

From Department of Clinical Science Intervention and Technology,  
Division of Orthopedics and Biotechnology  
Karolinska Institutet, Stockholm, Sweden

# **THE NEXT LEVEL: VIDEO GAMING, COGNITION AND MOTIVATION IN SURGICAL SIMULATOR TRAINING**

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Department of Clinical Science Intervention and Technology (CLINTEC),  
Division of Orthopedics and Biotechnology

## The Next Level - Video Gaming, Cognition and Motivation in Surgical Simulator Training

### THESIS FOR DOCTORAL DEGREE (Ph.D.)

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**Stockholm 2015**



*To Sonja and Ivan, stay curious and keep asking questions.*



## ABSTRACT

Image guided surgery uses small incisions or existing entry ports of the body in order to decrease surgical trauma which will hopefully lead to less infections, complications and number of days needed in the hospital. It is associated with great difficulties and a steep learning curve due to several reasons such as inverted movements and 2D representation of the operating area. In order to excel in minimal invasive surgery a large amount of training is required which has spurred the rise of virtual reality (VR) surgical simulators offering a safe training environment with the possibility of customized scenarios and quantifiable feedback. Another advantage with VR simulators is easily conducted research due to objective assessment of performance and standardized task content and scenarios. Previous research has identified visual-spatial ability, the ability to mentally rotate and manipulate objects as well as visual working memory, the ability to hold visual information during a delay and recall that information, to be important for simulator training and performance. Video gaming experience has also been identified as an important background factor. This thesis consists of work derived from four studies that all take advantage of VR simulators as a tool for investigating which individual factors are needed for performance and training of minimal invasive surgery and whether or not they can be altered. In the first study the hypothesis was that the importance of visual-spatial ability (VSA) and visual working memory (VWM) would differ with different simulator task content. 25 subjects were tested for VSA, VWM and performance in three different simulators. A multivariate analysis showed that the importance differed; one task seemed to be more visually loaded than the others. That result was followed up in study II that examined whether it was possible to actually improve simulator performance by video game training and if the transfer effect differed according to simulator and video game task content. 30 subjects were matched and randomized into training with a 2D chess game or a 3D first person shooter game for five weeks, pre and post training subjects were tested with two different simulators. A control group consisting of 10 subjects was also tested. There was a transfer effect, surprisingly also from the 2D game. Suspicions about a general cognitive workload lead to the aim in study III that investigated whether simulator performance would predict written examinations results. 158 subjects were tested in a simulator and a written examination in basic surgery. There was a performance-examination correlation in female but not male subjects, which lead to study IV that investigated the role of motivation for surgical performance. In study IV, 30 subjects were tested for motivation while training in a surgical simulator. Motivation as defined by the self-determination theory correlated only in male subjects to performance when highly motivated medical students were examined. It appeared to be less important for performance than visual spatial ability. Training in surgical simulators enhanced subjects' interest in choosing surgery as a future work field. The thesis identifies the importance of certain background factors and suggests alternate means of minimal invasive training that will meet the requirements of tomorrow's surgeons, taking surgical training to the next level.

## SAMMANFATTNING

Sedan urminnes tider har människan försökt läka sjukdomar och skador med kirurgiska interventioner. Tidiga bevis finns för trepanation, företeelsen att knäcka ett hål i skallbenet för att t.ex. släppa ut onda andar. I samband med den moderna medicinens utveckling har kirurgin utvecklats med nya metoder såsom minimalinvasiv kirurgi. Denna typ av kirurgi använder befintliga öppningar i kroppen, alternativt så skärs små ingångshål för redskapen som skall användas för det kirurgiska ingreppet i t.ex. bukhålan, en ledhåla eller i ett blodkärl. Syftet med minimalinvasiv kirurgi är att göra ingrepp i kroppen med så lite trauma som möjligt vilket åtminstone teoretiskt skall ge kortare tider på sjukhus, mindre infektioner och smärta samt färre postoperativa komplikationer.

Minimalinvasiv kirurgi är dock tekniskt svårare än vanlig öppen kirurgi, eftersom kirurgen inte tittar direkt på operationsområdet utan på en monitor med en videoöverförd bild från operationsområdet. Vid exempelvis laparoskopi blir rörelser inverterade på skärmen, d.v.s. om operatören för instrumenten nedåt kommer de att åka uppåt på skärmen. Vidare presenteras operationsområdet som en tvådimensionell bild och inte en tredimensionell sådan varvid bilden måste omvandlas i operatörens medvetande. Ökad svårighet ger större risker och försvårar inläringen. När kirurgen arbetar med långa verktyg minskar förmågan att avgöra hur hårt eller djupt en rörelse ska utföras.

På grund av svårigheterna med minimalinvasiv kirurgi och de stora risker som är associerade med träning på patienter så har kirurgiska simulatorer utvecklats. De senaste årens utveckling av simulatorer har utnyttjat s.k. virtual reality, d.v.s. en datorgenererad virtuell miljö som tillåter oändligt med standardiserade scenarios till en varierande svårighetsgrad, utan någon fara för patienten. Denna typ av simulator kan ge en objektiv och kvantifierbar återkoppling. Flera simulatorer som innehåller virtual reality har visat sig dels kunna utvärdera kirurgisk förmåga men också ge en transfer effekt; träning i simulatormen ger en förbättring på verklig kirurgi.

För att veta hur träning skall utformas måste vi veta vilken typ av träning som fungerar och vilka typer av förmågor som krävs av operatören. Därför har tidigare forskning försökt kartlägga dessa typer av förmågor och faktorer som påverkar träning och prestation. Denna avhandling syftar till att kartlägga vissa förmågor som är viktiga för färdighetsutveckling inom minimalinvasiv kirurgi, genom att ta hjälp av simulatorer med virtual reality.

Visuospatial förmåga, d.v.s. förmågan att mentalt manipulera och rotera två och tre dimensionella figurer, samt visuellt arbetsminne som inbegriper förmågan att hålla visuella stimuli i minnet under en kortare tid och sedan återge dessa, har visat sig vara viktiga för prestation i minimalinvasiv kirurgiska färdigheter. I den första studien undersöktes huruvida betydelsen av visuospatial förmåga samt visuellt arbetsminne skulle variera beroende på simulatorövningarnas innehåll. 25 medicinstudenter testades för nämnda förmågor och sedan i tre olika simulatorövningar med olika innehåll och karakteristika. Det visade sig att beroende på övningarnas innehåll, varierade betydelsen av förmågorna. Denna insikt antyder



att framtida träningsprogram som skall utformas måste ta hänsyn till hur visuellt krävande uppgiften som skall tränas är i relation till kirurgens visuospatiala förmåga och arbetsminne. Senare forskning har visat att visuospatial förmåga och visuellt arbetsminne till viss del kan tränas upp, vilket ger intressanta möjligheter för framtiden.

En annan faktor som visat sig vara av vikt för prestation är tidigare datorspelsfarenhet och förmåga. I studie nummer två, undersöktes huruvida det faktiskt är möjligt att bli bättre i kirurgiska simulatorer genom att träna datorspel. Vidare, eftersom den första studien visade att övningarnas innehåll påverkade betydelsen av visuospatial förmåga och arbetsminne, ställdes frågan om detsamma gällde för olika typer av datorspel? 30 försökspersoner lottades till att antingen spela ett tredimensionellt skjutarspel eller ett tvådimensionellt schackspel under fem veckors tid; 30 minuter per dag i fem dagar. Ytterligare 10 försökspersoner utgjorde en kontrollgrupp som inte utförde någon träning. Före och efter träningsperioden testades alla försökspersoner i två olika typer av simulatorer. Det visade sig att det faktiskt går att bli bättre på minimalinvasiv kirurgi presenterad i simulatorer genom att spela datorspel. De försökspersoner som spelade actionspelet blev bättre i båda simulatorerna medan kontrollgruppen inte förbättrades alls. Intressant nog förbättrades schackgruppen i en av simulatorerna. Studien visar att datorspel skulle kunna utgöra ett komplement till färdighetsträningen, men att rätt typ av innehåll måste identifieras för att optimera träningen precis som vid visuospatial förmåga och visuellt arbetsminne.

Fyndet med att även schackspelarna förbättrades väckte tanken att en allmän mental belastning kunde förbättra resultatet i simulatorerna vilket ledde till den tredje studien. I denna undersöktes huruvida det fanns en koppling mellan prestation i simulatorerna och teoretisk prestation. 158 läkarstudenter som gick kursen Klinisk medicin inriktning kirurgi på läkarprogrammet testades i en simulator och skrev sedan ett slutprov omfattande de kirurgiska ämnena. De kvinnor som presterade bra i simulatören presterade även bra på provet, någon sådan koppling fanns dock inte för män. Resultatet var förbryllande och endast spekulativa svar kunde ges; Är män mindre brydda än kvinnor av dåliga resultat och påverkas därmed inte inför senare prov? Var de kvinnor som presterade bra på simulatortestet mer motiverade och studerade därmed även mer inför examinationen, eller blev de mer motiverade av det goda resultatet?

Den sistnämnda frågan ledde till studie fyra som undersökte motivationens roll för träning och prestation. Motivation definierades i detta fall med den s.k. self-determination teorin, som delar in motivation utifrån pålagda yttre faktorer som påverkar viljan att göra saker eller inifrån kommande faktorer. 30 läkarstudenter fick träna i en simulator. Innan testades de för videospelsfarenhet, visuospatial förmåga och fick frågor om deras intresse för kirurgi som framtida specialitet. Deras motivation i relation till simulatorövningen testades med ett formulär i samband med introduktionen av simulatören, efter deras första försök samt efter träningsperiodens slut. Resultaten visade att motivationen inte påverkade simulatorresultatet, däremot påverkade simulatorresultatet motivationen hos män. Detta resultat motsade den

tidigare spekulativa hypotesen att män skulle påverkas i mindre utsträckning av hur det gick i simulatorm. Visuospacial förmåga visade sig vara av större betydelse än både motivation och videospelserfarenhet. Vidare ökade intresset för kirurgi av träning i simulatorm. Resultaten i studie fyra var svårtolkade, sannolikt till följd av att motivation är ett så pass komplext ämne att studera samt det faktum att försökspersonerna var mycket motiverade redan vid inträdet i studien.

