutureringsövningar i en simulerad miljö då de använde en nydesignad laparoskopisk nålförare jämfört med en konventionell (marknads) laparoskopisk nålförare.

Slutsats

De positiva effekterna av laparoskopisk simulatorträning är tydliga. För att underlätta för blivande kirurger att prestera bättre och säkrare kirurgi bör man ta hänsyn till individuella skillnader i samband med konstruerandet av framtida träningscurriculum. Således kan förbättrade förutsättningar med gynnsammare träningsmöjligheter av dagens och framtidens kirurger potentiera patientsäkerheten.

LIST OF PUBLICATIONS

I. **Oussi N**, Enochsson L, Henningsohn L, Castegren M, Georgiou E, Kjellin A.
Trainee performance after laparoscopic simulator training using a Blackbox versus LapMentor.
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II. **Oussi N**, Renman P, Georgiou K, Enochsson L.
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III. **Oussi N**, Loukas C, Kjellin A, Lahanas V, Georgiou K, Henningsohn L, Felländer-Tsai L, Georgiou E, Enochsson L.
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IV. **Oussi N**, Georgiou K, Larentzakis A, Thanasas D, Castegren M, Georgiou E, Enochsson L.
Validation of a novel needle holder to train advanced laparoscopy skills to novices in a simulator environment.
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LIST OF ABBREVIATIONS

2D	Two Dimensional
3D	Three Dimensional
AEs	Adverse Events
BT	Box Trainer
CAMST	The Center for Advanced Medical Simulation and Training
CLINTEC	Department of Clinical Science, Intervention and Technology
ERCP	Endoscopic Retrograde Cholangio-Pancreatography
FLS	Fundamentals of Laparoscopic Surgery
FPS	First Person Shooter
HFLS	High Fidelity Laparoscopic Simulator
IOM	Institute of Medicine
MIS	Minimally Invasive Surgery
MIST-VR	Minimally Invasive Surgical Trainer – Virtual Reality
ML	Mastery Learning
MNH	Market Needle Holder
MPLSC	Medical Physics Lab-Simulation Center
NNH	Najar Needle Holder
OR	Operating Room
OVEST	Objective Video Evaluation Scoring Table
PC	Personal Computer
RPG	Role Playing Games
SBOS	Simball Box Overall Score
VR	Virtual Reality

1 INTRODUCTION

"What we do is dangerous", the supervising colleague-surgeon and associate professor Folke Hammarqvist once said while instructing in a laparoscopic cholecystectomy during my residency at Karolinska University Hospital in 2006. These words sometimes echo's in my head while performing surgery, and when appropriate, I also use them when supervising my residents. Teaching surgery, surgery training and patient safety, are inseparable, and everything we do in our quest to help and treat patients should be with the safety of the patients in mind - the number one priority at all times. For the individual patient, no political decision affecting healthcare, change in the healthcare organization, nor any healthcare management issues are more important than the role taken to improve patient safety - defending the individual being.

2 BACKGROUND

"And if anything that I say should bear the appearance of arrogance or conceit, let me publicly confess that this book has arisen from a sorrowful contemplation of the many surgical errors which I have myself committed."

Harold Burrows (1875-1955)

Pitfalls of Surgery, 2nd Edition, New York: William Wood, 1925.

2.1.1 *From the Cradle of Civilization to "Above All, Do No Harm"*

Evidence of early medical achievements date back to the Stone Age [1,2]. Simple medical kits and herbs like the ones belonging to Ötzi the Iceman were found conserved in ice in the Alps in the 1990s. Archaeologists uncovered evidence of treatments used by the Assyrian, and later Egyptian civilizations, including those that facilitated delivery or trepanation (drilling into a skull) [3].

The origin of rational medicine has been traced back to Hippocrates in 420 BC and his famous oath, which medical students, at least in the Western world, are taught: "Above all, do no harm" (Latin: *primum non nocere*). However, this exact phrase was never written by Hippocrates and dates to later years. It was first expressed by the English physician, Thomas Sydenham, in 1860 [4]. The approach of "do no harm" is still the essence of all medical treatments and should be the guide in our quest to find the right cure for the right patient and with minimal harm.

2.1.2 *Apprentice Becomes Surgeon*

Physicians in general, and surgeons in particular, are responsible for human lives and the bodies of patients literally lay in their hands. Surgery, like any craft, for many years was taught to the surgical resident under the supervision of a more experienced surgeon, similar to an apprenticeship; this was originally championed by William Halsted in 1904 [5]. The main components were to observe, coach and train, and this led to the “see one, do one, teach one” approach in surgical training [5]. This approach could often lead to a trial-and-error practice with unacceptably high costs, not the least of which was from a patient’s safety perspective. Despite the fact that this method did train exceptional surgeons, one may assume that it had a negative impact on patient safety. It was not until the 1980s that surgeons’ creative inventions with minimally invasive surgery [6], later gave rise to the introduction of surgical skills training for surgical residents in laboratory settings which put to end the Halsted era [7].

2.2 Patient Safety

“Patient safety” is an expression often used to measure patient outcomes of how the healthcare sector performs. According to the World Health Organization, patient safety is: “the absence of preventable harm to a patient during the process of health care and reduction of risk of unnecessary harm associated with health care to an acceptable minimum” [8]. The famous legal Code of Hammurabi (meaning Kinsman Healer) created c. 1754 BC, depicted several pronouncements on medical care, some of which held physicians accountable both for success and failure [3]. Perhaps it could be called the ancient precursor of patient safety.

2.3 Money and Patient Safety

By the turn of the century, the report “To Err is Human: Building a Safer Health System” [9] was released by the Institute of Medicine (IOM) Committee on Quality of Health Care in America. According to this report between 44,000 and 98,000 patients died annually in American hospitals as a consequence of in-hospital medical errors. The financial burden of preventable adverse events (AEs) in the U.S. only was estimated to range between $17-$29 billion. The public outrage after this report was instant and resulted in actions from the government to find a means to implement the recommendations declared by the IOM report [9].

In a recent Swedish study [10], detailing the high financial burden of avoidable AEs, the incidences decreased in somatic acute care hospitals in 2016. However, as patient care out of hospital care increases, so do AEs, thereby challenging patient safety [10]. To indicate the likelihood of any AEs, a Global Trigger Tool was put together by the Institute of Healthcare Improvement in the US and is the most frequently used tool to measure AEs on a national level [11].

Moreover, according to a report by Slawomirski et al. [12], AEs make up 15% of hospital expenditures in the Organisation for Economic Co-operation and Development countries, and when patient harm is accounted for, including the aggregated costs of lost patient productivity, trillions of dollars are lost each year [12]. A majority of all medical patient involved AEs are due to surgery [13], and among these, a majority are intraoperative and thus potentially preventable [14,15]. In particularly, stress has negatively affected surgical performance [16]. The stressful environment of a surgeon is well known, with surgical challenges, requirements of technical skills performance, and time pressures [17]. Acute stress directly effects surgical performance and patient safety [18,19], and one approach to minimize the risk for patients during surgery is to provide surgeons with sufficient training [20].

Training surgeons to reach proficiency levels requires not only time but high expenses, and according to Bridges and Diamond (1999), the costs to train surgery residents in the operating room in the U.S. in 1997 was estimated to be $53 million annually [21]. These financial constraints are essential hurdles and led to the development of a curriculum by the American College of Surgeons and the Association of Program Directors in Surgery, with setup costs of around $4,000,000 USD. This includes an annual expenditure for equipment of up to $33,000 USD for each resident and another $22,000 USD to $30,000 USD annually for crew and faculty time [22,23]. A recent study, although with few participants, stressed the importance of “a structured, extended training course including simulation, precepting, and surgical coaching” to assist surgeons in their progress of learning new techniques, such as laparoscopic inguinal hernia repair [24]. This program has an approximate total cost per surgeon of $8,640 USD [24], which is nearly the annual financial savings when adopting the strategies of training for the Fundamentals of Laparoscopic Surgery (FLS) skills test by using a low-cost platform according to Franklin et al. (2016) [25].

2.4 Teaching and Learning

Comments from younger students similar to “my grades are low, because the teacher was bad”, are perhaps not rare. The pressure on a teacher to meet the expectations of, and satisfy students with that kind of attitude may seem burdensome. However, mastering teaching skills requires more than barely possessing the knowledge in a certain field or a subject; it also depends on various individual abilities and perhaps a great amount of patience. Moreover, the learning process is complex. To learn, however, the presence of the teacher is not always necessary since obtaining knowledge or a skill can be done by studying, via instruction, or through experiences. In a recent review by Wulf and Lewthwaite (2016), several different concepts of learning were displayed, which included a variety of “scientific perspectives and levels of analysis, including behavioural, social cognitive, neuro-physiological, and neurocomputational”. The authors further stated, “Conditions that optimize performance facilitate learning” [26]. The abilities to learn are complex and multifactorial and depend on, e.g., the learning environment, former knowledge, individual abilities, and defined goals.

2.5 Laparoscopy

The initial operations taught to junior surgeons often include appendectomies, cholecystectomies due to inflammation (cholecystitis) or symptomatic gallstones (cholelithiasis), and inguinal hernias. These are routine operations and at least appendectomies and cholecystectomies are minimally invasive surgeries using laparoscopy.

The word *laparoscopy* is from the ancient Greek *lapara* (flank or side) and *skopeó* (to see), and was first coined by the Swedish internist Jacobaeus, who performed the first laparoscopies on humans in 1910 [27]. Today laparoscopy is also known as “keyhole surgery.”

The introduction of laparoscopy into the field of surgery was initially poorly received with few advocates. However, the German gynecologist and engineer, Kurt Semm, began using the laparoscopic technique for gynecological diseases in the 1970s. He also created some of the instruments to facilitate the procedures [28]. Not until Semm, performed an “endoscopic appendectomy” [29] in 1982, did surgeons start to pay attention. Yet, despite this, Semm was greatly criticized [6]. The German surgeon, Erich Mühe, customized equipment in order to perform the first reported laparoscopic cholecystectomy [28]. Since a laparoscopic cholecystectomy was possible, then why should not other intra-abdominal operations be possible to perform using laparoscopy?

2.5.1 *A Flying Start*

To understand the importance of simulator training, flight simulator training for pilots must be mentioned as a parallel process. In order to prevent incidents and ultimately airplane crashes, airline pilots are required to complete several tests annually and also pass the flight simulator exams every sixth months [30] to improve their response to the many unusual situations they may confront. Recently, the American Federal Aviation Administration upgraded the requirements for using simulators for training pilots [31], a procedure that the medical establishment should also follow.

Several states in the US have already implemented mandatory simulation-based laparoscopic training in surgical residents training programs [32–34]. Unlike the US, Scandinavia, although having readily available simulation equipment, appears to lack a structured simulation-based training [35].

2.5.2 *Stairway to the Top – The Ten-Thousand-Hour Rule*

> *"… ten thousand hours of practice is required to achieve the level of mastery associated with being a world-class expert – in anything."*
>
> **Daniel Levitin** (1957-)
>
> This Is Your Brain on Music: The Science of a Human Obsession, Dutton Books, 2007.

Practice makes perfect, or more precisely, several thousand hours of purposeful and deliberate practice (under the guidance of a teacher), leads to the acquisition of expert performance, according to Ericsson et al. (1993) [36] and Ericsson (2020) [37]. This was inaccurately [38] represented by Levitin (2007) and Gladwell (2008) as the famous *ten-thousand-hour rule* [39,40]. Several psychologists have shown similar results regarding practice, not least when it comes to musical achievement [41]. Furthermore, Sadideen at al. (2013) stated, "Surgical experts are made, not born," proposing this as one of many requirements for the acquisition of surgical competence and expertise. These also include: psychomotor skills, which are attained after continuous deliberate self-practice; memory and deep learning; communication; and decision-making skills as the non-technical skills. Subsequently, it is a combination of multiple factors that leads to the "making of a surgeon" [42]. A surgeon, with the above-mentioned skills, born with innate capabilities and prerequisites to practice has a greater probability of success. Nevertheless, for learners to reach the higher level of expertise, a set of educational conditions and the assessment plan of a comprehensive curriculum are required [43,44]. Moreover, simulator training used solely for proficiency levels and skill transfer to the clinical setting is insufficient. In order to reach automaticity, the amount of simulator training needs to surpass the initial accomplishment of proficiency [45,46]. Nevertheless, as mentioned earlier, practice makes perfect and training in practical skills is crucial for the surgeon; to reach the level of acceptance, enormous amounts of training are required.

Open surgery and its complications and recovery differ from laparoscopic surgery [47,48], as does its training [49]; laparoscopic surgery demands new and unique psychomotor skills that are somewhat different from those required for open surgery [50]. Furthermore, earlier studies indicate that an experienced surgeon with no laparoscopic experience is not the teacher of choice for junior surgeons [49], which the initial complication rates after the introduction of laparoscopic surgeries foretells [51,52]. Both Wilkiemeyer (2005) and Kauvar (2006) show that both operating time and the complication rates of junior surgeons compared to seniors increases under such circumstances [53,54].

The number of hours needed to sufficiently train surgeons to proficiency levels has faced a considerable decline in allowed working hours due to the European Working Time Directive in Europe [55], and correspondingly by the Accreditation Council for Graduate Medical Education in the US [56]. Furthermore, with decreased time for practice following a limited amount of operations available for surgical trainees, the call for more effective and time-efficient means for surgical training is of the essence [57].

2.6 Medical Education

“Practice isn’t the thing you do once you’re good. It’s the thing you do that makes you good.”

Malcolm Gladwell (1963-)

<u>Outliers – The Story of Success</u>, Penguin Books, Psychology, 2008.

The basis of how medical education ought to be designed faces a major reconstruction due to the transition into the information age. New innovative technologies, new methods, and also academic, social and political factors all fuel such changes [58]. The rapid changes also require a new approach and not only an updated, but also a dynamic curriculum that meets the needs of the medical education of today. The time of only traditional cathedral lectures is, since long, overdue. The quest for more effective interactive education of higher quality has been on the call, as well as the demands of a more individually designed education, distinguishing the different students’ and residents’ needs, according to their skills levels, abilities and personalities, in order to meet the proficiency levels necessary for providing safe professional care.

2.7 Medical Simulation

The introduction of advanced medical simulators has provided education with an additional tool for surgical skills training. In randomized trials, these simulators have shown improvements in both operating time and in reducing the number of errors in laparoscopic cholecystectomy by residents [59–61]. Simulators have been verified as a valuable tool not only for surgical training but also for basic skills training, since they provide instant feedback of the student’s progress

[62,63]. Additionally, training in more advanced laparoscopy skills such as bariatric procedures, indicate improvement in surgeons' technical skills and long-term results [64].

However, advanced medical simulators are expensive and, due to this fact, not available in all teaching centers in Sweden. Furthermore, the majority of procedures in these high-tech surgical and endoscopic simulators are mainly addressed at training residents and not students, even though this may provide a deeper understanding of the complexities of surgery. Many procedures, such as laparoscopic cholecystectomy, appendectomy, and endoscopic treatment of Forrest 1 bleeding are both too difficult and of limited interest for medical students. Students during their medical education are more likely to find value in knowing how to handle the laparoscopic instruments and perform basic skills maneuvers with the instruments in order to get a more profound understanding about these types of surgery.