Systematisk simulatorträning är ännu inte ett lagstadgat och självklart träningsalternativ inom medicinen till skillnad mot andra högriskorganisationer som t.ex. flyget. Denna avhandling har syftat till att bidra till den utvecklingen genom att undersöka betydelsen av olika bakgrundsfaktorer och om den betydelsen varierar för den kirurgiska uppgiftens specifika innehåll samt att undersöka effektiviteten av alternativa träningsmetoder. I framtiden med ytterligare forskning, kan träningsprogram utformas som är riktade mot de specifika mentala bakomliggande processer som behövs vid minimalinvasiva ingrepp. Möjligtvis kommer vi få se motiverande datorspel designade för kirurgisk träning med visuospacialt utmanande komponenter och träning i visuellt arbetsminne. Utvecklingen av kirurgisk träning till nästa nivå för att möta behovet av morgondagens läkare kommer att fordra nya tekniker och arbetssätt.

## LIST OF SCIENTIFIC PAPERS

- I. **Schlickum M**, Hedman L, Enochsson L, Henningsohn L, Kjellin A, Felländer-Tsai L. Surgical simulation tasks challenge visual working memory and visual-spatial ability differently. *World J Surg.* 2011 Apr;35(4):710-5.
- II. **Schlickum MK**, Hedman L, Enochsson L, Kjellin A, Felländer-Tsai L. Systematic video game training in surgical novices improves performance in virtual reality endoscopic surgical simulators: a prospective randomized study. *World J Surg.* 2009; 33:2360-2367.
- III. **Schlickum M**, Felländer-Tsai L, Hedman L, Henningsohn L. Endourological simulator performance in female but not male medical students predicts written examination results in basic surgery. *Scand J Urol.* 2013 Feb;47(1):38-42
- IV. **Schlickum M**, Hedman L, Felländer-Tsai L. Motivation during surgical simulator training differs among medical students - an analysis of background variables. Manuscript.

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## LIST OF ABBREVIATIONS

2D	Two dimensional
3D	Three dimensional
ABOS	American Board of Surgeons
ANOVA	Analysis of Variance
MIST-VR	Minimal Invasive Surgery Trainer Virtual Reality
MRT-A	Mental Rotations Test A
OITE	Orthopedics In training Examination
OR	Operating Room
SDI	Self-Determination Index
SDT	Self-Determination Theory
SIMS	Situational Motivational Scale
USMLE	United States Medical Licensing Examination
VR	Virtual Reality
VSA	Visual-spatial ability
VWM	Visual working memory
WAIS	Wechsler Adult Intelligence Scale



# 1 INTRODUCTION, CHAPTER 1

## Background

### *The development of minimal invasive surgery and associated difficulties*

Since the early beginnings of mankind, humans have intentionally sought to heal and correct perceived illness and unwanted conditions through surgical interventions. The history of surgery runs with various results ranging from trepanation in order to release evil spirits to open-heart surgery [1]. Parallel to the general surgical evolution runs the development of minimal invasive surgery, i.e. surgical interventions with minimal trauma to the human body such as endoscopic surgery using existing orifices of the body e.g. the mouth, laparoscopic surgery using small incisions in the abdominal wall for entry ports, arthroscopic surgery entering joints (illustrated in figure 1) and endovascular surgery taking advantage of existing blood vessels. Early documentations of endoscopic examinations traces back to Hippocrates [2]. In order to assess internal environments in the body, lighting has for long been the limiting factor[3]. During the last century surgeons have gone from natural and reflecting light to artificial light, starting in the 1950's which in addition to inventions such as electrical cauterization and video imaging has driven development to present minimal invasive surgery[2].

Figure 1. Arthroscopy. The operating field is projected on a monitor at distance from the operating field.



The main advantage with minimal invasive surgery in comparison to conventional open surgery would be fewer traumas to the body that hopefully lead to a faster recovery phase and less postoperative pain. The outcome of minimal invasive techniques for different surgical procedures varies. Review studies conducted to evaluate minimal invasive techniques versus traditional open surgery are all stressing the need for further studies and that several conclusions about outcome need to be interpreted with caution. For example, open bile duct surgery seems superior to minimal invasive Endoscopic Retrograde Cholangiopancreatography (ERCP) in achieving common bile duct stone clearance based on evidence from the early endoscopic era [4] while regarding the management of small bowel Crohn's disease, research suggests that there is no significant differences between laparoscopic surgery and open surgery [5]. When removing ovarian tumors researchers have found that laparoscopic interventions seem to reduce infections and postoperative complications as well as days needed in a hospital and costs [6]. Laparoscopy leads to better short-term post-surgical outcomes in terms of recovery for non-locally advanced colorectal cancer [7]. It also seems feasible and better in terms of hospital stay and mortality reduction in obstructive small bowel [8] and is claimed to have various advantages over open surgery in appendicitis [9].

Although these techniques take use of small entry ports, the potential damage may be severe while using the tools inside the body. Regarding hernia, laparoscopic repair takes longer and has a more serious complication rate in respect of visceral and vascular injuries, but recovery is quicker with less persisting pain and numbness [10]. It has been shown that after the introduction of image-guided surgery there was an increase in mortality and morbidity rates for certain procedures [11]. This can probably be explained by the difficulties associated with image-guided surgery. A statement that modern medicine is harmless could not be further from the truth. When the 1999 report "To Err is Human: Building a safer health system" was published by the Institute of Medicine Committee on Quality of Healthcare in America, the public became painfully aware of the fact that between 44000 and 98000 patients die each year in the US due to medical errors in hospitals with a calculated cost of 17-29 billion dollars each year [12]. Since surgical procedures and the operating room (OR) setting accounts for approximately 50-60% of all medical errors [13] it is easy to see the potential damage done by improper minimal invasive surgery. Of all errors committed, inexperience or lack of competence has been blamed for approximately 50 %, although it is considered to be system-based problems that lead to a chain of events rather than individual errors [14].

Image guided surgery is in many cases considered to be more difficult than open surgery and characterized by longer learning curves [11]. Difficulties associated with minimal invasive surgery are derived from the fact that the surgeon does not look directly at the area where the procedure takes place: instead, the surgeon is looking on a monitor. One of those difficulties is the so-called fulcrum effect; when operating guided by a camera, the movements of long inserted tools are inverted on both the x-axis and y-axis such as during laparoscopy and arthroscopy. That is, when moving tools to the left and up they appear to go to the right and



down on the monitor. This has been associated with great concerns for the surgeon and cannot be corrected by increased attention and caution, only by automation as a result of repeated practice [15]. Training under alternating viewing conditions has been proven to help trainees automate faster to the fulcrum effect [16].

Another difficulty when performing image-guided surgery concerns vision. When looking at a monitor, the surgeon needs to rely on two-dimensional (2D) images from the operating area instead of the direct three-dimensional (3D) vision presented in traditional open surgery [17]. It has been shown that this creates a problem in the OR as the optimal placement of the monitor to facilitate performance is right in front of the operator, low and close to the operators hands just like open surgery [18].

A third identified problem with learning image-guided surgery is the difference in tactile feedback. Tactile feedback from the long instruments used in minimal invasive surgery differs from the feedback in open surgery but is still present [19]. There is no consensus in the literature of the importance of haptic feedback in minimal invasive surgery simulation although the majority of studies performed suggest there is a positive correlation to performance [20].

### *Virtual reality surgical simulation*

Traditional surgical training has for long been characterized by a time-consuming use of apprenticeship [21]. The see one, do one, teach one paradigm was introduced by William Halsted over 100 years ago but has become outdated due to several factors in the last years [22] such as greater public expectations and increased demands for competency-based education [23]. In Europe, many countries have implemented the European Working Time Directive that has resulted in fewer work hours, and therefore fewer hours available for training [24]. Another problem associated with the master-apprentice learning model is that the evaluation of the learner by the expert has been proven to be very subjective and biased [25], which drives the need for an unbiased measurement of progress. Furthermore, when training on high-risk procedures such as surgical interventions, the OR is highly unsuitable for basic training. First of all, the OR is a stressful environment that does not encourage sufficient time taken for training. This severely limits time taken for reflections and parts of procedures cannot be repeated. Also, since operations are performed on a rigid scheme, training time during work hours becomes quite arbitrary which certainly constitutes a problem with the reduction in work hours. With the expanding technological development of modern surgery the demands on surgical training has even increased [26].

In 1993, Ericsson and coworkers proposed the so called “deliberate practice”, a theory that states that crucial to reaching expert level is the amount of practice conducted as engagement in structured activities created specifically to improve performance in a domain and that reaching expert level often requires 10000 hours of practice [27]. The theory of deliberate practice has been very influential for the last 20 years but also received some

criticism. In a recently conducted meta-analysis of the role of deliberate practice in music, games, sports, education and professions authors found out that while deliberate practice is important in many areas it is just one of many factors contributing to expert level [28]. Furthermore, while deliberate practice was an important factor for performance in games and sports it was less important in less predictable activities such as handling an aviation emergency [28]. Hence, practice is undoubtedly an important factor in expertise but is not the sole determinant [29]. Innate abilities could to a large extent explain individual differences in training required.

The previously described learning difficulties and risk of severe errors associated with minimal invasive surgery has driven the development of surgical simulators [30]. Simulation is a phenomenon of deliberate imitation of an event and a simulator is a device that facilitates learning of a procedure by assessment and recording of progress [31]. Early medical simulation included performing surgical procedures on cadavers and live animals while recent years have seen a development of manikins, computers and virtual reality [32]. Simulators for minimal invasive surgery range from simple box trainers (a physical box with an inside filmed by a camera) to high-fidelity full-scale arrangements with virtual reality. Some extensive research has validated high fidelity medical simulation. In a literature review, several conditions for effective simulation has been listed, among others feedback and repetitive practice [33]. Although medical simulations are considered highly valuable, they are to be regarded as a complement in education preparing the learners for real patient contact [33]. An important argument has been raised regarding simulators, namely that the simulator device is of secondary importance, what is important is the curriculum that includes error identification and skills acquisition [34].

The digital revolution of the last two or three decades has introduced virtual reality into surgical simulation in order to cope with the mentioned challenges. A virtual reality is a fictive environment created by computers. The environment allows interaction and therefore creates a sense of immersion. The first virtual reality simulator for surgery was developed in 1991 [35]. At an early stage, virtual reality simulation was proven to improve operating room performance [36]. Virtual reality simulators offer a safe training environment since no patient is involved in the training procedure. Since the environment is computer generated, scenarios are unlimited and not dependent on disposable training materials such as sutures or cadavers. No ethical considerations have to be taken into consideration unlike training on live animals and human cadavers. The former, most importantly, also differ anatomically from the human body. Furthermore, computerized environments offer the possibility to customize training to specific tasks, and probably in the future, to the specific patient that the procedure will be performed on with the help of radiology. Since patients are not involved in a virtual reality simulator, training can take place whenever the trainee finds the time, 24 hours a day, 365 days a year. Since a computer records performance, assessment of progress and success is objectively measured and measurement is done in an identical way each time. Quantifiable feedback is given instantly and there is no mandatory need of constant presence of an instructor. Finally, a virtual reality simulator offers the opportunity to change the procedural

complexity of tasks and therefore it is possible to train with a gradually increasing level of difficulty.

In laparoscopic surgery, virtual reality appears to decrease the operating time and improve the operative performance of surgical trainees with limited laparoscopic experience when compared with no training or with box-trainer training but in order to answer to which extent, further research is required [21]. Regarding endoscopic interventions, there are several simulators on the market. Some of these simulators have been shown to improve colonoscopy skills in the clinical setting for the initial phases of training and improve hemostasis skills. Since their long-term benefit is uncertain more randomized trials has been suggested in order to assess the role of simulation in endoscopy training programs [37]. Also endovascular virtual reality simulation has been proven to transfer to real surgical tasks [38].

The promises virtual reality simulator training brought some 15-20 years ago that it would revolutionize surgical training the way minimal invasive surgery revolutionized surgery [39] has somewhat been put on hold. Although most of the studies conducted investigating virtual reality to operating room transfer effects show a positive correlation, they still leave some uncertainties due to narrow scopes and the use of medical students instead of surgical residents. This may become an obstacle in implementing virtual reality training [40]. Further, it has been shown that voluntary simulator training leads to minimal participation in a training curriculum [41, 42] that of course may lead to unused simulators once they are purchased. Another problem with the implementation of simulators is the fact that there are limited consistent data to suggest how to set proficiency levels in the simulators used [43]. In an interview study with 22 program directors, authors found that only 4 programs perform formal basic surgical skills evaluation with mandatory remediation and none of 22 program directors would prevent residents with demonstrable poor basic surgical skills from going to the OR [44]. Obstacles to implementation of basic surgical skills included a lack of time, resources, and validated tests [44]. It is considered to be a complex task to implement a nationwide curriculum and human barriers are often the limiting factor, stressing the need to alter cultures and motivation in hospital personnel and the medical profession [45].

In e.g. the aviation industry virtual reality simulation is widely accepted, and no one would think of a pilot managing an aircraft with passengers without first showing a certain level of proficiency in a simulator. In the medical industry, virtual reality simulation is far from being an integrated part of everyday training and practice. In order to change this, a culture shift is needed to foster an environment that stresses safety and encourages training the way other high-reliability organizations such as aviation and the nuclear industry already function since many years ago [46].

The term pre-trained novice is the preferred state of the learner and refers to the trainee who has automated spatial judgment and psychomotor skills [47] which is achievable with surgical simulation by training technical skills in a safe environment [48]. Simulators can be evaluated based on their face validity, which is the level of realism that the learner experiences while using the simulator. Construct validity translates to if the simulator measures what it is supposed to measure. The predictive validity shows if it predicts future outcome based on the results. Content validity means whether simulator content correlates to real content while concurrent validity measures to what extent successful results in the simulator correlate to the golden standard of the procedure being simulated. Face validity, the realism of the content experienced by the users does not automatically transfer to effective training [49] although this is often the first characteristic which users evaluate a simulator by. The goal with creating surgical simulators is to establish that there is an actual transfer effect from training with the simulator to performance in the OR [50]. A simulator is built up by several task components that address different demands and challenges to the learner. When two simulators share the same essential components they are considered to be similar [51]. In order to discover which task-components of the simulators are vital and which are not, research is needed to identify these common denominators so that simulator training can be as effective as possible [52]. This research can facilitate development of reliable simulators, effective training programs and curricula, as well as alternative training modules. Furthermore, studies have shown that the learning curve sometimes differs substantially between learners of a procedure, resulting in many hours more needed for the same task by certain trainees [53]. Complete lack of improvement in certain domains has been suggested to be associated with innate abilities [54]. The innate abilities and task-components needs further research.

In order to facilitate the implementation of virtual reality simulator training for minimal invasive surgery there is a need for more knowledge about what type of training works and why so that future training may be optimal in regards to time and cost. This need of information has spawned various studies that address the background factors presumed to affect minimal invasive training and performance. Surgical simulators offer a safe environment in which studies can be conducted and also present quantifiable feedback and standardized scenarios. It has been suggested that an obstacle to implementing virtual reality simulator training has been the lack of validated curricula for minimal invasive surgery training, and that these curricula need both a technical and cognitive component in training [55]. This would justify further research to understand the aspects of virtual reality surgical simulation, moving away from just showing that virtual reality simulation works.

Several previous studies have been focusing on the psychomotor aspects of minimal invasive surgery. In a study investigating time required to reach specific goals in a laparoscopic simulator in relation to amongst others, psychomotor aptitude, there was a positive correlation pointing out that specific factor [56]. The same result has been found when

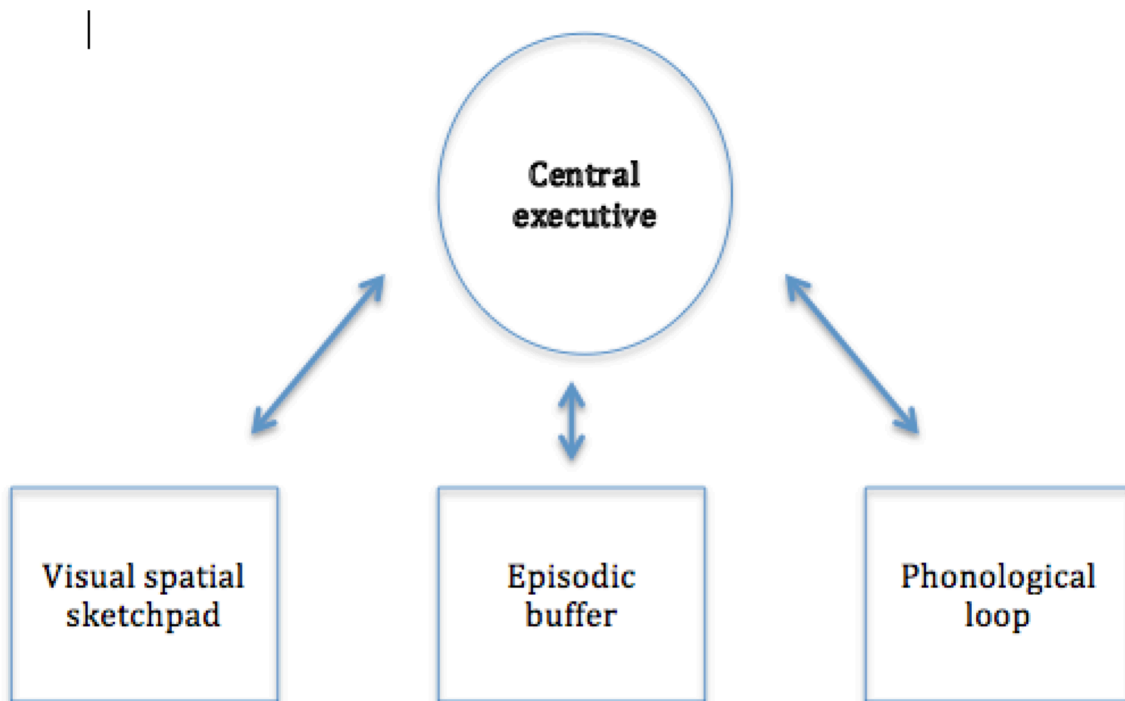
looking at an endovascular simulator and correlating performance to fine motor dexterity assessment [57].

One of the background factors that have been of great interest is visual-spatial ability. Visual-spatial ability is the capability to mentally rotate and manipulate 2D and 3D objects. Spatial ability generally refers to the ability to generate, represent, transform, and recall spatial information [58] whereas spatial orientation is the complex of all the skills used for locating themselves with respect to a point of reference or an absolute system of coordinates [59]. It has been suspected that visual-spatial ability is important in learning medicine due to the spatially complex environment that constitutes the human body. It was shown in 2001 that visual-spatial ability is a governing factor when learning anatomy [60]. Hence, a study was conducted a year later which proved high level visual-spatial ability to be related to initial competency and quality of results in a surgical procedure [61]. It has been demonstrated in various studies to affect minimal invasive surgery [62]. It has been suggested that surgical training could be targeted to specific areas in the brain that has been associated with surgical performance [63]. Visual-spatial ability is associated with gender differences, where men tend to score higher on mental rotations tests than females [64]. Researchers have tried to explain this difference by investigating different correlations to gender and visual-spatial ability. One of those areas is video gaming experience, which has been shown to mediate the gender difference in spatial ability observed on a mental rotation test. It has been suggested that encouragement of video game usage of girls might decrease the gap in visual-spatial ability [65]. Furthermore, it has also been proven that training in a video game challenging in mental rotation renders a transfer effect to visual-spatial tests in contrast to training in a non-challenging video game [66]. It has been proven that high aptitude measured as visual-spatial ability, depth perception and psychomotor ability combined correlates to performance in a laparoscopic suturing simulator [67]. Furthermore, when a group with high aptitude was compared to a group with low aptitude, authors found that subjects in the former group reached proficiency in the simulator after 7 attempts, while 40% of subjects in the latter group improved but did not reach proficiency. 30% of the subjects in the low aptitude group did not reach proficiency at all [67]. A very interesting study was conducted in 2005, examining the predictability of small paper and pencil tests in relation to real life navigation and virtual navigation. The study defined a separate navigational factor for real life environment in contrast to virtual navigation, largely explained by the extra sensory input from the body associated with real environment navigation [68]. There was a high predictability on virtual environment navigation from paper and pencil tests [68].