Introduction of surgery early in the medical education can motivate the students' choice of surgical professions in the future [43]. Additionally, when studying medical students without prior laparoscopic experience, Nomura et al. (2018) found common characteristics (confidence in driving, male gender, and manual dexterity), factors that significantly improved the training results [65]. Furthermore, short motivational interference influences both motivation and procedural performance among students participating in activities involving medical simulation-based training [66]. Moreover, the advantages of obtaining instructor feedback while practicing with laparoscopic simulators compared to no feedback has been determined in several studies [63,67,68]. Furthermore, there is no significant difference in feedback as given by "peers versus pros" when provided to medical students training laparoscopic basic skills in a simulator [69]. An improvement in "intraoperative surgical performance" was seen after feedback was given the surgeons [70]. In addition, when the physician's coaching style is excessively critical and skeptical, surgical trainee's face increased stress that may negatively affect their acquisition of surgical skills in a simulated environment [71].

Nevertheless, it should be of value to introduce simulation-based training in the basic medical education, since a majority of the surgical and gynecological operations are performed using laparoscopic techniques. In addition, all endoscopic procedures (gastroscopy, colonoscopy, and ERCP) demand that the performers have a good visuospatial ability (the skills to convert a 2D screen picture to a 3D reality) in order to conduct a procedure successfully. At the Center for Advanced Medical Simulation and Training, Karolinska Institutet, Stockholm, Sweden (http://www.camst.se), visuospatial ability was found to be of great importance in students, residents, and experts in how they perform laparoscopic, endoscopic and gynecologic simulation [67,72–77]. Also, in studies from the same institution [72,77] visuospatial ability tests have been used to determine the correlation between these results and performance in the thoroughly studied laparoscopic simulator MIST-VR (Minimally Invasive Surgical Trainer – Virtual Reality, Mentice Medical Simulation AB, Gothenburg, Sweden) [78].

Regardless of the medical students' choice of future profession, an awareness about these modalities should at least be present. However, most of the clinical teaching of interactive procedures during the medical education is taught without having access to expensive simulators. Apprenticeship has traditionally been the standard for surgical training, where the resident learns surgical performance under the supervision of an experienced surgeon.

It is unknown whether assessment and information of the experienced teachers' visual focus in conjunction with the interactive procedures is effective in facilitating the teaching process. Studies on surgeons performing laparoscopic surgery have clearly indicated differences between experts and novices regarding eye movements and visual focus [79]. Additionally, a recent review demonstrating the benefits of non-verbalized motor skills through other means of learning, i.e., observational learning [80], showed that this could be an initial step for junior surgeons prior to practicing on patients. Furthermore, different surgical procedures have been shown to have different learning curves [59–61,81–84]. Both operating time [53,54,85,86] and complication rates increase for junior surgeons compared to senior surgeons [53,54].

Laparoscopic simulator training was introduced to, in a safe way, further train junior surgeons in laparoscopic surgery. Virtual reality (VR) or box trainers (BT) of various types have been used and the additional cost of these items must be balanced against the increased expenses of longer operating time and added complication rates during traditional surgical training [87].

A recent review showed that simulation-based training improves both laparoscopic cholecystectomy and endoscopy in regard to proficiency levels [20]. However, since the simulators are expensive and availability is limited, it could have a negative impact on the opportunity for laparoscopic training among residents. Whether laparoscopic basic skills training in Blackboxes is an adequate alternative to high fidelity simulators for students and residents in this high-tech era was, to our knowledge, not known at the time of this research. In a recent review by Li and George (2017) examining the accessibility of low-cost simulators, several commercially and non-commercially available simulators were recognized as providing straightforward and feasible self-assembly, although some had not yet been validated as an affordable solution in permitting basic skills training to junior surgical trainees on a regular basis [88]. In addition, a recent Danish review described the benefits of take-home laparoscopic simulators as being more available, resulting in increased time for training, and subsequently improving laparoscopic practical skills training [81].

In regard to the more advanced laparoscopic skills, Champion et al. (1996) demonstrated improvements in performing laparoscopic suturing tasks even for novice medical students. They were given instructions via a designed video suturing program, followed by two hours of practice. They were then tested to see if they could perform an intracorporeal laparoscopic suture (3-throw knot) in an average of 3 minutes and 12 seconds [89]. Moreover, in a recent review, Ahmet et al. (2018) demonstrated the potential of video-based education for surgical trainees [90]. As seen above and by the available literature, the support for laparoscopic simulation-based training is clear. However, the issues related to proficiency and transfer of laparoscopic simulator training is moving relatively slow, and the association between simulation training and patient outcomes is still uncertain [91].

2.8 Simulation-Based Education

Simulation-based education has been identified as an attractive choice of training modality for surgical trainees due to its benefits in practicing clinical skills in a low-risk setting prior to OR performance [92,93]. However, practicing technical skills alone is insufficient. A focus on the non-technical skills is far more unclear and future curricula should incorporate a multi-professional team including surgeon trainers, learners, surgical organizations, as well as hospital representatives [94]. Transferability of non-technical skills to the OR acquired under simulated conditions has not been sufficiently examined [95,96]. However, in a recent review investigating the impact of non-technical skills during minimally invasive surgery, the operating teams' non-technical skills seem essential for both enhancing workflow and preventing errors, something that can be improved by working in steady teams [97]. Moreover, unsatisfying teamwork based on trivial team behavior is yet another factor for stress and adverse events. Effective teamwork is, therefore, crucial to patient safety [98,99] and something that needs to be addressed when discussing improvements in surgery outcomes. Furthermore, the consequence of cognitive demands surpasses the surgeon's ability to cope with those demands and is, according to several studies, one of the greatest hurdles to successful surgical performance [18,19,100–102].

When residents and faculty were asked their views on how useful faculty teaching skills in the OR were, a discrepancy was seen, suggesting a need for appropriate methods in excellent surgical teaching [103].

Recently, the concept of mastery learning (ML) has been further recognized in medical education. The adoption of the “seven core principles of the mastery learning bundle” addresses that all driven learners can attain a predefined mastery standard when given resources and time to reach that standard [104]. The basis of ML relies on the foundation of “deliberate practice” as introduced by Ericsson [36,105]. This explains the process where mastery may be achieved by any motivated student through a process of thorough, goal-oriented practice combined with prompt feedback [106]. Implementing the idea of mastery learning in combination with deliberate practice in simulation-based education has culminated in a growth of several simulation-based curricula. Simulation-based mastery learning generates unique opportunities in surgical training where novices may achieve the technical skills necessary to perform a procedure prior to practicing in the OR, and residents can practice procedures that are typically uncommon in the clinical training [104].

2.9 The Effects of Music on Surgical Performance

> *“I would teach children music, physics, and philosophy; but most importantly music, for the patterns in music and all the arts are the keys to learning.”*
>
> **Plato** (c. 428-348 BC)
>
> The Republic, c. 360 BC. 2nd Edition, Penguin Classics, 2007.

Recent reviews have evaluated the effect of music on surgical performance and on the performance of the surgical team, and have found that the positive effects override the negative ones. The research suggests that classical music played at a low to moderate volume increases both accuracy and speed and thereby improves surgical task performance [107], as well as the performance of the surgical team [108]. Additionally, in a recent randomized controlled trial evaluating the impact music has on transferability and lasting procurement of laparoscopic suturing skills, non-disturbing music was shown to significantly improve knot quality, performance, and speed [109]. Although the evidence of positive effects of music on surgical performance in the OR, its advantageous effect in the simulated environment has yet to be proven [110]. Regardless of the positive effects music have on surgeon cognitive and technical skills, the negative effects on communication should be taken into account, where a lack of communication has been associated with bad surgical outcomes in nearly 45% of cases [98]. Furthermore, auditory distractions via phone calls were tested on medical students, interested in surgery, undergoing laparoscopic surgery training, where strong distractions were seen to impair their laparoscopic performance, suggesting recurrent phone calls should be avoided in the OR for novice surgeons [111].

Nonetheless, in regard to musicians' achievements, Rui et al. (2018) provide a number of proposals for surgeons in comparison to musicians' strategies for training and its effects on their performance, where surgeons too would benefit from "extensive training and deliberate practice and a high level of ambidexterity". The study also suggests reflective feedback and repetitive peer- and self-evaluation as a means to enhance technical excellence, as well as for surgeons presenting with performance anxiety and unavoidable intraoperative hand-tremors, treatment with beta-blocking agents pre-surgery has been suggested [112].

3 TERMINOLOGY

It is warranted to address a few key terms when mentioning or discussing medical simulators.

Validity involves the accuracy of the tool, i.e., how precisely a tool does what it is supposed to do or measures what it is supposed to measure.

Construct validity reflects if the test or tool, for example, separates a novice from an expert. Does the test detect disparity in competence or level of performance?

Face validity defines the subject, normally the expert's opinion, whether or not the tool "feels" or "looks" like the real thing.

Predictive validity regulates whether or not the tool or simulator provides a transfer of skills to the operating room.

Reliability is continuance, i.e., when a repeated task provides the same result.

Furthermore, particularly for laparoscopic simulators:

Virtual reality is a computer-generated simulation that provides three-dimensional environment or images of reality.

2D/3D represents the actual dimensions in a computer workspace. 2D uses two dimensions, horizontal (X), and vertical (Y), to present an image that is flat; while 3D, uses the third dimension, depth (Z), thus creating a "real" image from a "plane" or "flat" image.

High-fidelity in laparoscopic simulation means a simulator that provides a high degree of realism or fidelity in tasks.

Blackbox or box trainer is the low-cost (lack of virtual reality features/simulation) alternative to high-fidelity laparoscopic simulators.

Fulcrum effect can be explained as the point or pivot on which the laparoscopic instrument balances against the abdominal wall when passing into the abdomen.

Haptic feedback can be described as the sense of touch in laparoscopic simulation, the distribution of physical resistance or vibration.

Visuospatial ability means the cognitive ability to process objects in more than one dimension, i.e., to comprehend, reason, and remember the dimensional or structural connection among objects or space. The four common types of spatial abilities include perception, visualization, mental folding, and mental rotation.

4 SUMMARY

- Patient safety must always be the number one priority in health care.
- Every surgical procedure should be considered potentially dangerous.
- Standardized surgical education is essential to reduce risks related to surgery.
- The evidence for simulator training in acquiring laparoscopic skills is paramount.
- Simulator training is a safe, financially feasible method for training surgeons, with positive effects on patient safety.
- Mentoring should be more integrated into the teaching process and curriculum, as it usually lacks structure.
- Feedback is an important part of the complexity of the learning process, and needs to be better utilized as a training facilitator in the teaching of surgeons.

5 AIMS

5.1 General Aim

The general aim of this thesis was to provide laparoscopic simulator training opportunities to surgical trainees regardless of financial resources, background/gender, or geographic distances.

5.2 Hypotheses and Specific Aims

The hypotheses for this thesis were:

1. Low-cost laparoscopic simulators (Blackboxes) provide a training effect that is equal to high-fidelity laparoscopic simulators (HFLS).
2. Laparoscopic basic skills training can be further facilitated by additional adjuncts and equipment to the Blackbox simulators.
3. Laparoscopic suturing skills can be facilitated when training in a laparoscopic simulator, using a different laparoscopic needle holder.
4. Training in laparoscopic suturing skills with a newly designed laparoscopic needle holder can provide better outcomes in performance, lessen the ergonomic discomfort, and shorten the time to perform laparoscopic suturing, compared to a conventional needle holder.

To test our hypotheses, four studies were conducted with the following specific aims:

1. To examine whether laparoscopic surgical training may be offered at a lower cost, with maintained equivalent level of training and effect in knowledge/learning using a low-cost laparoscopic Blackbox (Paper I).

2. To study the impact of PC-gaming experience, visuospatial ability and gender on the various parameters of the MIST-VR simulator and its effect on the score (Paper II).
3. To examine if additional adjuncts to the Blackbox, such as automated video analysis software, could provide more information regarding the effects of training (Paper III).
4. To evaluate novices and the effects on time to learn laparoscopic suturing skills, as well as to study the differences in outcomes regarding performance, ergonomic discomfort, and time to perform laparoscopic suturing, when comparing two different needle holders in a more advanced Blackbox simulator (Paper IV).

6 MATERIALS AND METHODS

"Exploration is the physical expression of the Intellectual Passion."

Apsley Cherry-Garrard (1886-1959)

The Worst Journey in the World: Antarctica, 1910-1913, Penguin Classics, 2006.

6.1 Participants

All participants volunteered freely and could at any time withdraw their involvement in any of the four described studies. The participants were fourth-year medical students (surgical course) at Karolinska Institutet, Stockholm, Sweden (Papers I-III), and medical students at Athens Medical School, National and Kapodistrian University of Athens, Greece (Paper IV). For details see Papers I-IV, and the section Study Designs**.**

6.2 Study Designs

The study design for each individual study is illustrated below (Figures 1-4).