Working memory, the ability to retain information during a delay and make a response based on the internal representation is regarded as a fundamental underlying human function in various cognitive functions [69] and is closely associated with visual-spatial ability. Working memory has been given significance in other high reliability organizations such as aviation [70]. Since interruptions, delays and multi-tasking is frequent in image-guided surgery, researchers sought and found a correlation between visual working memory and laparoscopic surgery [71]. Baddeley has early on developed a commonly accepted

model of working memory that defines it as a system consisting of interlinked parts: a visual-spatial part that handles vision and the phonological loop that concerns speech and sound. A third part has later on been introduced called the episodic buffer that holds chunks of information sequenced in code. The system temporarily stores and manipulates information needed for several cognitive abilities [72]. Working memory has been considered a constant trait until a recent study that has suggested plasticity in dopamine receptors and changing cortical activity in the brain [73]. The working memory model proposed by Baddeley is illustrated in figure 2.

Figure 2. Working memory model derived from Baddeley [72].



Another background factor associated with minimal invasive surgery is video gaming performance and experience. Video games all have in common that the gamer navigates on a monitor using different navigational tools such as mouse, control and joystick. The similarity to minimal invasive surgery may also be contextual depending on what type of video game is at hand. Previous video game experience has early on been identified to affect laparoscopic surgery [74] as well as demonstrated video game performance [75]. One study has demonstrated that a warm-up with select video games prior to laparoscopic surgery enhances both time and error rate when compared to no warm-up [76].

The first aim of this thesis was to further investigate the role of the previously mentioned visual-spatial ability and working memory. Since those background factors had been associated with simulator performance in different simulators, the question arose whether or not the importance of the abilities would differ in different tasks. Such a finding would motivate task specific training, and therefore the first study was targeted at rating the importance of mentioned abilities in relation to different task content.

The conclusions from the first study built the foundation of the second study. If simulator training cannot be regarded as something static that is constant regardless of content and trainee, then video gaming can neither be regarded in the same fashion. Hence, video game content in relation to performance was targeted in the second study. Since previous studies have shown a correlation between video game experience and demonstrated skill, the actual transfer effect of video game training was investigated in the second study.

The logic of the third study was derived from results from the second study regarding presumed general cognitive workload and simulator performance. The question arose whether there was a correlation between academic performance and simulator performance. In a study conducted in 2009 with 113 medical students enrolled, gross motor skill was associated with objective measures of medical school cognitive performance such as class rank and United States Medical Licensing Examination (USMLE) scores [77]. There was no correlation to a laparoscopic simulator versus academic measures [77]. When comparing, amongst other factors, class rank and USMLE scores authors found no correlation to the ability to pass both the American Board of Surgery qualifying and certifying examinations on the first attempt [78]. Van Herzeele has demonstrated that a 45 minutes didactic session combined with a procedural demonstration of an endovascular task results in better performance among surgical novices in an endovascular simulator than just a procedural demonstration without the theoretical lecture [79]. The third study of the thesis focused on a specific written test in surgery in correlation to performance in a visually loaded simulator. The question was highly relevant since historically selection for surgical training has been based on surgical experience, passing examinations and academic achievement [62].

Results from the third study implied that there could be an explanation to the findings by a governing factor not yet thoroughly examined in surgical training; namely motivation. Also, it could be questioned whether motivation was a confounding factor in the video game study? In the final study the area of interest was whether there was a correlation between motivation and performance. An earlier study has shown that basic virtual reality laparoscopic training based on peer-group derived benchmarks with external assessment is superior to self-controlled training, resulting in higher trainee motivation and better performance in simulated laparoscopic cholecystectomies [80]. Trainee motivation in this case was measured by trainee adherence to the course, time spent on the simulator and number of visits to the training facility [80]. This finding supported results from a previous study where unsupervised simulator trainees did not improve their surgical performance in relation to a control group with no simulator training [81]. When self-rating motivation on a scale from 1-20, researchers have found that motivation ratings correlated positively with attendance rates, number of repetitions, performance improvement, and achievement of proficiency and best goals. It did also improve by setting specific training goals [82]. No study as of yet had investigated virtual reality surgical simulation training in relation to motivation defined by the motivational research area.

Minimal invasive surgery is hard and training is timely, costly and risky. Therefore VR simulators that mimic procedures have been developed but have been difficult to implement. VR simulators transfer surgical skills to real tasks but it is not known exactly why, i.e. which elements are necessary and which are not. By knowing more of which elements are important for minimal invasive surgery we can optimize training and develop cheaper and more efficient methods. This thesis investigates the role of certain background factors for simulator performance and furthermore opens up for new training possibilities. The background factors analyzed are summarized in table 1.

Table 1. Background factors in studies.

<b>Background factors</b>	<b>Focus of investigation (studies)</b>
Visual-spatial ability	Correlation to performance according to task content (I), level of importance versus other factors (I, II, IV)
Visual working memory	Correlation to performance according to task content (I), level of importance versus other factors (I,)
Video gaming	Transfer effect by training (II), level of importance versus other factors (IV)
Theoretical knowledge	Correlation to performance (III)
Motivation	Correlation to performance (IV), level of importance versus other factors (IV)



## **Aims of the studies**

-In the first study, the aim was to perform a detailed analysis on how visual-spatial ability and visual working memory were associated with metrics in surgical virtual reality simulator performance with different task contents. The hypothesis was that the importance of these background factors varies with different task content.

-The aim of the second study was to perform a prospective randomized study investigating whether five weeks of systematic training in either of two different video games would influence performance in two different virtual reality endoscopic surgical simulators. The hypothesis was that systematic video game training would show a transfer effect with improved performance in virtual reality endoscopic simulation if the visual characteristics in the simulator were similar to those of the video game.

-The aim of the explorative third study was to investigate whether there was a correlation between demonstrated simulator performance and the acquisition of theoretical knowledge. The hypothesis was that there would be a correlation.

-Finally, in the fourth study the hypothesis was that surgical simulator performance would correlate with higher intrinsic motivation to train that specific task. Furthermore the aim was to examine how important intrinsic motivation and self-determination are for simulator performance in comparison to video gaming experience and visual-spatial ability. An additional hypothesis was that higher self-determination and intrinsic motivation would correlate with a preference to choose a surgical specialty in the future. Also, it was examined whether simulator training could increase the interest in choosing that same work field. Due to the graphic psychomotor-based similarities between surgical simulation and certain video games it was examined whether there was a correlation between video gaming experience and intrinsic motivation to train a specific surgical task.



## 2 MATERIALS, METHODS AND RESULTS, CHAPTER 2

### Materials and methods

#### *The subjects and setting*

All studies were conducted at the Center for Advanced Medical Simulation and Training (CAMST), Karolinska University Hospital in Huddinge, Sweden. This was the location for all simulator training and psychometric testing. Tests for theoretical knowledge were administered at different classrooms/seminar rooms in the hospital. Recruitment of subjects was conducted at Karolinska University Hospital and Karolinska Institutet's Campus in Solna, Sweden. Subjects were training with video games in their respective homes.

All subjects were medical students at Karolinska Institutet. For all studies, exclusion criterion was previous training in a surgical simulator. Subjects were recruited on a voluntary basis through posted advertisements or word of mouth. In study I, twenty-five subjects participated in the study, 14 females and 11 males. Forty medical students participated in study II, 21 women and 19 men. In study III, 166 students were recruited of which 158 remained after exclusion criteria of which 83 were female and 75 were male. In the final study, 30 subjects participated, 12 females and 18 males. Age of subjects ranged from 19-39. Participants are summarized in table 2.

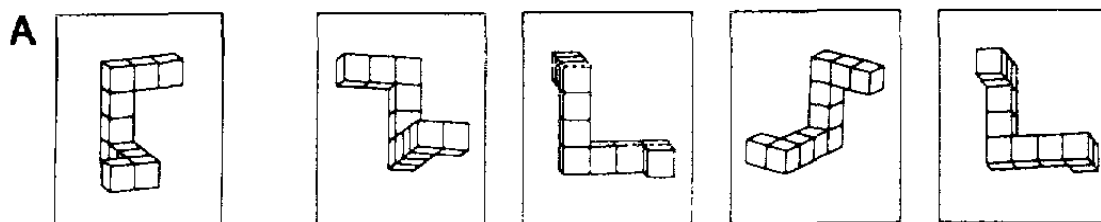
Table 2. Participants.

<b>Study</b>	<b>Total number</b>	<b>Number of female</b>	<b>Number of male</b>	<b>Semester in medical school</b>
<b>I</b>	25	14	11	8/11
<b>II</b>	40	21	19	5-7/11
<b>III</b>	158 (25 from study I, 40 from study II)	83	75	8/11
<b>IV</b>	30	12	18	1-11/11

### *The tests and tools*

In order to test for visual-spatial ability, a version of the original Vandenberg and Kuse test [83] called mental rotations test A, MRT-A, was used. The test is considered to measure high-level visual-spatial ability. The test consist of 24 target figures that subjects need to match with the two correct corresponding stimulus figures that are available out of four options. Subjects are given three minutes to complete as many correct answers as possible. The score of 1 is given for every two correct answers; hence the maximum result is 24. To solve the task, subjects need to mentally rotate the figures along the vertical axis thus testing their visual-spatial ability. The MRT-A test has been correlated to simulator performance in previous studies [84] using a validated simulator and was shown to have the strongest correlation to a surgical task in the study in 2002 by Wanzel [61]. The MRT-A test was used in study I, II and IV, an example of the test is illustrated in figure 3.

Figure 3. MRT-A [83]. The target is the stimulus on the left and the four test stimuli are to the right.