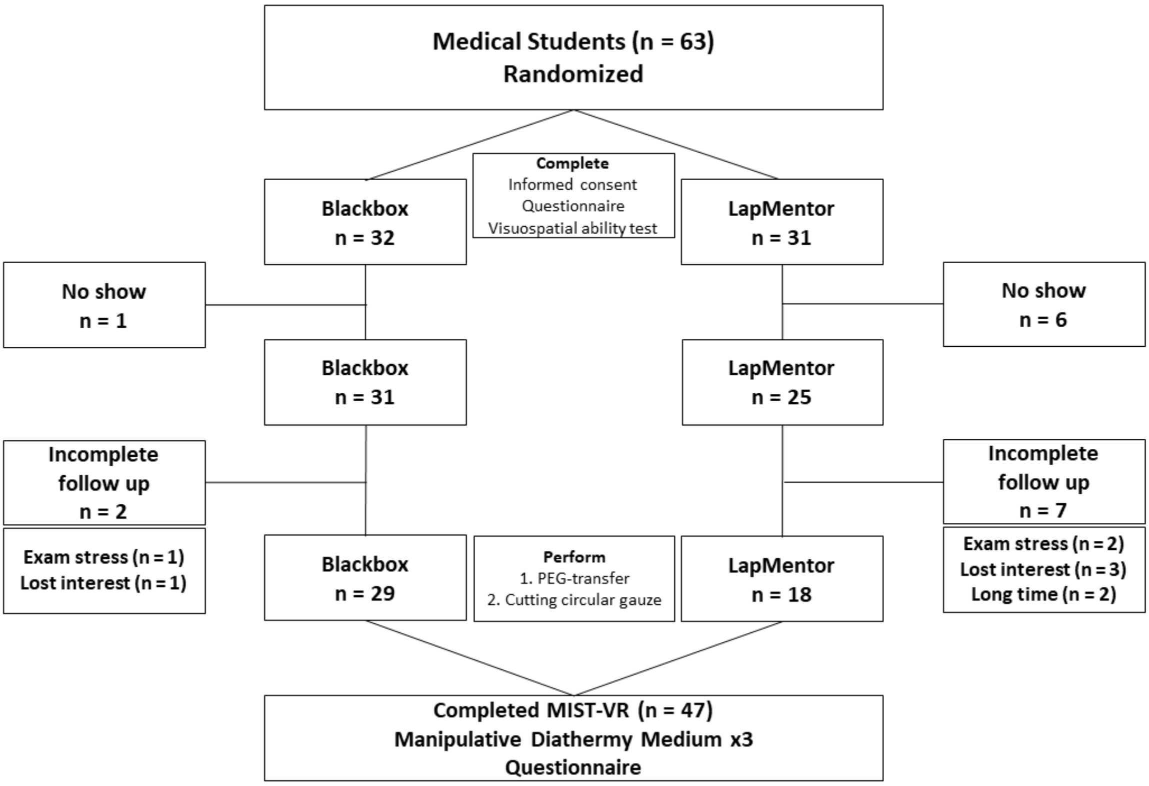

Figure 1. **Flowchart of Study I.**

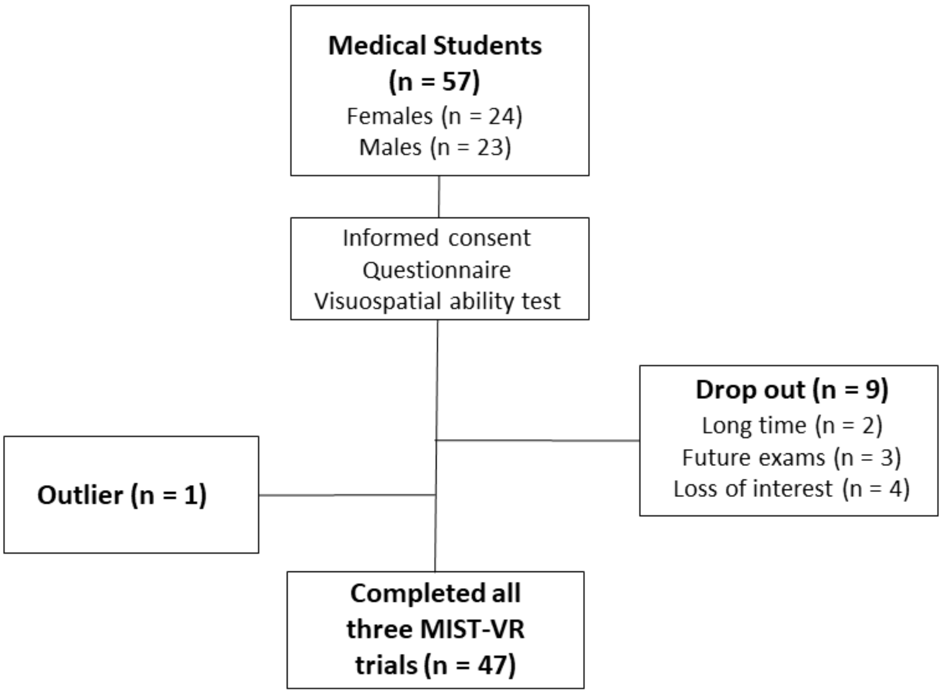

Figure 2. **Flowchart of Study II.**

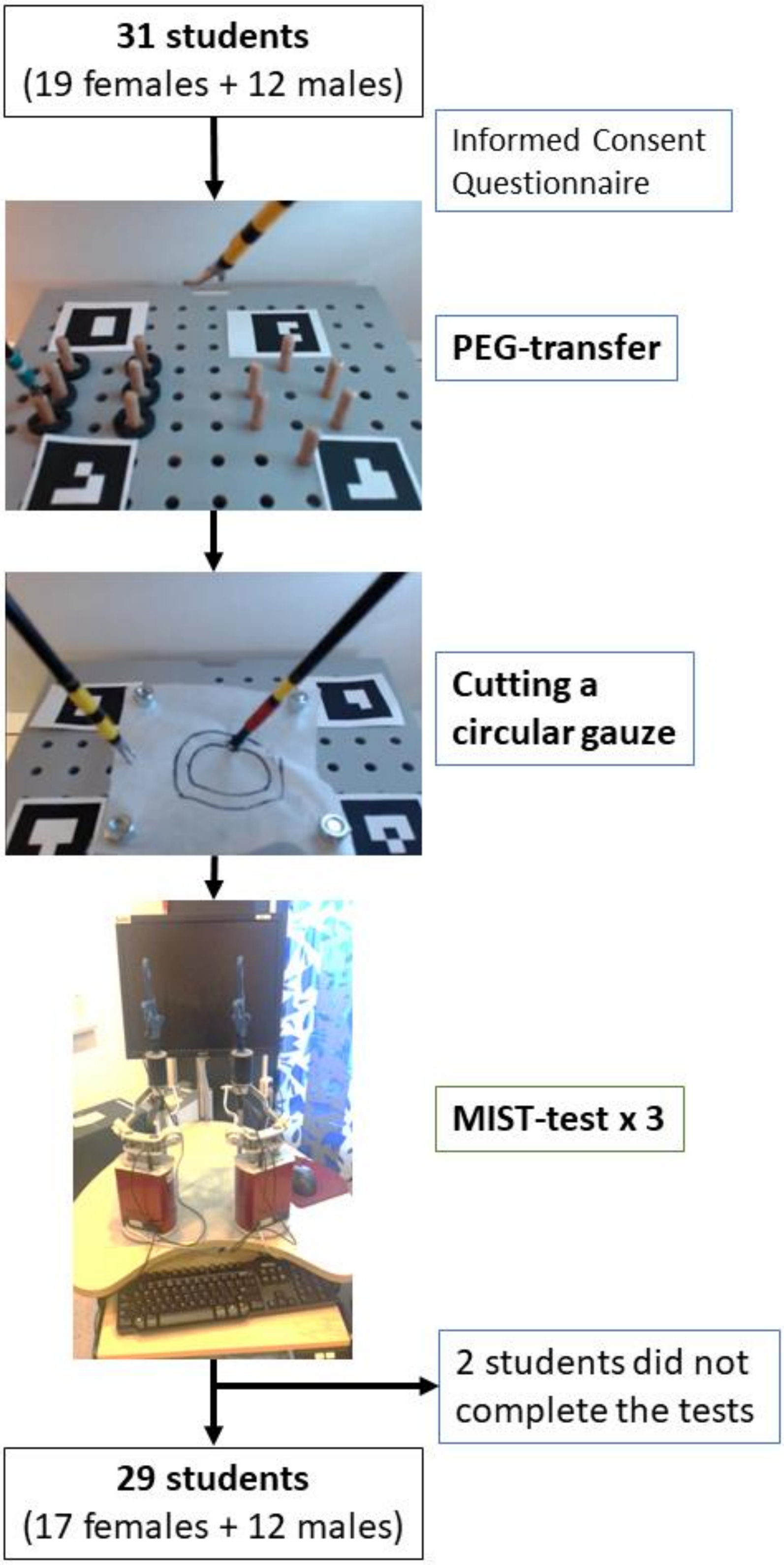

Figure 3. **Flowchart of Study III (Photo credit by the author).**

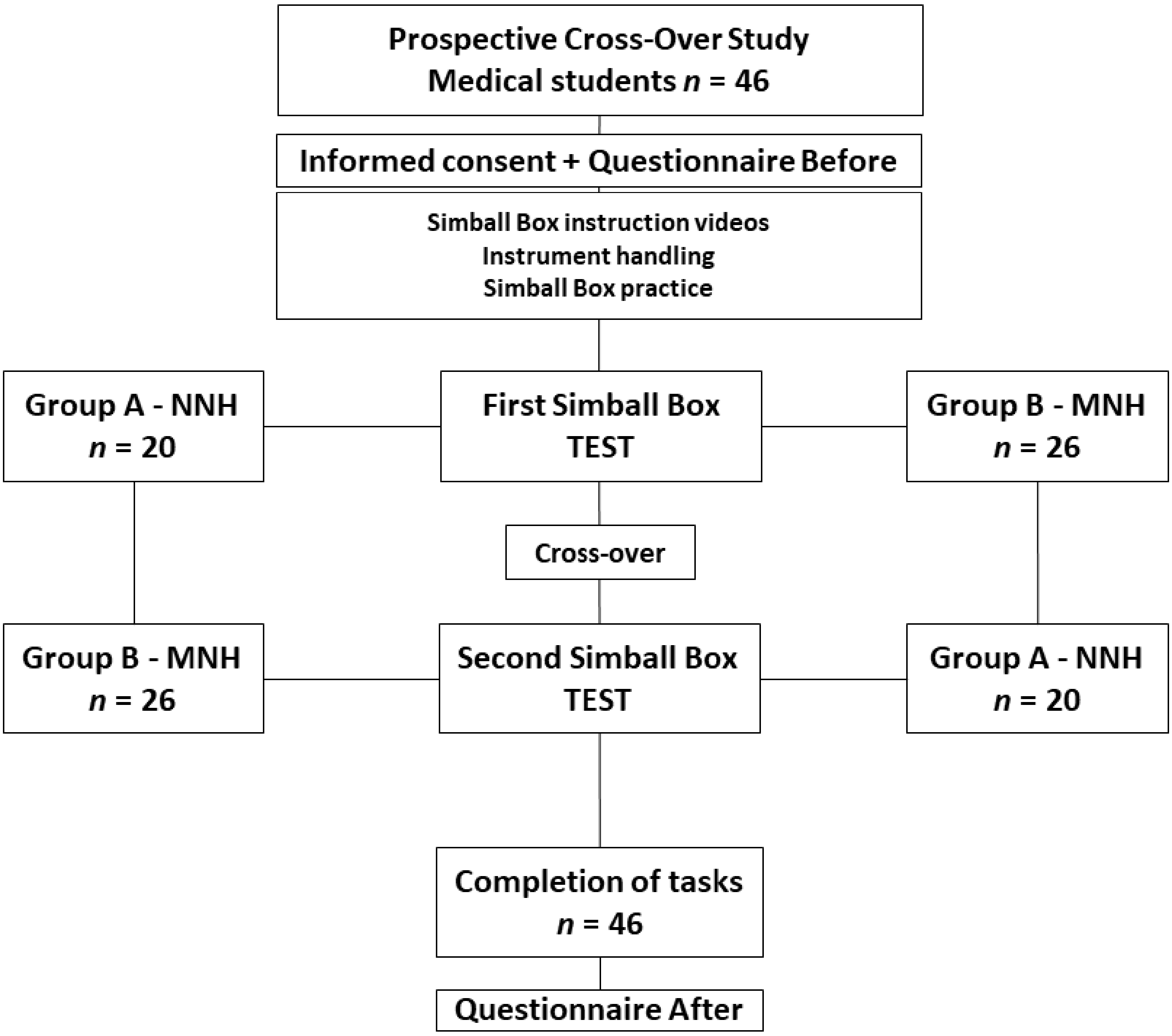

Figure 4. Flowchart of Study IV.

6.3 Overall Study Design

Study	I	II	III	IV
General aim	Determine if laparoscopic basic skills training in a low-cost Blackbox can serve as an adequate alternative to laparoscopic high-fidelity simulator (LapMentor) regarding motivation and surgical skills performance.	Investigating the impact of previous Personal Computer (PC) gaming experience, the types of games played, on the laparoscopic simulator performance, as well as the parameters constituting the score, and to analyze the impact of visuospatial ability and gender on simulator performance.	Assess if automated video analysis of low-cost Blackbox laparoscopic training could provide an alternative to laparoscopic high-fidelity simulator in basic skills training.	Evaluate if a newly designed laparoscopic needle holder shortens time for novices to improve advanced laparoscopy techniques, compared to conventional needle holder, and validate a new video-scoring system.
Number of subjects (finalized)	63 (47)	57 (47)	31 (29)	46 (46)

Simulators used	Blackbox, LapMentor, MIST-VR	MIST-VR	Blackbox, MIST-VR	Simball Box
Simulator tasks	Peg transfer, Precision cutting, and Manipulative Diathermia Medium	Manipulative Diathermia Medium	Peg transfer, Precision cutting, and Manipulative Diathermia Medium	Knot-tying, and Running Sutures
Psychomotor tests & Questionnaires	Visuospatial ability test, Questionnaires	Visuospatial ability test, Questionnaires	Questionnaires	Instrument familiarization, Questionnaires
Statistical analysis (p-value <0.05 was regarded statistically significant)	Wilcoxon/Kruskal-Wallis test, Pearson Chi-Square test, and Fit line analysis.	Matched pairs test, linear fit, and Student's t-test.	Linear fit and Student's t-test.	Wilcoxon signed rank test, matched pairs analysis, and linear regression
Statistical tool	JMP® Pro version 14.0.0 (SAS Institute Inc., Cary, NC)	JMP® Pro version 14.2.0 (SAS Institute Inc., Cary, NC)	JMP® Pro version 12.1.0 (SAS Institute Inc., Cary, NC)	JMP® Pro version 14.0.0 (SAS Institute Inc., Cary, NC)
Training tools or devices	Graspers	Graspers	Graspers	Graspers and Needle Holders

Table 1. Overall design of the thesis.

6.4 Simulator Centers, Simulators, and Tests

During these studies, all simulator training and tests were conducted in Simulator Centers at the Center for Advanced Medical Simulation and Training, Karolinska University Hospital, Stockholm, Sweden (Studies I-III), and at the Medical Physics Lab-Simulation Center (MPLSC), Athens Medical School, National and Kapodistrian University of Athens, Athens, Greece (Study IV).

6.4.1 *Blackbox*

For Studies I and III, a Blackbox (Figure 5A) was used, which is a wooden box containing three separate holes in its roof. Each hole represents the placement of the instruments used during the tasks. One hole is used for the camera (Logitech web-camera, with a processor image resolution of 720 x 576 and a frame rate of 25 frames per second) and two separate holes for each laparoscopic instrument. The web-camera was attached to the roof of the Blackbox, connected to a laptop for video recordings, and a flat-screen for visualization of the procedures (for details see Papers I and III).

On the bottom of the Blackbox (Figures 5B and 5C), materials for managing the different tasks were arranged:

A. A multi-cavernous plastic frame rigged with wooden plugs (pegboard) with rubber rings for the peg transfer task.

B. Screws and screw nuts organized to hold a 10 x 10 cm gauze marked with two circles: one internal and one external, where subjects may cut the perimeter between the two circles (Figure 5C). Conventional laparoscopic graspers and scissors were used for these tasks, and the distal ends were marked with different colored markers (Figures 5B and 5C).

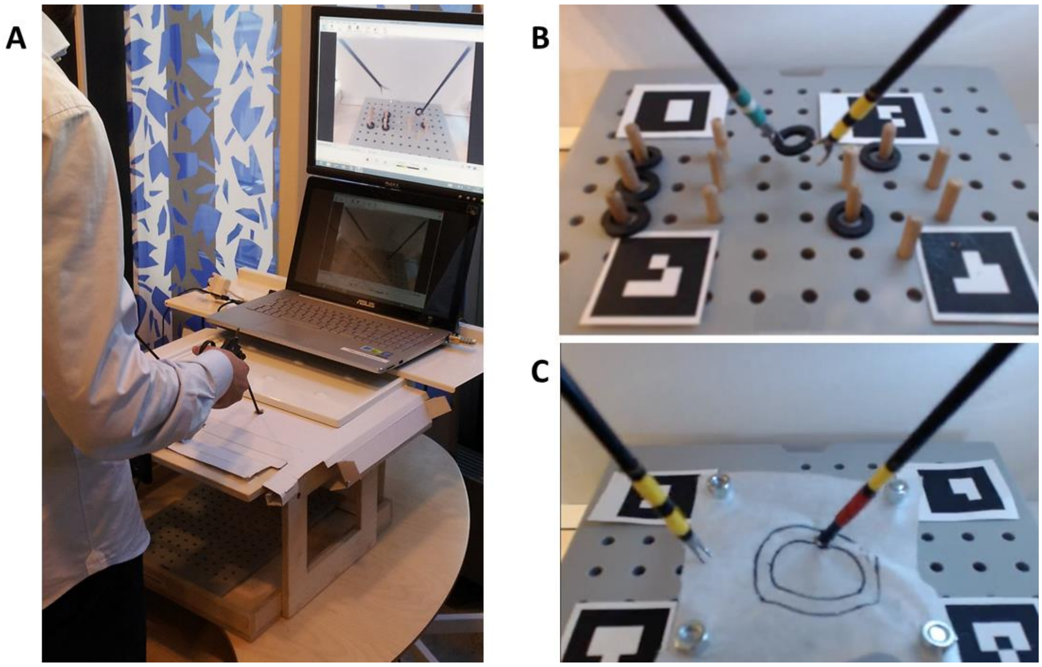

Figure 5. **The naive version of the Blackbox (A) used in Studies I and III, displaying the pegboard (B) and circular cutting (C) tasks (photo credit by the author).**

6.4.2 *LapMentor*

The LapMentor (3D Systems, formerly Simbionix Ltd., USA) (Figure 6) is a computer-based virtual reality simulator used to practice both basic laparoscopic skills (*basic skills training module*; e.g. peg transfer) and advanced laparoscopic skills (*procedure training module*; e.g. laparoscopic cholecystectomy) [113]. The LapMentor is equipped with one camera and two mock working handles. The handle movements and camera view are translated into a virtual surgical environment presented on a 17-inch flat screen. The LapMentor incorporates haptic feedback or "haptics," which are characterized as the sense of touch, and in laparoscopic simulation, the distribution of vibration or physical resistance, which is of great importance for minimizing tissue damage during surgery [114]. Different VR simulators present different quality in haptics, where some may present a communication lag for feeling and, therefore, they are incapable of providing the instant feeling as with the Blackbox.

Furthermore, simulation in the Blackbox does not provide instant data feedback after completing a task, in contrast to simulation in high-fidelity simulators. Therefore, instructor feedback is desired, when practicing in a Blackbox simulator. In regard to Studies I and III, the participants performing their tasks in the Blackbox simulator received similar feedback since it was given by the same instructor at all times. The participants performing their tasks in the LapMentor received the feedback from the simulator's software, instantly displayed on the flat-screen after each completed task (Paper I). Similarly, for Study IV, the feedback was presented on the flat-screen of the Simball box after each completed task (Paper IV).

Figure 6. The LapMentor used in Study I (photo credit by 3D Systems, formerly Simbionix Ltd., USA).

6.4.3 *Minimally Invasive Surgical Trainer – Virtual Reality (MIST-VR)*

The MIST-VR (Figure 7) is a high-fidelity laparoscopic simulator, produced to train surgeons for basic laparoscopic skills training, and in particular, laparoscopic cholecystectomies (MIST-

VR, Mentice Medical Simulation AB, Gothenburg, Sweden). The MIST-VR has been widely studied and its functions have been validated [59,78]. It trains the subjects using laparoscopic instruments in a fairly clear and straightforward graphic virtual environment. In its original form, the simulator system consisted of a 200 MHz Pentium PC with a 32 Mb RAM, attached to a ploy containing two laparoscopic instruments clutched in position-sensing gimbals, rotatable with 6 degrees of freedom (Figure 7).

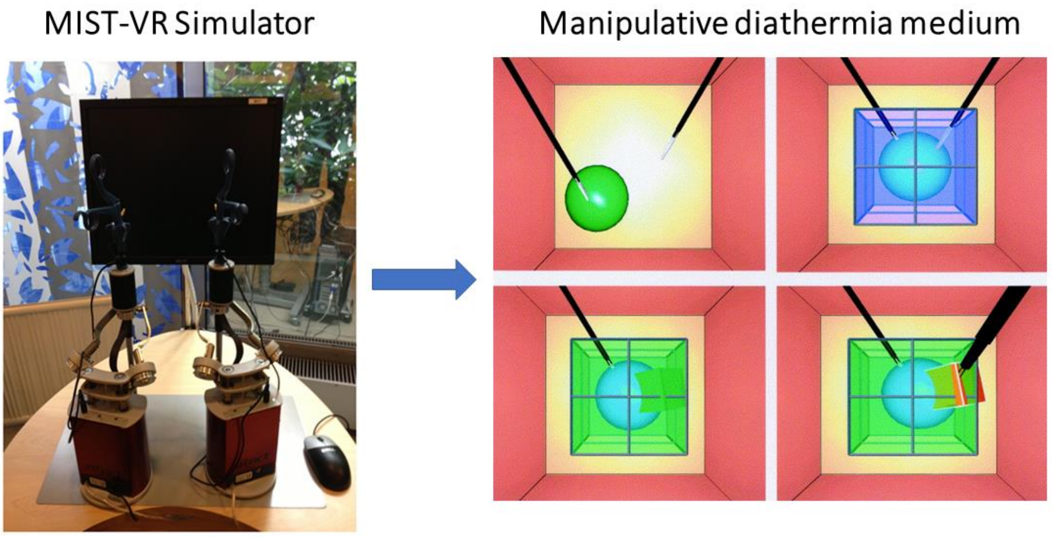

Figure 7. The MIST-VR simulator including a display of the *Manipulative Diathermia Medium* task performed in Studies I-III (photo credit by the author, image credit by Mentice Medical Simulation AB, Gothenburg, Sweden).

By moving the instruments, a real-time graphical display of the instruments appears, presented as a 3D cube on the computer screen, in a correctly scaled operating volume of 10 cm^3. Targets appear on the screen, randomly, and may be grasped and manipulated within the operating field of view, according to the skill task [115]. Different tasks may be used to train the surgeons. In Studies I-III, we used the *Manipulative Diathermia Medium* task, which simulates laparoscopic cholecystectomy (described in detail in Papers I-III). Each completed task produces a score ranging between 0-700, where a lower score expresses a better result. A detailed table of the different MIST-VR-parameters is presented in Paper I; Table 1.

6.4.4 *Simball Box*

The Simball box (Surgical Science Sweden AB (formerly Simball, G-coder Systems), Gothenburg, Sweden) [116] (Figure 8) is a video box trainer that provides performance feedback utilizing authentic standard surgical instruments (Figures 8A and 8B). The simulator detects motion and position parameters of the surgical instruments by the Simball 4D input devices that are integrated in the Simball box, which consists of round globes with 3 degrees of freedom (Figure 8C).

A 3D angular position of the globe is detected by the patented machine vision technology that is used. With a laser pointing to the exterior of the globe, a dot pattern code is created, which in turn, generates a unique configuration. The configuration depends on the laser positioning on the exterior of the globe (Figure 8C). The image is presented as a dot pattern, updated 100 times each second, with each image analyzed producing a precise 3D angular position with the connection of the globe [117]. Via the globe connection, an instrument carrier is inserted, rigged with a linear potentiometer that accurately measures the linear motion of the instrument holders (in and out movements). Authentic surgical instruments are introduced and secured in the instrument holder when box training (Figure 8B). Different rubber trays can be placed inside the box creating a range of tasks (Figure 8D). To create a laparoscopic procedural environment, a camera and flat-screen including LED-lights were all connected via USB ports to a PC. The image and video recordings were captured by the camera (See 3CAM 80, high-performance 8MP auto focus UVC USB camera module equipped with an OV8825 CMOS image sensor (OmniVision Inc., Santa Clara, CA, USA).

Computer analysis provides the measured parameters that quantify each attempt, including acceleration, angular distance, instrument distance, smoothness, speed, and time to finish the task. The instrument holders are outfitted with buttons for computer program maneuvering and video recording. Graphs and statistics are routinely saved and displayed in Microsoft Excel 2010.

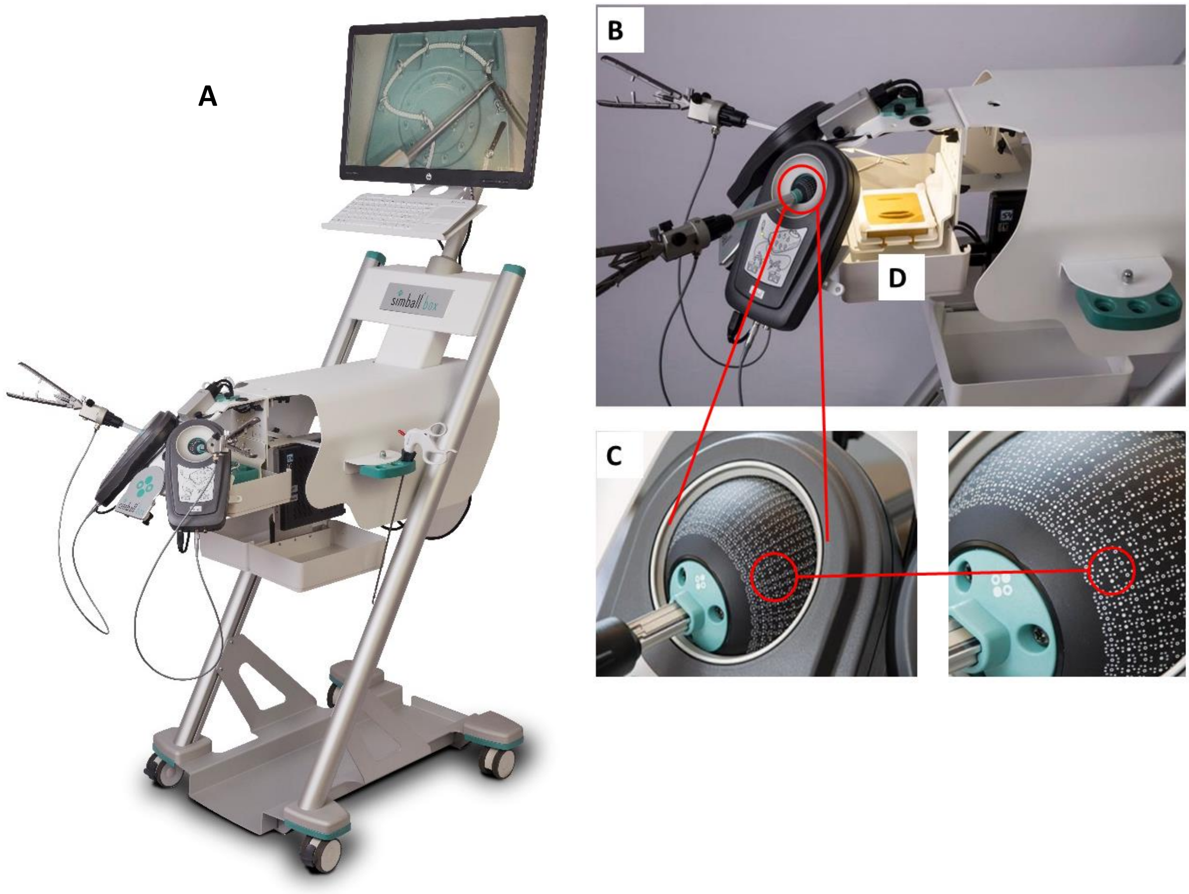

Figure 8. The Simball box (photo credit by Surgical Science Sweden AB) (A) with authentic standard instruments (B), inserted through the globes for motion detection (C), with changeable rubber trays inside the box (D) [118].

6.4.5 *Simball Box Metrics*

By combining the measured 3D angular position of the globe together with the instrument holders' linear position (by the surgical instruments) a precise position and motion of the distal end of the instrument is continually detected. Moving the instruments in all dimensions (X, Y, Z and instrument rotation) provides a value of the instruments' total motion distance, also called 4D motion. After each trial, feedback is presented on the flat screen as a percentage of the tutorial video performance of each parameter (Table 2).

Simball box parameters	
Parameters	**Definition/Description**
Average speed (cm/s)	The average speed of the instruments' movement.
Angular distance (radians)	The sum of angular movements at every 0.01 seconds (sampling instant (SI)). The difference in orientation between each SI is computed as the axis-angle rotation. The sum of the absolute values of angles during total task time provides the angular distance.
Average acceleration (mm/s^2)	The sum of accelerations affected the tool at every SI. Positioning differences between each SI is computed as a vector. Vector magnitude/sampling time = sampled velocity. The variation of the velocity along two subsequent sampling instants; ((final velocity) – (initial velocity))/sampling time = sampled acceleration. The sum of the absolute values of the sampled acceleration during total task time/task time = average acceleration.
Smoothness ($\mu m/s^3$)	The third derivate of instrument position with respect to time, measuring the variation of the acceleration. The variation of the sampled acceleration (as defined in the "average acceleration" definition) between subsequent sampling instants/sampling time = the so-called jerk (derivative of the acceleration of third derivative of the position). The sum of the absolute value of the sampled jerk provides the average jerk, which is motion smoothness. Motion smoothness calculated for both left and right instrument, as previously described [119,120].

Table 2. The definitions and descriptions of the Simball box parameters.

6.4.6 *Mental Rotation Test - A*

The Mental Rotation Test-A (MRT-A), is usually used when studying cognitive science, and accurately measures visuospatial ability in the tested individuals [121]. It has been demonstrated that MRT scores correlate with performance of both advanced surgical [122] and advanced laparoscopic simulator tasks [123]. MRT tests has also been used in several studies from the Center for Advanced Medical Simulation and Training at Karolinska Institutet [73,75,77].

6.4.7 *Questionnaires*

Collection of the participants' background data (e.g. age, sex, previous PC-gaming experience, etc.) was gathered via questionnaires (Papers I-IV).

6.5 Materials and Methods Study I

Initially 63 participants volunteered in the study; however, after dropouts (detailed in Paper I), only 47 medical students remained for analysis (Figure 1). All 47 participants completed a pre-questionnaire with background questions, and were pretested regarding their visuospatial ability using a mental rotation test. In the first task (peg transfer) the participants were assessed regarding their laparoscopic basic skills training using either a low-cost Blackbox, or a high-fidelity LapMentor simulator. They had to move six rubber rings from one side of the pegboard to the other side using the graspers. They first grasped the rubber rings with the left handle, and then shifted to the right handle; thereafter, they placed the rings on the opposite side of the pegboard. The same procedure was repeated in the opposite direction, moving the rubber rings back to their starting position, from right to left handle (Figure 5B). This was done three times consecutively.

The second task consisted of cutting a circular gauze. Participants had to use a laparoscopic scissors to cut the perimeter of the circular gauze, cutting between the internal (diameter 3.5 cm) and the external (diameter 5.5 cm) circles, while avoiding the marked lines (Figure 5C). The other group completed corresponding identical tasks using the LapMentor.

All participants completed three consecutive tests using the MIST-VR simulator. The MIST-VR trains the users to use laparoscopic instruments in an adequately clear and straightforward graphic virtual setting. Targets randomly emerge on the screen, and may be grasped and maneuvered within the operating field of vision according to the task [115]. The participants performed the *Manipulative Diathermia Medium* task (Figure 7) three times consecutively. This test was also described by Schlickum et al. in 2009 [124]. Briefly, the intricacy of the procedure is to grasp a virtual ball with one laparoscopic handle, touch it with the corresponding handle, withdraw that handle and, thereafter, by re-inserting it, transform it to a diathermia hook; by pressing a pedal burn, the cube appears in different positions on the ball three times. This is performed by a continuous positioning of the ball with the left handle, locked in a 3D location while synchronously maneuvering the diathermy hook to the cube, and pressing the pedal until it disappears. The process is repeated with the right handle. Oral information and practical instructions on how to achieve the lowest possible score were given to the participants prior to the start. The lower the MIST-VR score, the better the performance. Afterwards, the participants completed a post-questionnaire regarding their simulation experience using a Visual Analogue Scale (VAS scale) [125].