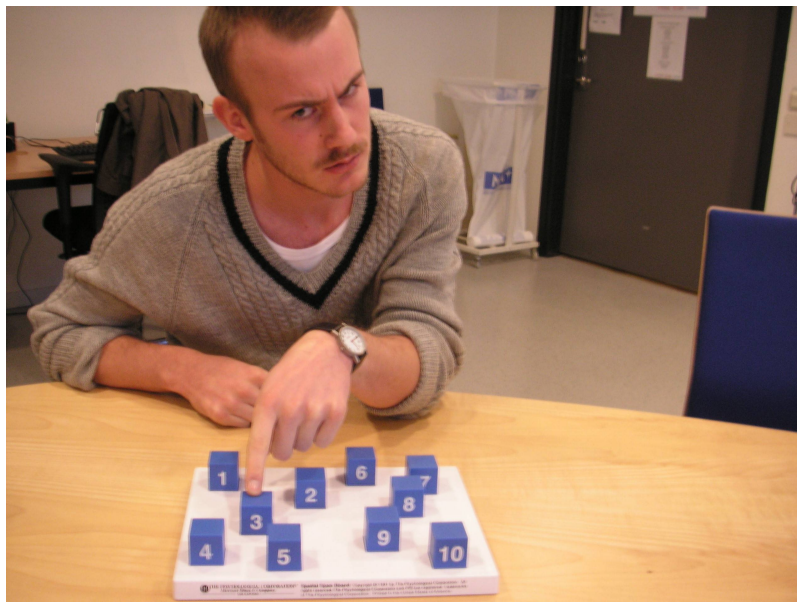


To test for visual working memory a computer program called RoboMemo (RoboMemo, CogMed, Stockholm, Sweden) was used. The program was originally designed for training visual and verbal working memory [85]. The visual tasks of the program were used, namely visual datalink, rotating datalink and 3D cube. In the first task subjects needed to remember and recall the location of lamps that were lit on a grid. The second task was similar to the first with the exception that the grid was rotated. In the third task the lamps were lit in a 3D room. The RoboMemo program was used in study I. Scoring followed the same criteria as used in a previous study by Klingberg [85].

In study II the Wechsler Adult Intelligence Scale (WAIS) III Block repetition test (WAIS-III, Pearson Assessment, San Antonio, Texas) was used to assess visual working memory. The test consisted of 10 blocks spread out on a board and the task at hand was to recall the correct sequence in which blocks are pointed out. The test started with two blocks in a row, followed by three etc. until the subject failed to recall the sequence in two subsequent tries. In the second part the subjects needed to recall blocks but in reverse order. Two scores were given,

one for maximum number of blocks recalled in the first part and one for the maximum number of blocks recalled in the second part. The Block repetition test is illustrated in figure 4.

Figure 4. WAIS-III Block repetition test.



To control for previous video game experience, a questionnaire was used in which subjects estimated their previous video game experience on a 7 points Likert-type scale where 1 corresponded to never playing and 7 corresponded to playing every day. The questionnaire was used in study II and IV.

Motivation was tested using the Situational Motivation Scale, SIMS [86]. It has been developed to measure motivation at the situational level. It taps four types of situational motivation: intrinsic motivation, identified regulation, external regulation, and amotivation. Intrinsic motivation captures participating in a task out of one's own will and interest. Internal regulation applies to tasks done because of a belief they do something good: the motivation coming from within. External regulation makes us do tasks because somebody has told us to do so: the motivation coming from something/somebody else. Amotivation applies to tasks we do not understand the aim and purpose for doing.

SIMS builds on the foundation of self-determination theory [87]. On a 7 point Likert-type scale ranging from 1; "does not correspond at all" to 7; "corresponds exactly". The scale consists of four items for each type of motivation. The scale can also be used to calculate a self-determination index, SDI, ranging from -18 to +18 where a higher value represents a more motivated subject. The index is weighed from the four types of motivation it measures. The SIMS scale has been validated in several studies [88]. It was used in study IV.

In study II, two different video games were used to systematically train subjects. A so-called first person shooter game called Half-Life (Half-Life, Sierra On-Line, Los Angeles) was used. A first person shooter game is characterized by an action plot and where the player navigates in the digital world from a first person perspective. This type of game uses 3D navigation and was therefore presumed to have similar 3D navigational demands as minimal invasive surgery. Half-Life was chosen since it was a popular game with low demands of computer performance and therefore would work on most computers. The other game used for training was Chessmaster (Chessmaster 10<sup>th</sup> ed., Montreuil-sous-Bois, France). The game was chosen since the player did not need to navigate in a 3D environment in contrast to the first person shooter game and was considered to have generally cognitive challenging characteristics.

### *Simulators used*

In study I, II and IV the Minimal Invasive Surgical Trainer Virtual Reality, MIST-VR (Mentice, Gothenburg, Sweden) was used. The simulator was chosen since it has been validated early on [36]. Building on earlier studies for purposes of comparisons, the same task was used as in earlier studies [71, 84]. The MIST-VR is a laparoscopic simulator using relative low-fidelity graphics. The task used in all studies was Manipulative diathermia, level medium (illustrated in figure 6). The task simulates a laparoscopic gall-bladder procedure. The task starts when the subject grasps a virtual ball with the left grasper and then withdraws the right trocar so that it is virtually exchanged to a diathermia rod. The subject then has to use the rod to burn three fictive bleedings while fixating the ball with the left grasper inside a virtual box. The task is then repeated with left hand burning for a total of three sessions per hand. When finished, a total score is given that is based on number of errors and time. Score ranges between 0-700, where a lower score represents a better result.

Figure 5. MIST-VR.



In study II an endoscopic simulator called GI-Mentor II was used (Simbionix, Cleveland, USA). The simulator was chosen due to the graphical content and navigational properties similar to a first-person shooter game. Subjects trained in the task Gastroscopy module I (illustrated in figure 7), in which they performed a simple gastroscopy navigating from the mouth to the duodenum with an endoscope. Performance was measured as the percentage of mucosa inspected and the efficiency that was inspected mucosa in relation to time. The task had previously been linked to visual spatial ability and video game experience [89].

Figure 6. GI-Mentor II. Gastroscopy module I.

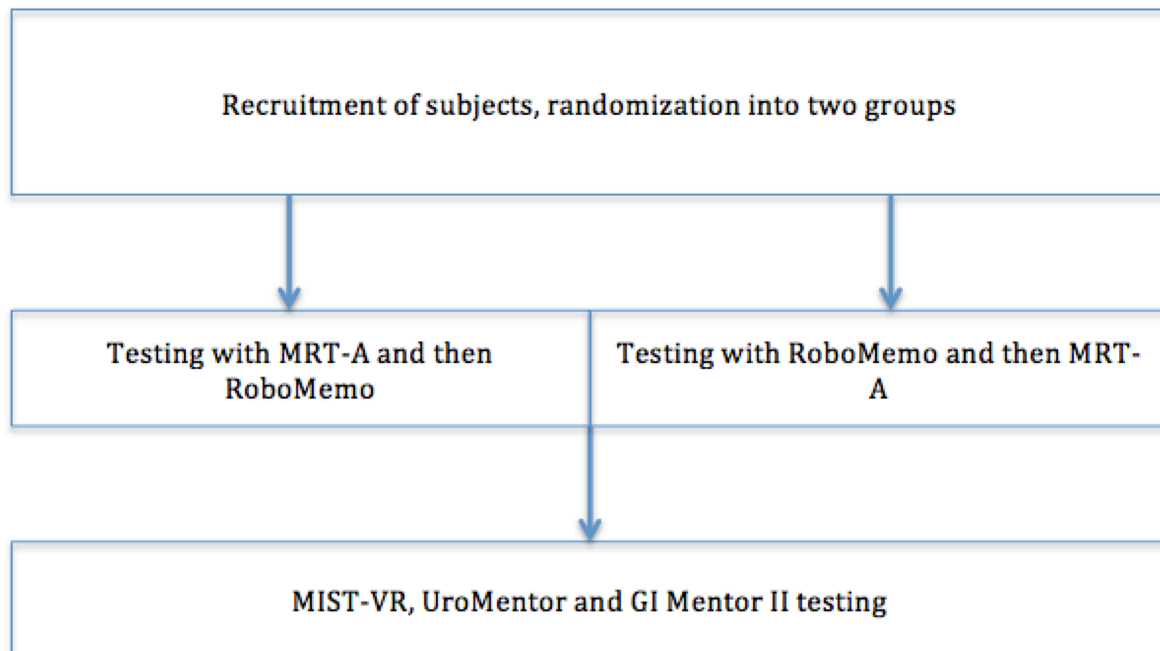


The urological simulator URO Mentor (Simbionix, Cleveland, USA) was used in study I and III. In both studies the task Hall of Fame was used. The task simulates navigation in the urinary tract using a scope with an inserted basket. In a virtual gym hall with connected corridors, the subject collects 13 basketballs and shoots them through a hoop. Performance was measured as total time needed to collect all basketballs.

### *Study design*

In the first study, 25 subjects were randomized into two groups, one starting with testing of visual-spatial ability by the use of MRT-A and then visual working memory testing through the RoboMemo program, the other group was tested in the reverse order. All subjects had completed a questionnaire regarding video game experience. Subjects were then given a standardized oral instruction in the GI Mentor II simulator were they performed the task Gastroscopy module I, and the MIST-VR simulator were they performed the task Manipulative diathermia, level medium. They trained for approximately 60 minutes in each simulator. On a different occasion, subjects were given a standardized oral introduction to the task Hall of Fame in the URO Mentor simulator with which they trained for approximately 20 minutes. After data was gathered, a multivariate ranking analysis was performed to test level of importance of the background variables versus performance in the three different simulators. Variables used were MRT-A score, the three types of working memory tests in the RoboMemo program, total score in the MIST-VR, time in seconds in the URO Mentor and the two different percentage scores in GI-Mentor II. The general design of study I is summarized in figure 9.

Figure 7. Flow chart study I.