6.6 Materials and Methods Study II

Fifty-seven medical students volunteered to participate in the study; however due to different reasons explained in Paper II, ten students dropped out, leaving a total of forty-seven participants (Figure 2). The students completed a pre-questionnaire with some background questions on age, sex, and previous PC-gaming experience. The participants rated their own PC-gaming experience on a VAS scale, creating a numeric value (1-100), where a median score of >60 equals "high PC-gaming experience," thereby establishing a binary parameter. The participants also completed a visuospatial ability test (MRT-A), where the scores were given in percentage; >49% was regarded as good visuospatial ability. Thereafter, the participants completed three consecutive trials in the MIST-VR simulator (the *Manipulative Diathermia Medium* task), as explained in Study I (Figure 7). The results from the questionnaires, visuospatial ability tests, and MIST-VR performance scores were analyzed. The MIST-VR total score was determined by multiple parameters and categorized into clinically relevant groups, detailed in Paper II; Table 1.

6.7 Materials and Methods Study III

Thirty-one participants initially enrolled in the study; however, two participants did not complete the tasks and, therefore, the analyses were performed on the remaining twenty-nine. None of the participants had prior task training, nor did they have any surgical or laparoscopic experience. However, a few presented prior simulation experience. Each participant was given oral instructions before the study, and thereafter all students performed two tasks in the Blackbox: peg transfer and precision cutting (Figure 3), which are further described in Study III. Their performances were video recorded and sent to MPLSC for a blind analysis. The analyzed components consisted of the total movements in the video displayed by optical flow metrics – creating positioned particles or so-called metrics; *path-length* (total displacement of particles (Pl)) and *total number of particles detected across all frames* (Prtcl_tot) (Paper III).

6.8 Materials and Methods Study IV

Forty-six medical students were selected according to simple randomization through a lottery draw to perform identical simulator tasks in the Simball box with either of two different needle holders; the market needle holder (MNH) or the Najar needle holder (NNH) (Figure 4). Prior to the simulator tasks the participants completed a questionnaire with some background questions, followed by instructional videos for each task being performed. Thereafter, they performed identical laparoscopic knot-tying and suturing tasks (described in Paper IV), using one of the two described needle holders, and later switched needle holders to perform the same task in a cross-over manner. Before switching, a rest period took place. After completion of the cross-over, a post-questionnaire was finalized.

6.9 Financial Aspects

> *"An investment in knowledge always pays the best interest".*
>
> **Benjamin Franklin** (1705-1790)
>
> The Way to Wealth: Ben Franklin on Money and Success, Editor Charles Conrad, CreateSpace Independent Publishing Platform, 2011.

Medical education in general, and surgical training in particular are associated with large costs [21]. With the introduction of more advanced and even more expensive simulators, the financial strains on educators have become more obvious, including the implementation of surgical skills training curriculum for surgical residents [23]. In a comparison of a low-cost platform with the standard platform for trainees in the Fundamentals of Laparoscopic Surgery (FLS), significant financial savings (approximately $8500 USD annually) were seen by adopting the more low cost platform for training [25]. In a recent review by Lin and George (2017), investigating low-cost laparoscopic simulators, excluding simulators that cost >£1500, several affordable and simple options were found; however, a great number of them lacked validation [88].

7 STATISTICAL ANALYSES

"No piece of research can be perfect and there will always be something which, with hindsight, we would have changed."

Martin Bland (1947-)

An Introduction to Medical Statistics, 3rd Edition, Oxford University Press, 2000.

All analyses were carried out using JMP® Pro (SAS Institute Inc., Cary, NC. These are presented below for each study, respectively. For variables where the normal distribution could not be assumed, non-parametric methods have been used.

7.1 Statistics Study I

Based on prior knowledge of data and the fact that some outcome data are not normally distributed, nonparametric statistical analyses were used and accordingly, results are presented in terms of median and range. When comparing two groups, the Wilcoxon/Kruskal-Wallis tests were performed. The Pearson Chi-Square test was used to analyze differences between proportions, when appropriate. When analyzing correlations between the students' experience of the training with the actual performance in the MIST simulator, fit line analysis was performed. A p-value <0.05 was regarded as statistically significant. Statistical analysis was carried out using JMP® Pro version 14.0.0 (SAS Institute Inc., Cary, NC).

7.2 Statistics Study II

The matched pairs test was used when comparing performance between the individual MIST-VR trials. When doing a regression analysis comparing two numerical variables linear fit with analysis of variance was used. When comparing the result of the various PC-gaming categories on the outcome of the coordination variables, the student's t-test was used. A p-value <0.05 was considered statistically significant. Statistical analyses were carried out using JMP® Pro version 14.2.0 (SAS Institute Inc., Cary, NC).

7.3 Statistics Study III

Linear regression with linear fit analyses were performed when analyzing the results of the automated video analysis, "Pl" and "Prtcl_tot," which correlated to the results of the MIST-VR scores I-III (presented as RSquare). Student's t-test was used when analyzing the MIST-VR score differences in gender, and also in the peg transfer exercises between frequent and infrequent PC-gamers (presented as mean SEM). A p-value <0.05 was regarded as statistically significant. Statistical analyses were carried out using JMP® version 12.1.0 (SAS Institute Inc., Cary, NC).

7.4 Statistics Study IV

When comparing two groups, the Wilcoxon signed-rank test was performed. When comparing the pre- and post-values of OVEST and SBOS, as well as the pre- and post-questions, a matched pairs analysis was made. Since the overall reviews of the OVEST score were normally distributed for each one of the two reviewers, in order to simplify, we used the mean value of Reviewer 1 and Reviewer 2 for each participant, respectively. The correlations between reviewers are analyzed with linear regression. The statistical analyses were performed with JMP® Pro version 14.0.0 (SAS Institute Inc., Cary, NC). A p-value <0.05 was considered statistically significant.

8 RESULTS

"To see what is in front of one's nose needs a constant struggle."

George Orwell (1903-1950)

In Front of Your Nose, 1946.

8.1 Results Study I

In the initial phase, 63 students were included in the study, and assigned to either the Blackbox or LapMentor group (32 vs. 31). Nevertheless, seven students were absent. The remaining 56 students completed the tests using one of the simulators mentioned; however, only 47 students completed the final three MIST-VR tests (Figure 1). The reasons for their dropping out are further described in Paper I. The demographics are given in Table 3. Due to the high dropout rate, especially in the LapMentor group, and with no changes made between the groups to legitimize this discrepancy, the initial randomization should subsequently be considered a forfeit.

For the abovementioned reasons there were more women in the Blackbox group compared to the LapMentor group (Table 3). Moreover, the participants in the LapMentor group expected the simulation procedures to be more difficult than did the participants in the Blackbox group (Table 3). For those who completed the simulation training, a rise was seen in the extent that the Blackbox group subjects liked the simulator training. This rise was only seen in women (77.3% to 87.7%; $p = 0.02$) (Table 4).

		Blackbox		LapMentor		
		n	**%**	**n**	**%**	***p****
Gender	**Females**	19	61.3	8	33.3	**0.04**
	Males	12	38.7	16	66.7	
		Median	**Range**	**Median**	**Range**	***p*#**
	Age (years)	25	(20-39)	25.5	(22-39)	0.74
	Computer gaming experience (%)	46.4	(1.5-100)	63.6	(0-100)	0.48
	Visuospatial score (%)	50	(25.0-83.3)	50	(33.3-66.7)	0.48
Expectations	**Will be difficult (%)**	59.2	(23.2-85.8)	68.9	(19.0-92.0)	**0.04**
	Will facilitate (%)	69.4	(25.0-98.6)	76.3	(49.9-100)	0.13
	Will like (%)	76.4	(7.8-98.1)	73.8	(50.3-100)	0.82

*p** Pearson Chi-Square

p# Wilcoxon/Kruskal-Wallis tests (Rank Sums)

Table 3. Demographics and expectations of the 56 students who were included in the study (extract from Paper I; Table 1).

Furthermore, for the female group in the LapMentor, a positive trend was found in how well they liked the training (85.5% to 94.7%; p = 0.06) with no differences in men using the same parameters (Table 4). Furthermore, no significant changes in either simulator group were found concerning the parameter's difficulty and facilitation (Table 4).

	Blackbox	vs.		LapMentor		
	Before	**After**		**Before**	**After**	
	Median (range)	**Median (range)**	***p***	**Median (range)**	**Median (range)**	***p***
Difficult	59.2 (23.2-82.5)	59.0 (18.0-86.6)	0.51	67.8 (21.1-90.2)	62.8 (16.4-100)	0.96
Facilitate(d)	69.4 (25.0-98.6)	74.5 (17.8-100)	0.97	78.0 (49.9-100)	78.0 (47.4-100)	0.80
Like(d)	76.8 (7.8-98.1)	85.3 (40.9-97.6)	*0.07***	77.1 (53.3-100)	84.1 (32.7-100)	0.33

	Females					
	Blackbox	**vs.**		**LapMentor**		
	Before	**After**		**Before**	**After**	
	Median (range)	**Median (range)**	***p***	**Median (range)**	**Median (range)**	***p***
Difficult	61.0 (37.7-82.5)	61.2 (29.9-86.6)	0.32	71.9 (57.2-90.2)	63.4 (56.1-100)	0.72
Facilitate(d)	65.0 (25.0-94.5)	71.8 (17.8-95.0)	0.74	86.6 (75.6-100)	80.1 (62.7-100)	0.14
Like(d)	77.3 (7.8-95.6)	87.7 (46.6-96.9)	**0.02**	85.5 (53.3-100)	94.7 (79.8-100)	*0.06*##

	Males					
	Blackbox	**vs.**		**LapMentor**		
	Before	**After**		**Before**	**After**	
	Median (range)	**Median (range)**	***p***	**Median (range)**	**Median (range)**	***p***
Difficult	52.0 (23.2-76.9)	50.6 (17.9-83.9)	0.91	63.5 (21.1-77.7)	62.2 (16.4-93.1)	0.87
Facilitate(d)	77.6 (46.7-98.6)	78.6 (40.0-100)	0.61	75.2 (50.0-95.8)	77.1 (47.4-100)	0.65
Like(d)	76.5 (53.8-98.1)	80.1 (40.9-97.6)	0.84	75.9 (63.8-91.6)	81.9 (32.7-93.9)	0.90

Bold: $p < 0.05$
Italic: $p < 0.07$
p: Matched pairs
**Prob < t=0.0327 (one-tailed)
##Prob < t=0.0315 (one-tailed)

Table 4. Motivation and experienced difficulty of simulator training in the 47 participants who completed the study. Values are given as a percentage on a VAS scale (extract from Paper I; Table 2).

Regarding the Blackbox group, significant correlations were noted between the experienced difficulty and MIST performance, and also between facilitation and MIST performance (Table

5). For the LapMentor group no such correlations existed (Table 5). Moreover, some gender-specific differences were noted. In females there was a strong association in how they thought the Blackbox facilitated their performance versus their actual MIST score performance. Furthermore, in the second MIST trial for women, a significant association was found between how well they liked the simulator training and their MIST score. No such correlations were found in men. However, in men, a clear correlation was noted between how difficult they perceived the Blackbox simulation and their actual MIST score, something that was not observed in the group of females (Table 5).

	Blackbox n=29					
	MIST score 1		MIST score 2		MIST score 3	
	β	*p*	β	*p*	β	*p*
Was difficult	2.65	0.07	3.3	**<0.01**	3.51	**<0.01**
Facilitated	-2.37	**<0.05**	-2.72	**<0.01**	-1.86	0.10
Liked	-0.8	0.66	-1.91	0.24	-1.5	0.37
	LapMentor n=18					
	MIST score 1		**MIST score 2**		**MIST score 3**	
	β	*p*	β	*p*	β	*p*
Was difficult	-0.31	0.83	0.23	0.74	0.32	0.62
Facilitated	0.65	0.75	0.11	0.91	0.09	0.92
Liked	1.72	0.37	0.13	0.89	0.23	0.79

	Females					
	Blackbox n=17					
	MIST score 1		**MIST score 2**		**MIST score 3**	
	β	*p*	β	*p*	β	*p*
Was difficult	2.81	0.22	3.84	*0.06*	3.46	0.10
Facilitated	-3.94	**<0.05**	-4.19	**<0.01**	-2.96	*0.06*
Liked	-3.84	0.19	-5.22	**<0.05**	-3.23	0.24
	LapMentor n=7					
	MIST score 1		**MIST score 2**		**MIST score 3**	
	β	*p*	β	*p*	β	*p*
Was difficult	-5.96	*0.07*	-1.14	0.21	-0.20	0.83
Facilitated	-0.72	0.90	-1.19	0.4	-1.39	0.28
Liked	-4.82	0.58	-0.83	0.71	-2.61	0.17

	Males					
	Blackbox n=12					
	MIST score 1		**MIST score 2**		**MIST score 3**	
	β	*p*	β	*p*	β	*p*
Was difficult	2.23	0.17	2.49	**<0.05**	3.42	**<0.01**
Facilitated	1.72	0.33	0.81	0.56	1.06	0.52
Liked	1.87	0.35	1.08	0.49	-0.19	0.92
	LapMentor n=11					
	MIST score 1		**MIST score 2**		**MIST score 3**	
	β	*p*	β	*p*	β	*p*
Was difficult	1.19	0.44	0.93	0.39	0.90	0.33
Facilitated	0.68	0.74	0.60	0.68	0.76	0.55
Liked	1.91	0.32	0.49	0.73	1.20	0.31

β: The estimated regression coefficient

Table 5. Simulator and gender-specific differences of how the participants' experiences correlated to completed MIST-VR-performance (extract from Paper I; Table 3).

The first MIST performance score correlated to visuospatial ability (b = -3.1; p = 0.01) with a persistent trend in the second MIST score (b = -1.7; p = 0.10), yet this was eradicated in the third MIST score. This finding was regardless of gender or simulator. Moreover, regarding the baseline visuospatial score, no gender differences of significance were observed.

8.2 Results Study II

Nine participants had to be excluded because they did not complete all three MIST-VR trials. The reasons are presented in Paper II. Furthermore, when displaying the data graphically, an outlier was identified in the PC-gaming experience group and consequently excluded; thus, analyses were carried out using 47 participants (Table 6).

		n	%
Sex	**Males**	23	48.9
	Females	24	51.1
PC-gaming experience	**High**	24	51.1
	Low	23	48.9
PC-gaming category	**RPG**	18	38.3
	FPS	23	48.9
	Sport	12	25.5
Visuospatial score	**High**	28	59.6
	Low	19	40.4

Table 6. Baseline characteristics for study participants (extract from Paper II; Table 5).

As seen in Table 6, a reasonably equal distribution is present among men and women (23 men, 24 women). In regard to PC-gaming category, nearly half played first person shooter (FPS). In a regression analysis no correlation was found between PC-gaming experience and the overall MIST-VR score (Paper II; Table 2). However, a significant association seemed to exist between the PC-gaming experience and some variables of the score associated with coordination, in the first as well as in the second MIST-VR trial. Nevertheless, this association was eradicated in the third MIST-VR-trial (Paper II; Table 2). No convincing gender specific differences were found in this pattern.

Regarding the variables comprising coordination (EconDiath, TmDiathAir, TipInSphOn and TmDiathSph; see Paper II; Table 1), those that played Sport games presented a significantly better performance in all MIST-VR trials (Table 7). Furthermore, those who played FPS games performed nearly as good, whereas in those who played role playing games (RPG), there were almost no differences found between those who played RPG versus those who did not (Table 7).