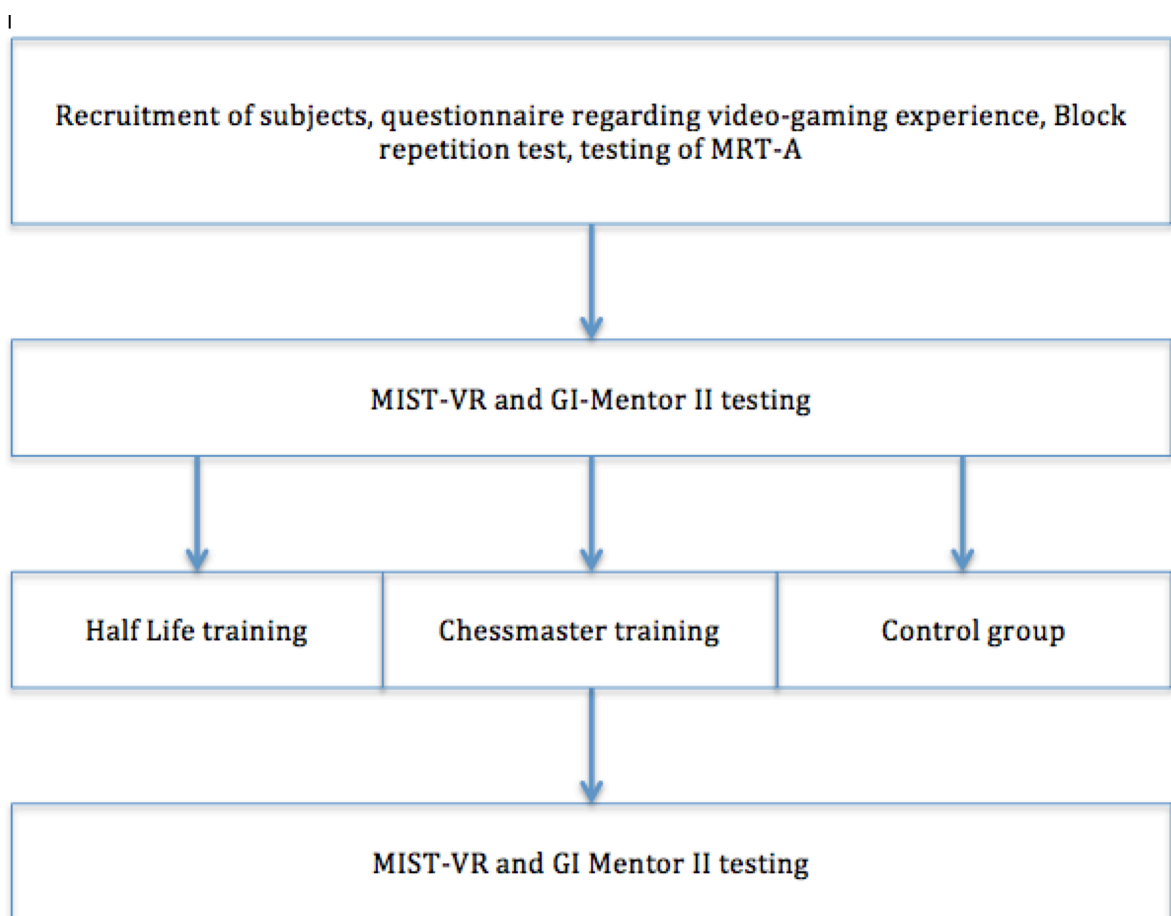


In study II, thirty subjects were matched and randomized to five weeks of systematic video game training in either the first person shooter game Half Life or the chess tutorial game Chessmaster. A control group with no training of 10 subjects was recruited separately. All



subjects were tested with MRT-A to control for differences in visual-spatial ability, and answered a questionnaire regarding video game experience. Subjects were tested pre- and post-training in the MIST-VR simulator were they performed Manipulative diathermia medium and the GI Mentor II simulator were they performed the task Gastroscopy module I. Subjects were given a standardized instruction in each simulator and given a training period of approximately 60 minutes. Pre training results were compared with post training results in all groups. The variables used were total score in MIST-VR and the two different percentage scores in GI-Mentor II. Study II design is illustrated in figure 10.

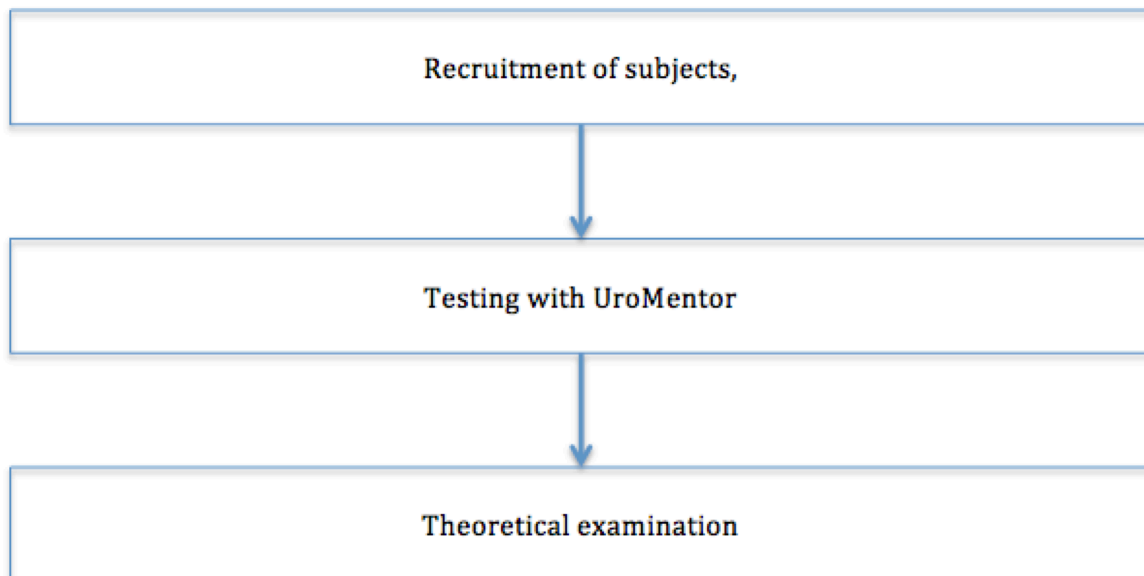
Figure 8. Flow chart study II.



In study III 158 subjects were given a standardized oral instruction regarding the goals of the task Hall of Fame in the URO Mentor simulator. They were then given a training period of approximately 20 minutes. After a period of between 4 and 12 weeks, all subjects took a written examination in basic surgery. The examination consisted of questions in urology, anesthesiology, orthopedics, radiology and general surgery. Overall design of study III is depicted in figure II. Although the specific questions differed from year to year as data was gathered during 12 semesters, the curriculum, the weighing of topics and learning objectives

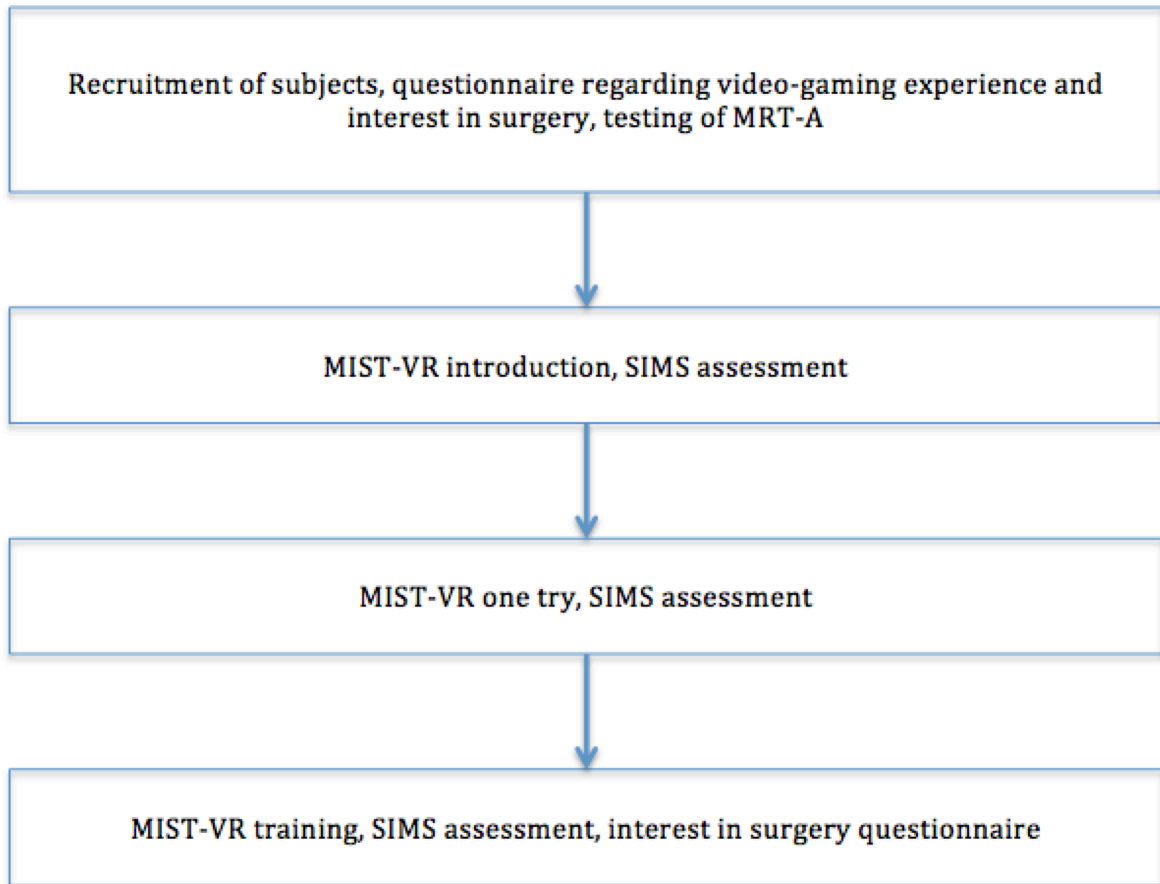
were the same during the entire period. The total percentage of correct answers from the examination was then correlated with total time in seconds in the final simulator test.

Figure 9. Flow chart study III.



In the final study, 30 subjects were recruited. All subjects were tested with MRT-A to assess visual-spatial ability. They answered a video gaming experience questionnaire and a questionnaire regarding interest in surgery as a future choice of specialty. They were then given an oral standardized instruction in the MIST-VR simulator and the task Manipulative diathermia level medium. Subjects then rated their motivation towards training in the simulator by using SIMS. Subjects then had one try in the simulator and then completed the SIMS, this time reflecting over their training in the simulator. Subjects were then given a training period of approximately 30 minutes. After the final try, they once again completed the SIMS and also the earlier completed form regarding interest in surgery. Correlations were then tested between motivation and simulator performance, video gaming experience and interest in surgery. A multivariate analysis was performed to test the level of importance of motivation, visual-spatial ability and video gaming experience in relation to simulator performance. As in previous studies, simulator performance was measured with total score for the task Manipulative diathermia level medium. The design of study IV is illustrated in figure 12.