		RPG-gaming		No RPG-gaming		
		Mean	**SEM**	**Mean**	**SEM**	**p**
MIST-task 1	**EconDiath**	7.50	1.85	13.28	3.39	0.1424
	TmDiathAir	15.99	4.57	26.74	7.47	0.2264
	TipInSphOn	3.86	0.88	6.02	1.07	0.1261
	TmDiathSph	3.50	1.05	10.09	2.92	**0.0411**
MIST-task 2	**EconDiath**	6.06	1.84	10.82	2.75	0.1574
	TmDiathAir	12.31	4.16	21.22	5.77	0.2167
	TipInSphOn	2.81	0.63	4.63	0.95	0.1162
	TmDiathSph	2.89	1.40	8.24	2.81	*0.0956*
MIST-task 3	**EconDiath**	3.77	1.03	7.24	1.64	*0.0808*
	TmDiathAir	6.89	2.38	15.28	3.57	*0.0568*
	TipInSphOn	2.53	0.66	3.34	0.65	0.3852
	TmDiathSph	1.44	0.77	3.40	1.60	0.2749

		FPS-gaming		No FPS-gaming		
		Mean	**SEM**	**Mean**	**SEM**	**p**
MIST-task 1	**EconDiath**	6.80	1.54	15.16	3.97	*0.0592*
	TmDiathAir	13.91	3.75	30.98	8.77	*0.0833*
	TipInSphOn	3.89	0.67	6.44	1.29	*0.0881*
	TmDiathSph	3.47	0.94	11.50	3.45	**0.0331**
MIST-task 2	**EconDiath**	5.10	1.32	12.73	3.26	**0.0377**
	TmDiathAir	10.05	3.00	25.25	6.86	*0.0508*
	TipInSphOn	2.65	0.43	5.17	1.15	**0.0493**
	TmDiathSph	2.26	0.99	9.96	3.33	**0.0352**
MIST-task 3	**EconDiath**	3.75	0.73	7.98	1.98	*0.0541*
	TmDiathAir	7.31	1.96	16.64	4.23	*0.0540*
	TipInSphOn	2.54	0.48	3.50	0.81	0.3158
	TmDiathSph	0.94	0.40	4.29	1.94	0.1039

		Sport-gaming		No sport-gaming		
		Mean	SEM	Mean	SEM	p
MIST-task 1	**EconDiath**	4.72	1.32	13.24	2.88	**0.0100**
	TmDiathAir	9.12	2.96	27.26	6.41	**0.0137**
	TipInSphOn	2.71	0.71	6.04	0.94	**0.0071**
	TmDiathSph	2.05	1.05	9.46	2.45	**0.0079**
MIST-task 2	**EconDiath**	2.73	0.35	11.15	2.38	**0.0013**
	TmDiathAir	4.68	1.01	22.31	5.05	**0.0015**
	TipInSphOn	1.75	0.41	4.69	0.82	**0.0024**
	TmDiathSph	0.51	0.20	8.14	2.39	**0.0031**
MIST-task 3	**EconDiath**	2.83	0.53	6.97	1.44	**0.0100**
	TmDiathAir	4.99	1.49	14.50	3.14	**0.0090**
	TipInSphOn	1.88	0.57	3.43	0.60	*0.0692*
	TmDiathSph	0.50	0.22	3.39	1.36	**0.0432**

Statistically significant p-values highlighted in **bold**; trends (p<0.10) in *italic*. Students t-test.

Table 7. The effect of different gaming categories on the coordination parameters of the MIST-VR score (extract from Paper II; Table 4).

When comparing the overall visuospatial ability and the MIST-VR score in a regression analysis, an association was found between all of the MIST-VR score variables and the visuospatial ability. An association that diminished gradually in the second MIST-VR trial, and completely disappeared in the third MIST-VR trial (Paper II; Table 3).

Furthermore, interesting gender specific differences where noted in that, in the coordination as well as in the precision parameters of the MIST-VR score, a significant association was seen between the visuospatial ability and the scores in females during the first MIST-VR trial. No such association was found in males regarding these parameters. Nonetheless, for males, an association was found between visuospatial ability and time in the first MIST-VR trial that gradually disappeared in the remaining second and third MIST-VR trials (Paper II; Table 3).

A significant improvement in the simulator performance was seen between the first two MIST-VR trials. Moreover, the third MIST-VR trial absolute score was better related to the second MIST-VR trial, although, not significantly. Additionally, the males' absolute MIST-VR trial scores were lower for every individual MIST-VR trial compared to females, although, not significantly (Paper II; Figure 2).

8.3 Results Study III

Of the initial 31 participants, 29 performed all three tasks (peg transfer, cutting a circular gauze, and the three MIST-VR tasks). However, two performed only one MIST-VR task and were excluded (Figure 3). An excellent linear association was found between the automated video analysis of the path-length (Pl) in the peg transfer test and all the three MIST scores (RSquare 0.48, $P<0.0001$; 0.34, $P = 0.0009$; 0.45, $P<0.0001$) (Paper III; Table 1). Moreover, the overall number of particles across all frame pairs of the video (Prtcl_tot) presented a significant correlation with all three MIST scores (Paper III; Table 1). Furthermore, a linear association, although not as distinct, was found between Pl in the gauze cutting experiment and the three MIST scores (RSquare 0.30, $P = 0.0022$, 0.23, $P = 0.0082$; 0.16, $P = 0.0317$, respectively), whereas Prtcl_tot presented a significant correlation only in the first two MIST scores (Paper III; Table 1). Surprisingly, gender-specific differences existed between Pl of the peg transfer group and the MIST-VR scores with correlations only found in the female group (RSquare 0.59, $P = 0.0003$; 0.43, $P = 0.0044$; 0.52, $P = 0.0010$), and not in the male group (Figure 9).

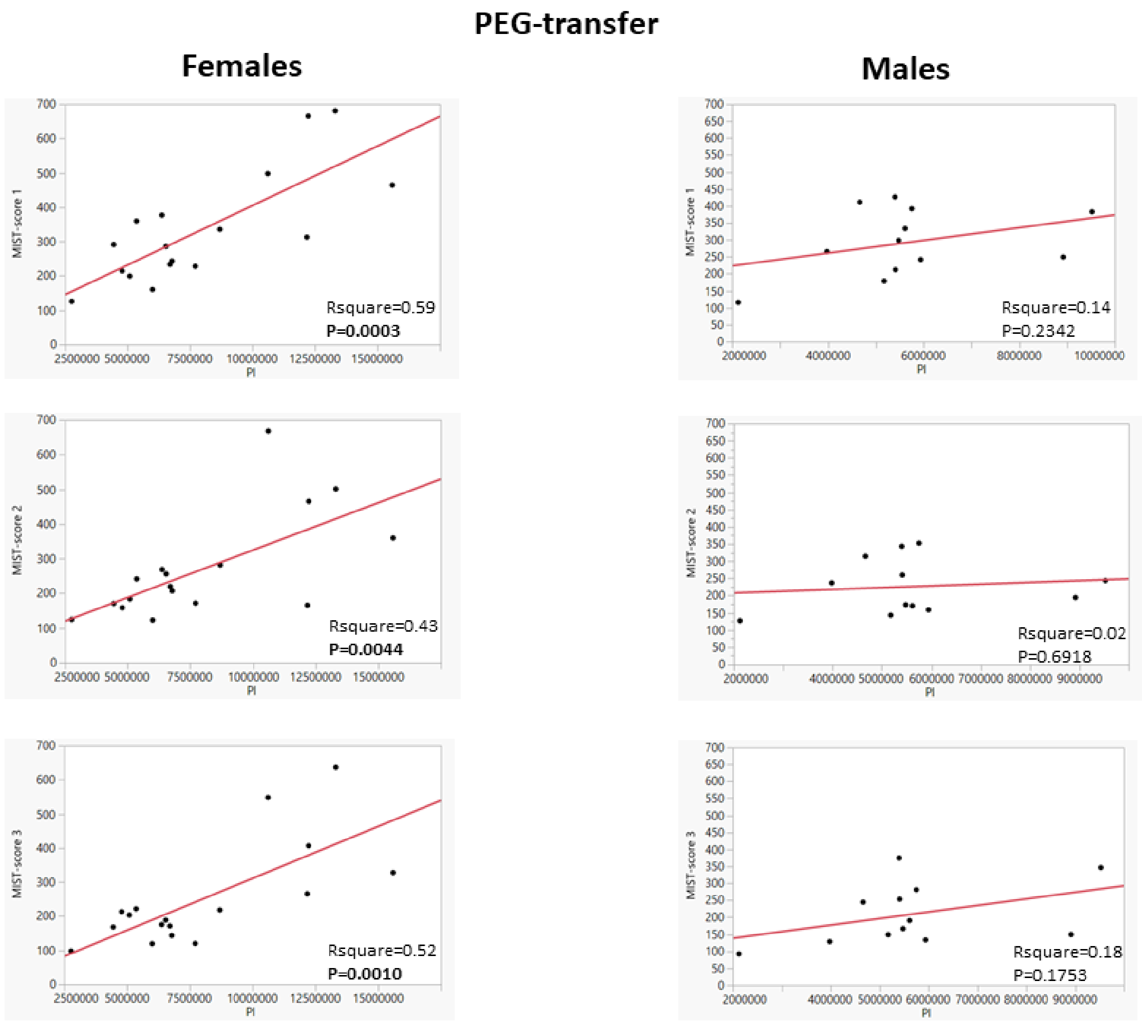

Figure 9. Gender-specific differences regarding correlations between the Pl variable and the MIST-VR scores in the peg transfer exercise (extract from Paper III; Figure 4).

Similarly, a gender-specific difference was noted in females in the gauze cutting task including strong linear correlations between the automated video analysis results and the MIST scores (RSquare 0.51, P = 0.0014; 0.46, P = 0.0026; 0.35, P = 0.0127, respectively), which were non-existent in the male group.

Furthermore, in the peg transfer exercise, a significant correlation was found with even more distinct correlations between the Pl variable in the video analysis and the MIST-VR scores (also reflecting the visuospatial haptic skills [75]) in the infrequent PC-gaming experience group. In contrast, the group with more PC-gaming experience had no such correlation (Figure 10). A similar pattern was noted between the Pl variable of the gauze cutting exercise among the infrequent PC-gaming group and the MIST-VR 1, 2, and 3 scores, respectively (RSquare 0.49, P = 0.0051; 0.49, P = 0.0055; 0.42, P = 0.0118), in opposition to the frequent PC-gaming group.

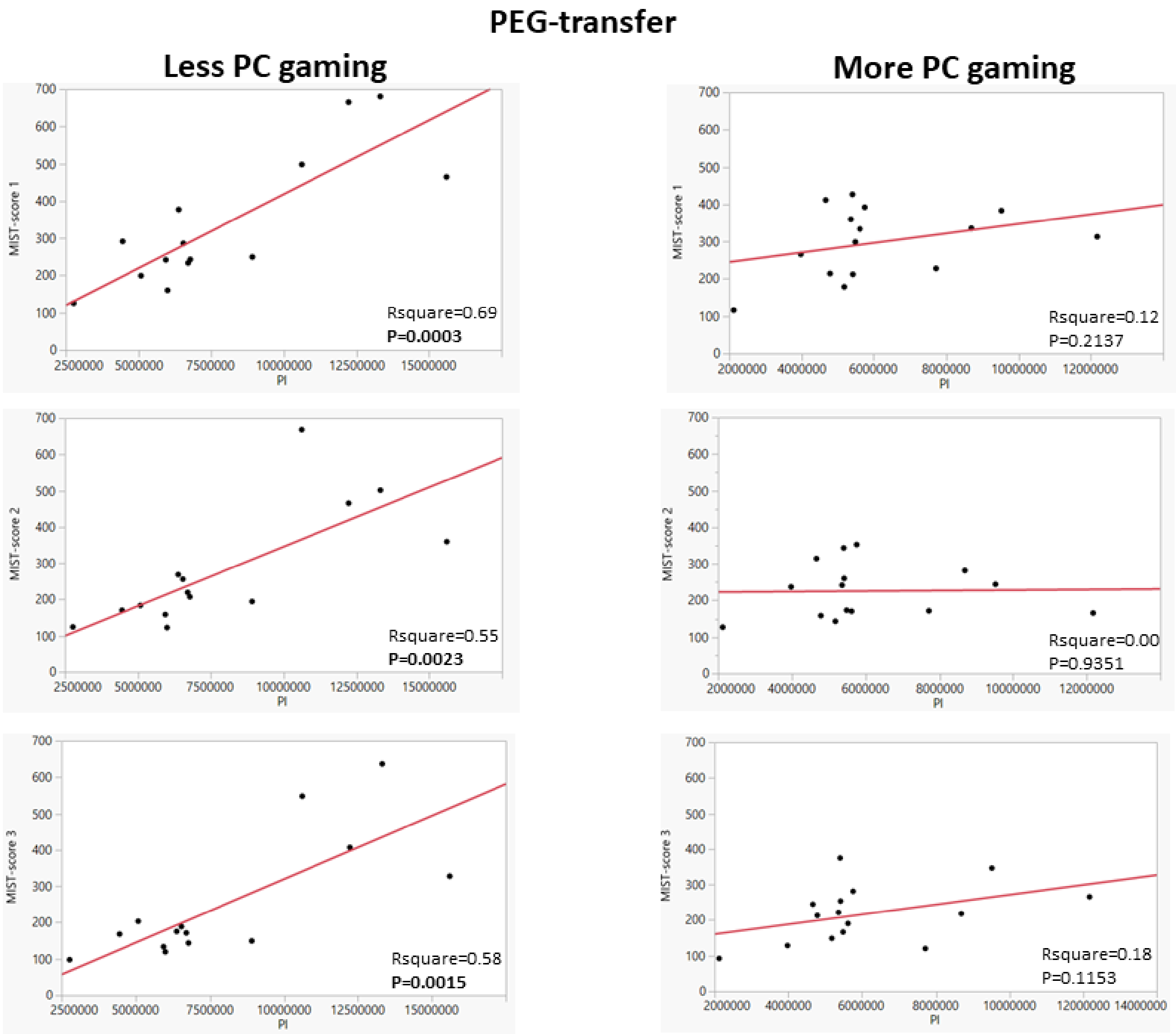

Figure 10. The correlation between MIST-VR score and PC-gaming experience in the peg transfer exercise (extract from Paper III; Figure 5).

Although a predominant number of the more experienced PC-gamers were males (67%), no significant difference was seen in simulation performance as determined by the MIST simulation scores, neither between experienced or not experienced PC-gamers, nor between females and males. However, an effect of the simulation training was noticed in that the MIST-VR scores declined between the first and last MIST-VR simulation in all groups (low scores indicating improved performance) (Paper III; Table 2).

8.4 Results Study IV

Forty-six medical students volunteered, all completing the study protocol (Figure 4). The demographics and background of the group, as well as the subjects' expectations concerning how the instruments would perform are displayed in Paper IV; Table 3. In both trials, the two independent reviewers' OVEST score results presented an excellent correlation (Figure 11A). Similarly, a significant positive correlation existed between the scores of both SBOS and OVEST from both trials (Figure 11B).

For the group that began the first trial with the MNH followed by the NNH, a significant increase in SBOS (30%) as well as OVEST (45%) scores were found between the two trials. In the group that began the first trial with NNH, followed by MNH in the second trial, an immediate increase for both SBOS and OVEST scores were seen; these were unchanged between the two attempts (Paper IV; Figure 3).

In regard to the questionnaires, several questions needed to be omitted from the analysis since an incommensurability was present between the before and after questions. Consequently, the question comparison was about *facilitating suturing, instrument handling,* and *musculoskeletal discomfort* (Paper IV; Figure 4). The questions concerning instrument handling (post-questionnaire Question 1 vs. pre-questionnaire Question 3) presented a significant difference, P = 0.0111 (Paper IV; Figure 5).