Figure 10. Flow chart study IV.



Subjects were divided into female/male groups and into low/high video gaming experience groups when performing statistical analyses. The cut off for video gaming experience was set at 1-3 for low video gaming experience and 4-7 for high video gaming experience on the self-rated Likert-type scale.

The overall design of the thesis is summarized in table 3.

Table 3. Thesis design.

<b>Study</b>	<b>I</b>	<b>II</b>	<b>III</b>	<b>IV</b>
<b>General aim and research question</b>	Does the importance of VSA and VWM differ according to different task content?	Is there a transfer effect from video-game training and does it vary depending on video game content?	Does simulator performance correlate to the acquisition of theoretical knowledge?	What is the role of motivation for simulator performance?
<b>Total subjects</b>	25	40	158	30
<b>Simulators used</b>	MIST-VR, URO Mentor, GI-Mentor II	MIST-VR, GI Mentor II	URO Mentor	MIST-VR
<b>Psychometric tests and questionnaires</b>	RoboMemo, MRT-A	WAIS-III Block repetition test, MRT-A	Basic theoretical examination surgery	MRT-A, SIMS
<b>Statistics performed</b>	Multiple stepwise regression analysis	ANOVA, Pearson correlations, pairwise t-test	Regression analysis, pairwise t-test	Regression analysis, pairwise t-test
<b>Training tools</b>	-	Chessmaster 10 <sup>th</sup> Edition and Half-Life video games	-	-

### *Statistics*

All analyses were carried out by use of the SAS system (SAS Institute Inc., Cary, NC, USA), and the 5% level of significance was considered. In the case of a statistically significant result, the probability value (p value) has been given. The descriptive statistics to summarize the background variables and single Pearson product correlation tests in study I and background variable correlations to simulator performance in study II were performed using Sigma Stat 3.5 (Systat, San Jose, CA, USA).

In study I, in order to rank the importance of the background variables with simulator performance a regression analysis was used. Spearman correlation coefficient was used in order to test independence between variables. The prognostic power of the different variables was compared by means of multiple stepwise regression analysis.

Repeated measurements analysis and multiple comparisons by analysis of variance (ANOVA) were performed in study II. When a statistically significant result was found in the ANOVA, Dunnett's post-hoc test was used to test differences in the two experimental groups using the procedure proposed by Fischer [90]. Post-training improvement was measured with a pairwise t-test.

In study III and IV, normal distribution was validated using the Shapiro-Wilks test and then differences between two independent groups was tested using students t-test. Regression analysis was made to test dependence of the variables and Pearson correlation coefficient tested independence between variables. To evaluate hypotheses of variables in contingency tables in study III, the chi-squared test was used or, in the case of small expected frequencies, Fisher's Exact Test.

### *Ethical considerations*

All studies were approved by the local/regional ethics committee of Karolinska Institutet (study I; 358-02, study II; 2007/427-32, study III; 2010/1171-32, study IV; 2011/752-32). Participation was voluntary and associated with an informed consent. Confidentiality was fulfilled. There were no conflicts of interests between participants and examination grades or the research teams.

## Results

### *Results study I*

In the multivariate analysis there were different results for different tasks. In the GI Mentor II task only MRT-A correlated with Efficiency of screening ( $p = 0.006$ ). When looking at Surface examined no significant correlations were found. Total time correlated with MRT-A scores ( $p = 0.01$ ). In the MIST-VR simulator, MRT-A score was the only significant variable ( $p = 0.02$ ). In the URO Mentor simulator, Total score correlated with MRT-A score ( $p = 0.004$ ) and the 3D cube test ( $p = 0.02$ ).

When analyzing background factors (table 4) to simulator performance independently from each other, MRT-A showed correlations to all simulator performance measurements except Surface examined in the GI Mentor II simulator. The Visual data link test correlated with Total score in the MIST-VR simulator and the URO Mentor simulator. The 3D cube test correlated with Total score in the URO Mentor simulator.

Table 4. Background factors vs. performance in study I.

Simulator variable	MRT-A	Visual datalink span score	Rotating datalink span score	3D cube test span score
GI-Mentor II, efficiency of screening	<i><math>p = 0.006, r = 0.55</math></i>	$p = 0.25, r = 0.26$	$p = 0.0513, r = 0.41$	$p = 0.87, r = -0.04$
GI-Mentor II, surface examined	$p = 0.23, r = 0.30$	$p = 0.13, r = 0.33$	$p = 0.87, r = -0.04$	$p = 0.29, r = 0.23$
MIST-VR, total score	<i><math>p = 0.02, r = -0.45</math></i>	<i><math>p = 0.04, r = -0.41</math></i>	$p = 0.30, r = -0.22$	$p = 0.98, r = 0.01$
Uromentor, total score	<i><math>p = 0.004, r = 0.56</math></i>	<i><math>p = 0.01, r = 0.50</math></i>	$p = 0.75, r = 0.07$	<i><math>p = 0.02, r = 0.45</math></i>

\* Values in italics are significant correlations

## Results study II

There was a transfer effect of training with either one of the video games when looking at Total score in the MIST-VR simulator. There was no improvement in the control group. Simulator improvement is summarized in table 5.

Table 5. Simulator improvement in MIST-VR in study II.

Group <sup>b</sup>	Mean score pre-training	Mean score post-training	Difference of means	P value	95% confidence limit
HL	160.86	94.29	-66.57	0.035*	-5.24 to -127.89
CM	192.40	135.63	-56.77	0.008*	-17.56 to -95.97
Cont.	138.03	109.63	-28.40	0.13	10.51 to -67.31

<sup>a</sup> A lower score represents a better performance

<sup>b</sup> HL indicates training in the video game Half Life,  $n = 15$ ; CM indicates training in the video game Chessmaster,  $n = 15$ ; Cont. indicates the controls, who received no training,  $n = 10$

\*  $P < 0.05$

When looking at the GI Mentor II simulator (table 6 and 7), only the Half-Life training group showed improvement both when looking at Efficiency of screening and Surface examined.

Table 6. Simulator improvement GI-Mentor II, Efficiency of screening in study II.

Group <sup>b</sup>	Mean percentage pre-training	Mean percentage post-training	Difference of means	P value	95% confidence limit
HL	85.80	91.47	5.67	0.009*	1.69-9.65
CM	88.13	88.80	0.67	0.67	-2.57-3.90
Cont.	85.00	89.60	4.60	0.07	-0.38-9.58

<sup>a</sup> A higher percentage represents a better performance

<sup>b</sup> HL indicates training in the video game Half Life,  $n = 15$ ; CM indicates training in the video game Chessmaster,  $n = 15$ ; Cont. indicates controls, who received no training,  $n = 10$

\*  $P < 0.05$

Table 7. Simulator improvement GI-Mentor II, Surface examined in study II.

Group <sup>b</sup>	Mean percentage pre-training	Mean percentage post-training	Difference of means	P value	95% confidence limit
HL	82.40	87.0	4.60	0.039*	0.28-8.92
CM	84.27	85.93	1.67	0.20	-1.01-4.34
Cont.	84.80	85.30	0.50	0.79	-3.70-4.70

<sup>a</sup> A higher percentage represents a better performance

<sup>b</sup> HL indicates training in the video game Half Life,  $n = 15$ ; CM indicates training in the video game Chessmaster,  $n = 15$ ; Cont. indicates controls, with no training,  $n = 10$

\*  $P < 0.05$

Like earlier studies have shown, previous and present video game experience showed three significant correlations (table 8) with performance scores in both simulators.

Table 8. Video game experience vs. simulator performance in study II.

Self-reported video game experience	Simulator test	<i>k</i> value	<i>P</i> value
Current age	GI Mentor—efficiency of screening, pre-training	0.35	0.03
Age 7–12	GI Mentor—efficiency of screening, pre-training	0.32	0.04
Age 13–18	MIST-VR—total score, pre- training	–0.33	0.04

Previous videogame experience was evenly distributed in the various groups. The only significant difference in background factors (table 9 and 10) was that the control group had a higher MRT-A score ( $p = 0.006$ ).

Table 9. Background factors in study II.

Group	Game play current	Game play age 1–6	Game play age 7–12	Game play age 13–18
Half Life, $n = 15$ , mean (SD)	2.67 (1.88)	1.33 (0.82)	4.33 (1.76)	3.93 (1.58)
Chessmaster, $n = 15$ , mean (SD)	2.60 (1.18)	1.67 (1.05)	4.60 (1.64)	4.40 (1.64)
Control, $n = 10$ , mean (SD)	2.00 (0.82)	1.30 (0.68)	5.00 (1.70)	4.50 (1.58)

Game-play self-rated on a scale of 1–7: 1 = never playing, 2 = playing very seldom, 3 = playing once every month, 4 = playing several times a month, 5 = playing once a week, 6 = playing several times a week, 7 = playing every day. There were no significant differences between the experimental groups because the groups were matched before randomization

Table 10. Background factors in study II.