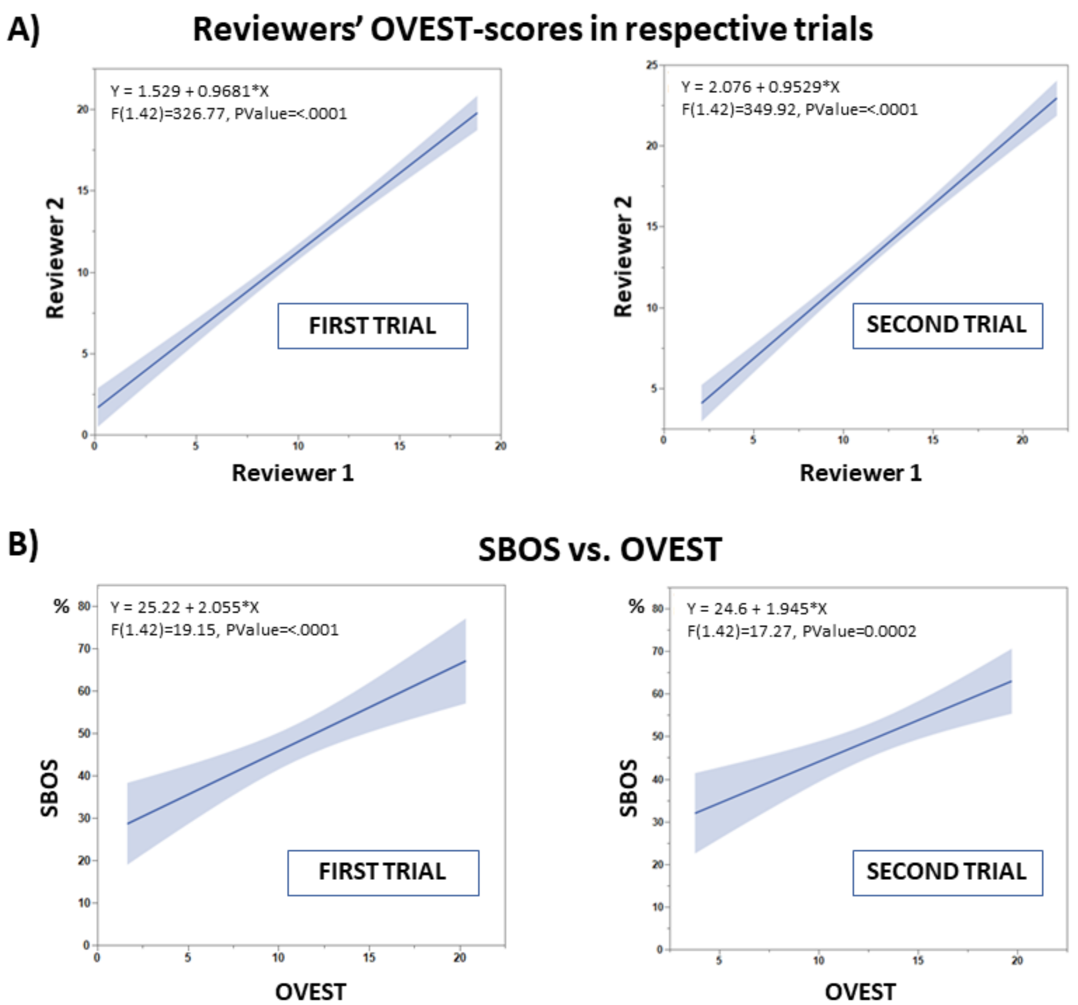

Figure 11. Comparison between A) the two independent reviewers' OVEST scores, and B) SBOS versus OVEST score, in the first and second trials (extract from Paper IV; Figure 2).

9 FUNDING

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10 ETHICAL CONSIDERATIONS

10.1 Risk Involved for Study Participants

No major risks were related to participation in these studies. The risks that could exist during implementation were related to the use of the laparoscopic equipment and the procedures in the simulators using them. Our focus was on how they could improve their practical skills during laparoscopy, evaluate completed questionnaires and eventual stress related to the tasks, and study hand movements in correlation with results from the laparoscopic simulator.

10.2 Benefits of Participation

The subjects had an opportunity to develop their practical laparoscopic surgical skills and at the same time receive feedback on how to further improve. This has also been shown to shorten the learning curve. Furthermore, the subjects received tips and recommendations on how to decrease eventual musculoskeletal disorders (MSDs) during laparoscopic operations.

10.3 Ethical Problems

The ethical problems that could occur, although small, are in case the subjects performed lower than average and reacted negatively on feedback received during performed tasks. This risk was minimized by providing all participants information regarding the increased practical skills and explaining that every individual would be compared to his or her own results. Furthermore, all records were de-identified, and cannot be traced back to their origin. We identify no other ethical issues.

10.4 Ethics Approval

The regional research ethics committee at Karolinska Institutet, Stockholm, Sweden, has approved Studies I-III, reference numbers 2013/2284-31/4 and 2018/69-31. The regional research ethics committee at Medical School, Athens University, Athens, Greece, has approved Study IV, reference number Dnr: 1718025227; and the regional ethics committee of Umeå University, Umeå, Sweden, reference number Dnr: 2018/69-31, has approved Study IV regarding the analysis, storage, and presentation of collected data.

Data were treated anonymously, without addresses or other personal details. All subjects had to complete an informed consent prior to participation.

11 DISCUSSION

11.1 Methodological Considerations

11.1.1 *Participants*

In Studies I-III medical students from Karolinska Institutet were enrolled. The aim was to determine whether laparoscopic basic skills training (BST) in a low-cost Blackbox simulator could be an acceptable alternative to corresponding BST using a laparoscopic high-fidelity simulator in regard to motivation and surgical skills performance (Paper I). Furthermore, the aim was to study the impact PC gaming and visuospatial ability had on laparoscopic simulator performance in the MIST-VR simulator in regard to the specific parameters of the performance score affecting simulator performance, the types of games, and any gender-related impact on simulator performance (Paper II). Moreover, an assessment was conducted to determine if automated video analysis of low-cost Blackbox laparoscopic training would be an alternative to laparoscopic high-fidelity simulators in BST (Paper III). Finally, in Study IV, medical students from Athens Medical School were included. The aim was to investigate whether a newly designed laparoscopic needle holder shortens the time for novice trainees, improving advanced laparoscopy (AL) techniques, compared to a market needle holder in a laparoscopy simulator (Paper IV) and to validate a new video scoring system determining AL skills (Paper IV).

11.1.2 *Internal and External Validity*

Internal and external validity reflect the trustworthiness of a study. Internal validity can be affected by two types of errors, random and systematic errors. The chances that random errors occur are greater in smaller study samples compared to larger samples. In our studies, 31-63 participants were included, which in case of validity could be classified as small sample sizes and therefore a limitation. Nevertheless, prior heavily-cited studies [59–61,78], have had no more than 16 participants.

Furthermore, selection bias concerns the study participants and the validity of the participants in the study, which is one type of systematic error. When comparing, for example, participants' outcomes after laparoscopic BST between two different simulators (Study I), it is crucial that the prior laparoscopic simulator training experience as well as prior PC-gaming experience are equal among the groups at baseline. The risk of a selection bias may be compensated by running prospective and randomized trials. All presented studies (I-IV) are prospective (with one cross-over (Study IV)); two cohorts (Studies II-III), and two randomized (Studies I and IV), where the latter reduces the exposure for selection bias.

External validity may be explained as the findings' generalizability. In Studies I-III, the participants could be considered representative for their group, i.e., surgical semester medical students in a university setting. All students during that particular semester were invited to enroll in the studies. However, since the participation was on a voluntary basis, one may assume that the more interested students chose to participate, and subsequently, some of them dropped out (n = 4; 7%) due to a loss of interest during the trials. Additionally, in Study IV, 47 medical students participated voluntarily and all concluded the trials. Their median age was 23 years (18-24), presenting a wider range between first-year and fourth-year medical students. Nevertheless, the baseline characteristics regarding prior laparoscopic and PC-gaming experience were minimal, and thereby similar across the groups. Furthermore, the advantages of a cross-over study are that a lesser number of participants are needed compared to a larger cohort and each participant functions as his/her own control. However, one disadvantage is the carry-over effect, with the so-called *wash-out* period that should be taken into consideration. In Study IV, the participants had a rest period before switching over to the other arm, and since the participants were trying two different needle handles, the carry-over effect is considered small to none. Moreover, in all studies, all participants were given sufficient time for each trial, and, therefore, time constraints should not have affected the results. However, since several students were enrolled, the schedule did not allow for testing at exactly the same time for each participant, that is, some were conducting the trials in the morning, while some in the afternoon. How, and if, this would affect the final result was not investigated.

11.1.3 *Dropouts*

As shown in Table 1, Studies I-III experienced dropouts, where the first two studies presented relatively high dropout rates (n = 9) of which four were due to a loss of interest (for details see Papers I and II). How this affected the final results has not been examined, although, it should not project a major impact. Study III had two dropouts, whereas Study IV had none.

11.1.4 *Simulator Training, Metrics, Parameters and Performance*

Different simulators were used during the studies as presented in Table 1. The metrics and parameters of each task are presented below.

Study I

The participants performed *peg transfer*, *precision cutting* and *Manipulative Diathermia Medium* tasks. The investigated parameters were *progression*, *total time* and *score*.

Study II

The participants performed *peg transfer*, *precision cutting* and *Manipulative Diathermia Medium* tasks. The investigated parameters were *progression, total time, score,* the impact of

PC-gaming experience on the different *parameters constituting the overall score*, as well as the impact of *visuospatial ability* and *gender* on *simulator performance*.

Study III

The participants performed *peg transfer*, *precision cutting* and *Manipulative Diathermia Medium* tasks. The automated video analysis generated the parameters: *Pl* and *Prtcl_tot* (an assessment of the total motion activity), which where correlated to the MIST-VR scores (*progression, total time and score*).

Study IV

The participants performed *knot-tying* and *running sutures* tasks. The examined parameters were *angular distance, linear distance, total time*, *Simball box overall score (SBOS)* and results from *the objective video evaluation scoring table (OVEST)*.

In all four studies medical students' performances in the different simulators were examined. Study I examined medical students' performances in the MIST-VR simulator after training in either a low-cost Blackbox or a high-fidelity laparoscopic simulator (LapMentor). The two basic skills procedures, *peg transfer* and *precision cutting,* were chosen for two reasons. Firstly, both tasks are part of the Fundamentals of Laparoscopic Surgery (FLS) [126] Technical Skills Proficiency-Based Training Curriculum, and secondly, they were the most appropriate tasks to compare the two simulators used (Blackbox and LapMentor); therefore, no other more advanced simulator tasks were used.

Study II investigated medical students' baseline characteristics as well as the affect *PC-gaming experience* and *visuospatial ability* had on laparoscopic simulator performance. In particular, it examined how the fundamental parameters of the MIST-VR simulator performance score affected simulator performance, the different types of games played, and the possibility of gender impact on simulator performance.

The third study examined an automated video analysis of the medical students' performances of a low-cost Blackbox in comparison to the MIST-VR simulator.

The fourth study investigated whether a newly designed laparoscopic needle holder would be superior and could lead to a shortening of time to perform knot-tying and suturing tasks for medical students as performed in the Simball box simulator, compared with using a market needle holder.

No surgical residents or surgeons were enrolled during these four studies. A cross-over study similar to Study IV was concluded including only expert surgeons; however, these results are not part of this thesis and, therefore, not presented.

The parameter *total time*, or time of operation, is usually used when assessing surgical performance, regardless of whether it is in the simulator or in the clinical setting [59–61,127,128]. Score, on the other hand, is used to assess the simulator performance, which is the sum of all containing parameters calculated by the simulator. Nonetheless, it is debatable as to whether all parameters are essential or representative to explain the actual performance. Accordingly, specific parameters (e.g., motivation, expectations, experiences and MIST-VR scores (Study I); coordination and precision (Study II); path length and motion activity (Study III); and needle drops and instrument handling (Study IV)) are more representative than others, and, therefore, further investigated (for details see Papers I-IV).

11.1.5 *Length of Surgery*

The evaluation of laparoscopic performance has extensively used time or duration of surgery as a parameter [59–61,127]. It is debatable, however, that the length of a surgical procedure or time of surgery is relevant. Further, a shortened surgical procedure could even be hazardous and negatively affect patient safety. Nevertheless, it has been shown that longer surgeries, or patients put under anesthesia (as required by laparoscopy) for a longer period, is disadvantageous for the patient [129,130]. Subsequently, the intention should always aim for a shortened length of surgery without sacrificing patient safety in the quest for surgical speed.

11.1.6 *Subjectively Scoring Objectively*

Inter-rater reliability is the assessment used when comparing several raters' or reviewers' subjective scoring of, for instance, video recordings of laparoscopic performance. Evaluating surgical performance via video recordings is usually done using a validated scoring system [59,61,127,131]. In Study IV, two independent reviewers subjectively scored the participants video recordings of the first and second trials in a blind fashion regarding the subjects and the reviewers respectively, using an objective video evaluation scoring table (OVEST) produced by the authors (for details see Paper IV; Table 1). In both trials the correlation between the two reviewers' OVEST scoring were found to be significantly similar ($p<0.0001$ vs. $p<0.0001$) and equivalent with the validated software of the Simball box, suggesting that OVEST was a useful evaluation tool in an experimental setting (for details see Paper IV; Figure 2A).

12 GENERAL DISCUSSION

"It is the mark of an educated man to entertain a thought without accepting it."

Aristotle (384-322 BC)

The Metaphysics, c. 350 BC, Penguin Classics, 1999.

This thesis demonstrates the impact of motivation and surgical skill performance after basic skills training (BST) for medical students using either a low-cost or high-fidelity laparoscopic simulator (Paper I). The results suggest no significant difference in students' performance in the MIST-VR simulator, regardless of the two simulators used in BST (Paper I). Furthermore, in line with earlier studies [124,132] we found that previous PC-gaming experience enhances laparoscopic simulator performance; however, after the third attempt it was no longer significant.

Similar to previous studies some gender-specific differences were noted, where females with low PC-gaming experience benefitted from an initial training focusing on coordination and precision, where any previous deficiency of PC-gaming experience, low visuospatial score, and gender differences were compensated by repetitive training (Papers I-II). Additionally, PC-gaming with sports games or first person shooter had an impact on the coordination parameters of the MIST-VR simulator score (Paper II). Factors needed to be taken into consideration when proposing training curriculum, preferably individualized. Moreover, the findings show that the results from the automated video analysis accurately align with those of the excessively studied MIST-VR simulator, thereby providing a continued value to the low-cost laparoscopic Blackbox training (Paper III). Furthermore, results illustrate significantly superior improvement in laparoscopic suturing skills in trainees training advanced laparoscopy skills using a novel needle holder compared to a market needle holder (Paper IV). Additionally, the use of an objective video evaluation scoring table (OVEST) has been shown to be a usable evaluation tool in an experimental environment for the assessment of advanced laparoscopy skills in novices (Paper IV).

One could argue to why the participants were not subject to more difficult tasks in the LapMentor since it may present several different levels of difficulty than merely the two we used (peg transfer and cutting task). The reason for our decision to use the basic tasks was that both tasks are part of the FLS; additionally, we wanted to aid the comparison of the tasks performed in the Blackbox versus the LapMentor. Furthermore, it is arguable to why no surgical residents were included in these studies since by now we know that there are gender-specific differences between medical students and surgical residents regarding outcomes of laparoscopic simulator training [133]. However, these data, were not available at the time we developed our inclusion criteria. Nonetheless, in our future work we have included expert surgeons to examine the outcomes in laparoscopic suturing skills using different laparoscopic needle holders.

According to previous studies, the question of why surgeons (regardless of novice, resident, or consultant) should practice laparoscopy skills needs no further elaboration. The evidence of the positive effects of laparoscopic simulator training for novices is paramount [87], as well as its benefit for experienced surgeons [64].

In line with earlier studies, we have seen that previous high PC-gaming experience and visuospatial ability lead to enhanced laparoscopic simulator performance. For those with low PC-gaming experience and low visuospatial ability, further training is proposed. Here we also illustrate gender-specific differences in that females with both these attributes, low PC-gaming experience and low visuospatial ability, benefit from increased initial training, and this merits consideration when constructing a training curriculum (Studies I and II). Furthermore, focusing on the specific parameters of VR simulators (for Study II, coordination and precision) may provide a better understanding of the differences between visuospatial ability, previous PC-gaming experience and gender, and thereby facilitate the construction of a more customized training curriculum. Regardless of these findings, the individually most important factor in the acquisition of laparoscopic basic skills performance is continued repetitive, deliberate practice [106]. Any previous differences based on PC-gaming experience, visuospatial ability or gender, all disappear given further training (Studies I and II).

The question we should ask us is how do we pinpoint medical students who exhibit the right surgical behavior, or even more importantly, lack the appropriate surgical behavior? To define a skillful surgeon is difficult [134]. Several characteristics are essential in recognizing surgical competence: commitment and motivation, good judgment (based on knowledge), patient concern, and technical as well as non-technical skills. These characteristics are difficult to measure. However, the assessment of surgical technical skills is a direct method and by using objective tools such as the OSATS (Objective Structured Analysis of Technical Skills) [135] initially based on the OSCE (Objective Structured Clinical Examination) introduced by Harden et al. [136], an objective evaluation of surgical technical skills can be done. In Study IV we chose to use a newly produced objective video evaluation scoring table (OVEST) to assess advanced laparoscopy skills, suturing and knot-tying (Paper IV; Table 1).

12.1 Technical Skills

Surgery requires technical skills, and with an increased number of laparoscopic surgical procedures it is the prioritized method for several different operations [137]. Therefore, the demands on specific skills like eye-hand-coordination, in comparison to open surgery are paramount. With laparoscopic handles of various lengths, hand movements amplify movements in the abdomen according to the distance of the hands to the wounds in which the instrument passes through the abdominal wall. Furthermore, the movement of the hand outside the abdominal wall leads to the opposite direction of movement inside the abdominal wall, known as the fulcrum effect [78]. As previously mentioned, both Blackboxes and HFLS increase dexterity in laparoscopy among surgeons and generate an improved outcome in the operating room [59–61,78], consequently decreasing errors during surgery.

12.2 Low-tech and Low-cost Training

The early introduction of laparoscopic simulator training demonstrated positive learning outcomes in laparoscopic cholecystectomies during preclinical training [34]; therefore, simulator training should be promoted early on in surgical skills training. In regard to the financial constraints several teaching centers face [57], low cost simulators may provide an excellent alternative in simulator based training [137,138]. Regardless of the simulator (BT or VR) used for training, a clear effect in shortening the learning curve for laparoscopic skills is seen. The VR contributes to a more efficient training modality, but it is less cost effective than the BT, a consideration when constructing training curriculum for residents [139]. Additionally, in a recent review and meta-analysis, equal results where demonstrated when performing minimally invasive surgery (MIS) following training in a VR or BT for all outcomes, despite the level of the participants, except for completion of the task (time to complete peg transfer) and MIST performance score, which favor VR training [140].

12.3 Simulator Reality

In Study I, the students regarded the Blackbox simulator tasks as feeling more realistic than the LapMentor, which is in line with previous findings [141]. Subsequently, to further optimize the feeling of realism in a BT, in an inexpensive manner, digital images depicting the abdominal cavity may be placed inside the box, thereby shaping an environment that improve users' experiences and engagement [142]. Additionally, realism in the BT may also be enhanced by using 3D printed organs inside the laparoscopic box trainer [143]. The students felt the basic skills training procedures were easier using the Blackbox, which could be interpreted as providing a more realistic feeling compared to the LapMentor. Perhaps the impact of haptic feedback could partly explain the feeling of realism in the Blackbox. Moreover, further improved haptic feedback when training more advanced tasks has been shown to improve performance [144].

Regardless of the simulator used (HFLS or Blackbox), both demonstrate a shortening of the learning curve in the OR [139,145,146]. Earlier findings propose haptics for experts rather than for novices, considering its benefits in more advanced procedures [144,147], and additionally, haptic feedback in the LapMentor II presented inferior effects on performance among novice trainees [148]. However, residents refined their performance using haptic [149] and visual feedback, where the effects of visual feedback on force and movement (motion) during training could likely better the learning curve [150].

12.4 Simulator Training Effect

Both in the presented papers as well as in earlier findings, the correlation of training and simulator performance are clear. A correlation between the visuospatial test and MIST-VR score was found (Studies I-III), although, the effect gradually disappeared in the final MIST-VR-test, which could be the result of a training effect. Extended time for laparoscopic simulator training, regardless of the simulator cost, clearly illustrates a shortening in learning the procedures [151,152]. However, no further improvement was seen after reaching the plateau, suggesting an introduction of advanced and more difficult tasks in laparoscopic basic surgical skills training [153].

The results of Studies I-III indicate an important role for low-cost and low-tech Blackbox regarding laparoscopic basic skills training, since it offered comparable training responses to high-fidelity simulators yet with a greater compliance. Consequently, training laparoscopic basic skills in a low-cost Blackbox can be, not merely a complement, but a reasonable alternative to more expensive VR simulators, especially for those with limited financial means or with unfavorable geographical distances to a simulator center. As the aforementioned studies show, low-cost simulators could literally neutralize this disadvantage [88,154].

12.5 Gender Differences

In Study I, simulator training, regardless of the simulator used, was preferred by the female group. Moreover, in the Blackbox group but not in the LapMentor group, the experienced difficulty and facilitation presented an excellent correlation with the MIST-VR performance. Additionally, in the Blackbox group, females' experience of facilitation, and experienced difficulty correlated well with the MIST-VR-score performance, which was not found in the LapMentor group. However, they indicated a low threshold for training using the Blackbox compared to the LapMentor. In Study II, gender-specific differences were noted, where females presented improvement between all three MIST-VR trials compared to males, reflecting a learning effect with repetitive simulator practice. However, females' and males' introduction to simulator training seemed to present different prerequisites, which are important to consider in the construction of a training curriculum.

Study III presented gender-specific differences, which were previously noted in other studies [124,155]. Furthermore, the correlations between automated video analysis and MIST-VR performance were only noted in females and those with no prior PC-gaming experience. In regard to Study IV, females were overrepresented in the group starting with the new needle holder. How this might affect the overall results has not been tested or evaluated. As illustrated in previous studies, male subjects performed tasks faster than females [156,157]; however, females and those without prior PC-gaming experience caught up by additional instructions and repetitive training [156]. Male residents anticipated their performance scores more correctly than female residents who underestimated their scores. The current differences regarding surgical ability presented no actual differences in performance [158]. A recent review elicited differences between surgical residents (considered a homogenous group) and medical students (considered a heterogeneous group) in their acquisition of surgical skills, where the female medical students underperformed compared to their male counterparts. The same results did not exist among the residents. Furthermore, instructor feedback as well as one-on-one practice presented better performance in females, leading to non-existing gender differences regarding the acquisition of surgical skills [133].

12.6 Feedback and Motivation

The presence and benefits of an instructor feedback compared to non during laparoscopic simulator training has been illustrated in several studies [63,67,68]. In regard to the simulators used for this thesis, the Blackbox demands an instructor or supervisor for feedback, whereas the HFLS displays the feedback on a flat screen after each completed session [87]. However, the benefits of tutor feedback in HFLS over BT has been disputed due to the difficulties, even for experts, of accurately determining whether or not a task was successfully completed [159]. Furthermore, short motivational interventions demonstrated an effect on procedural performance and motivation among students in secondary school engaged in medical simulation-based training exercises [66]. Additionally, intrinsic motivation was shown to increase after simulation-based team training [160].

12.7 Limitations

"He who knows all the answers has not been asked all the questions."

Confucius (551-479 BC)

The Analects, c. 479-221 BC, Penguin Classics, 1979.

Firstly, no power calculation prior to the study start was performed. Furthermore, the number of participants for each study could be considered small (Study I (initially 63 to 47); Study II (initially 57 to 47); Study III (initially 31 to 29); Study IV (46)). Moreover, there were relatively high dropout rates (Studies I and II). Nevertheless, in regard to previous heavily cited papers, where a maximum of 16 subjects were used [59–61,78]. In regard to the dropout rates in Studies I and II, one may question the randomization accuracy and quality, due to the prominent dissimilarity that emerged between the compared groups (the risk or reality of no longer representing a randomized sample). Furthermore, since the participants were volunteers (Studies I-IV), selection bias cannot be excluded. In addition, females were overrepresented (F: 70% vs. M: 30%) in the group that started with NNH in Study IV. Moreover, the participants consisted of medical students rather than surgeons (Studies I-IV). Whether or not these results are fully transferable between the two groups are unknown.

Second, instructors are needed for the initial simulator training regardless of simulator used

(Blackbox or HFLS) (Studies I-IV). However, the feedback in the HFLS is given instantly by a built-in analysis software program after each completed task, whereas for the Blackbox, it needs to be provided by an instructor. The same instructor taught all subjects (Studies I-III); however, variations in feedback including direct feedback to each subject could be a possible cause of observed outcome bias. Study IV included more than one instructor, which may be a source of bias depending on possible unequal instructions and feedback during the tasks. Nonetheless, the instructors had identical information to provide to each subject during the trials, and since video recordings of the tasks were demonstrated prior to each task, the likelihood of having a large dissimilarity between the instructors' instructions were lessened and the risk of instructor bias should be considered relatively small.

Third, using the validated tests of the rather old MIST-VR simulator when newer, more advanced and sophisticated simulators are available is also arguable (Studies I-III). However, the MIST-VR has been widely studied and validated. As presented by Gallagher and O'Sullivan 2011, no attempt has been made to simulate the tissue, but rather it focuses on the psychomotor skills in coordination of eye-hand movement required in laparoscopic cholecystectomies [161].

Fourth, the questionnaires as outlined in the Studies I, II and IV, could have been more satisfyingly and exhaustively prepared in order to gather additional information regarding the different types of previous PC-gaming experience (Studies I and II), and to further minimize bias in regard to the sentence structure of the questions (Study IV).

Fifth, in Study III, the automated video analysis in its current form did not provide instant feedback, which is desirable in the learning process.

13 CONCLUSIONS AND FUTURE PERSPECTIVES

"Life is the art of drawing sufficient conclusions from insufficient premises."

Samuel Butler (1835-1902)

Erewhon, (1872), 23rd Edition, Penguin Classics, 2006

13.1 Conclusions Study I

When comparing low-cost Blackbox and high-fidelity laparoscopic simulators, we show no significant differences in the performance of laparoscopic surgical basic skills performance. As described previously, gender-specific differences regarding visuospatial ability and performance were found (Paper I).

13.2 Conclusions Study II

The knowledge of the impact of both PC-gaming experience and visuospatial ability in laparoscopic simulator training has been shown in several studies [72–75]. In this study we focused on extending our understanding of the impact visuospatial ability and PC-gaming experience had on the different parameters of the well-studied MIST-VR simulator (economy of movement, errors, time to completion and total score). We found that both PC-gaming experience and visuospatial abilities had a significant impact on various parts of the performance in the simulator. However, when separated by sex, males presented a steeper learning curve between MIST-VR Trials 1 and 2. Both females and males showed similar patterns over time, yet, these were only significant between Trials 1 and 2. Furthermore, females also showed a trend toward an improvement between Trials 2 and 3, thereby indicating a value in identifying this group (females with low PC-gaming experience) to provide opportunities for additional simulator training. Furthermore, the impact of visuospatial abilities and PC-gaming experience were no longer significant by the third simulation which indicates a learning effect that could be more important than baseline skills. The group with both low PC-gaming experience and low visuospatial scores performed poorest in the simulations and, therefore, we believe this group could benefit from additional simulator training. Additionally, any correlation between visuospatial ability and MIST-VR score in the first trial ceased to exist by the third MIST-VR trial.

13.3 Conclusions Study III

Developing feasible Blackboxes without lowering the standard in surgical skills training can be made by adding different adjuncts or using less costly materials (presented in detail in Paper III). By using a video software program to evaluate the recorded videos, we found gender-specific differences in correlations between movements in the Blackbox and the MIST-VR scores in the peg transfer exercise. We also found that those with more PC-gaming experience performed better in the MIST-VR simulator, which is in line with previous studies. Furthermore, neither computer gaming experience nor gender significantly affected performance as assessed by the MIST-VR scores, albeit there was a trend toward better performance both in experienced PC gamers as well as in males.

13.4 Conclusions Study IV

Considering that the participants had no or very poor experience in laparoscopy and no prior laparoscopic suturing experience, it is arguable as to more experienced surgeons were not included when testing the participants' performance in advanced laparoscopy skills. However, our results demonstrate that when novices first perform laparoscopy suturing tasks with the market needle holder followed by the new needle holder, they significantly improve both their

SBOS and OVEST scores. This was not present in the opposite order, i.e., from the new needle holder to the market needle holder. This suggests an important role of the new needle holder in the improvement of performance by shortening the training time in laparoscopy suturing skills. Earlier studies proposed that ergonomically better handles for laparoscopic suturing created less stress to the performer [162–164]. Since less stress among surgeons produces fewer errors and adverse events [18], all training surgeons, not just those in basic skills training, should be equipped with better and more ergonomically correct instruments for surgery and laparoscopic suturing. This would be vital in improving surgical outcomes, and, thereby, patient safety.

In conclusion, given the available literature on surgical training and its effects on patient safety as well as the financial benefits, the importance of a structured, preferably individualized, on-going simulation-based training cannot be emphasized enough. Furthermore, in continuing studies we watch expert surgeons using two different laparoscopic needle holders, similar to the study design of Study IV, to evaluate whether or not the results of using the novel needle holder present similar results as for the medical students. In addition, we will be evaluating factors of stress (e.g., via saliva tests and wearables) in conjunction with laparoscopic simulator performance and perhaps find answers to what causes surgeons stress during surgery, and if possible, how to try preventing it.

Subsequently, as depicted in this thesis, there is not one single truth or solution; rather several angles and different factors affect learning in general and surgical performance in particular. Things to consider when producing laparoscopic skills training curriculum for future surgical trainees. My strong belief, given the literature scoped, including my personal experiences of learning and teaching, interest in and passion for the subject, goal-orientation (motivation to train) and guidance, hours and hours and hours of preparation and practice [105] (preferably with good music – consider the Mozart effect [107]), belief in self, and fearlessness yet humility toward what lies ahead, are all fundamental elements in reaching the level of expertise needed to be considered a master-class surgeon.

Other attributes that may, positively or negatively affect the surgeon's persona, could also impact the outcome of a surgical procedure considering what results communication deficiencies might have on operating room teamwork, or how a lack of empathy might affect the doctor-patient relationship. Furthermore, a professional and humane attitude toward people and a willingness to help are characteristics I believe people wish to see in a surgeon.

Finally, future studies focusing on not merely gender, but preferably individual differences in training with surgical trainees instead of medical students as subjects should be conducted. In addition, studying transferability to operating room performance, including the effects of stress in the operating room, might narrow the knowledge gap and need for individually designed surgical training curriculum.

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