Group	Block repetition forward	Block repetition in reverse	MRT-A
Half Life, $n = 15$ , mean (SD)	9.47 (1.60)	9.60 (1.18)	6.62 (1.81)
Chessmaster, $n = 15$ , mean (SD)	9.60 (2.38)	10.07 (1.28)	4.92 (1.85)
Control, $n = 10$ , mean (SD)	11.20 (1.62)	10.40 (1.65)	8.80* (1.55)

<sup>a</sup> Visual working memory was measured with the WAIS-III Block Repetition test, and visual-spatial ability was tested with MRT-A (Mental Rotations Test, version A)

\*  $P < 0.05$

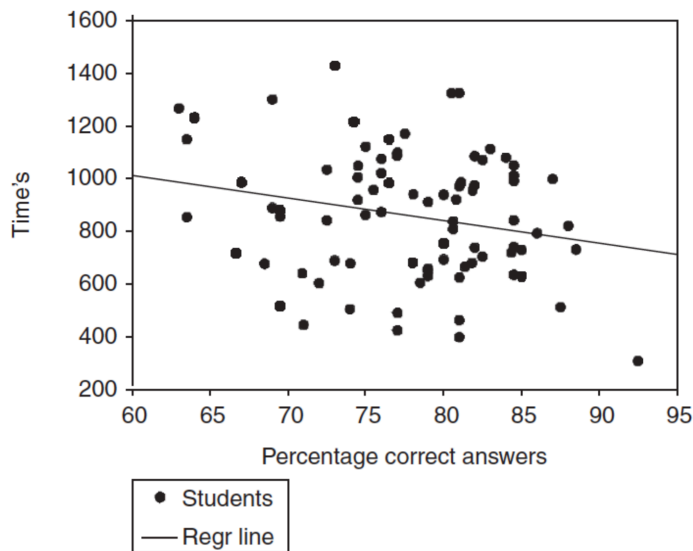


### Results study III

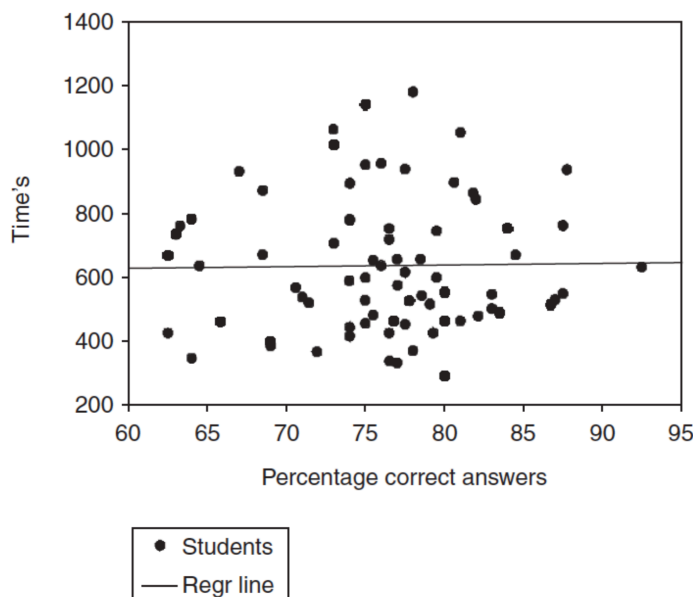
There was a statistically significant difference in the task Hall of Fame between male and female students in total time,  $s$  ( $p = 0.0001$ ,  $-222.9$ ). There were no statistically significant differences regarding age or theoretical examination results. There was no statistically significant correlation between surgical simulator performance and the theoretical examination when looking at the total study population ( $p = 0.58$ ,  $r = -0.04$ ) or when looking at male medical students ( $p = 0.9$ ,  $r = 0.01$ ). In female medical students there was a significant correlation ( $p = 0.04$ ,  $r = -0.22$ ). Male and female student correlations are illustrated in figure 13.

Figure 11. Theoretical examination scores vs. simulator performance measured in time,  $s$ .

(a) Female students



(b) Male students



There were significant differences between gender regarding total time in the first ( $p = 0.001$ ,  $-153$ ), second ( $p = 0.001$ ,  $-228.8$ ), the third ( $p = 0.001$ ,  $-268.8$ ) and fourth ( $p = 0.001$ ,  $-231.8$ ) quartiles when dividing all the students into quartiles according to simulator total time with the first quarter corresponding to the fastest times. Male students were faster in all quartiles. Regarding test percentage, only in the first quartile there was a significant difference, where female students had better results than males ( $p = 0.03$ ,  $-4.16$ ).

#### *Results study IV*

There were no significant correlations between the first simulator trial, intrinsic motivation and level of self-determination (derived from the second SIMS test occasion) when looking at the total population, females or groups divided into high/low video gaming experience. There was a significant correlation for male subjects, where a good result in the first simulator trial correlated with a higher self-determination index ( $p = 0.05$ ,  $r = -0.46$ ). Motivation and simulator performance in the groups is summarized in Table 11, please see the methods section for description of the variables.

Table 11. Motivation and simulator performance in the different groups. Mean values.

<b>Group</b>	<b>Motivation before first try, intrinsic/SDI</b>	<b>MIST VR first try, total score</b>	<b>Motivation after first try, intrinsic/SDI</b>	<b>MIST VR best total score</b>	<b>MIST VR mean total score</b>	<b>Motivation after last try, intrinsic/SDI</b>
<b>Total population, n = 30</b>	5,19/10,84	405,6	5,3/10,88	136,2	190,7	5,61/12,59
<b>Males, n = 19</b>	5,11/10,45	372,3	5,13/10,24	123	161,7	5,46/11,93
<b>Females, n = 11</b>	5,34/11,52	463	5,59/11,98	159,2	176,5	5,87/13,73
<b>Low video gaming experience, n = 12</b>	5,02/11	475,8	5,04/11,1	154,7	222,6	5,42/13,06
<b>High video gaming experience, n = 18</b>	5,31/10,74	358,8	5,47/10,72	123,9	169,4	5,74/12,28

There were no significant results in the multivariate analysis with MRT-A score, intrinsic motivation and video gaming experience in relation to simulator results when looking at the total population. The first simulator trial vs. the second SIMS test as well as the best simulator trial and mean simulator performance vs. the last SIMS test occasion were analyzed. Significant results were found in male subjects. Visual-spatial test score was proven to be the most important underlying factor followed by intrinsic motivation score and finally video gaming experience ( $p = 0.02$ ,  $p = 0.05$ ,  $p = 0.11$ ). The same results were true when including SDI instead of intrinsic motivation ( $p = 0.01$ ,  $p = 0.01$ ,  $p = 0.05$ ). Video gaming experience, visual-spatial ability and self-rated interest in surgery are summarized in Table 12. Please see the methods section for description of the variables.

Table 12. Self rated video gaming experience, MRT-A scores and interest in surgery, divided into groups. Mean values.

<b>Group</b>	<b>Video gaming experience</b>	<b>MRT-A</b>	<b>Interest pre-training</b>	<b>Interest post-training</b>
<b>Total population, n = 30</b>	3,29	7,9	3,91	4,1
<b>Males, n = 19</b>	3,84	8,53	3,76	3,97
<b>Females, n = 11</b>	2,34	6,82	4,16	4,32
<b>Low video gaming experience, n = 12</b>	2,02	7,92	4,02	4,17
<b>High video gaming experience, n = 18</b>	4,14	7,89	3,83	4,06

A higher interest in surgery and expressed wish to choose a surgical specialty as a future specialty correlated with a higher level of self-determination, both before ( $p = 0.03$ ,  $r = 0.39$ ) and after training ( $p = 0.03$ ,  $r = 0.46$ ) when looking at the total population. No similar correlations were detected in the subgroups except among females where a high interest in surgery correlated with a low intrinsic motivation to train before but not after training ( $p = 0.01$ ,  $r = -0.74$ ). Interest in surgery increased by simulator training when looking at all subjects ( $p = 0.01$ ), male subjects ( $p = 0.02$ ) as well as subjects with low video gaming experience ( $p = 0.02$ ).

There was a significant correlation between a higher amount of video gaming and a lower amount of intrinsic motivation ( $p = 0.05$ ,  $r = -0.48$ ) after the simulator introduction in the subgroup with low video gaming experience when investigating the role of video gaming for motivation to train in the simulator before having tried for the first time. There were no correlations in the other subgroups or the whole population.

To detect a correlation between motivation and video gaming in relation to actual training in the simulator video gaming experience, intrinsic motivation and SDI derived from the second SIMS scale test occasion, i.e. after their first trial, was examined. There was a correlation among females, where a high video gaming experience correlated with a higher intrinsic motivation ( $p = 0.05$ ,  $r = 0.6$ ) but a lower SDI ( $p = 0.01$ ,  $r = -0.72$ ). The last result proved to be true also among the low video gaming experience subgroup ( $p = 0.02$ ,  $r = -0.67$ ).

### 3 DISCUSSION AND CONCLUSION, CHAPTER 3

#### General discussion

In study I, the findings implicated that virtual reality surgical simulation tasks with different content challenge visual-spatial ability and visual working memory differently. Visual-spatial ability in surgical novices had a stronger correlation with performance metrics in surgical simulators than visual working memory. These findings were regardless of simulator task content. Of all three simulator tasks, the Hall of fame task in the URO Mentor simulator seemed to be the most challenging regarding visual working memory since the 3D cube test in the RoboMemo program was the second most important variable when looking at Total score. In the URO Mentor task the subjects needed to navigate in a 3D environment, looking for virtual basketballs. It is arguable that this kind of task demands more of a spatially oriented visual working memory, since during the procedure the subject needs to go back and forth through two virtual corridors to collect the virtual basketballs and therefore needs to remember the physical environment. The question is intriguing in light of the recent advances in understanding the spatial representation of the brain where grid cells, place cells and head-direction cells as computational units forming organizational networks have been proven to form organizational networks. Specific maturational programs and experiences may be necessary for the development of an adult map-like organization [91].

At first, working memory was believed to be static. Researchers of recent years have suggested that there is a plasticity of neurons of areas in the brain associated with working memory and that mental exercises and training can enhance working memory capacity [92]. The discoveries of these findings indicate that there might be an opportunity to enhance the performance in image-guided interventions using similar training methods. Reviewers have stressed the fact that future research is needed since studies often are characterized by the tendency of researchers to define change to abilities using single tasks, inconsistent use of valid working memory tasks, no-contact control groups and subjective measurement of change [93]. It seems visual-spatial working memory is easier to maintain by training in relation to verbal working memory, but that training effects appear to be task specific and do not generalize working memory to other skills [94]. Nonetheless, if such a training regime would be pursued, study I implies that such a regime needs to be customized in accordance to the content of the specific tasks the surgeon undertakes.

Studies investigating training of visual-spatial ability deliver some mixed results. The answer whether specific visual-spatial training leads to a generalized improvement of visual-spatial ability ranges from transfer of training to new stimuli within the same task [95], new stimuli within similar tasks [66] and no transfer to other tasks [96]. A study performed in 2008 showed that an actual training effect on general visual-spatial ability can be achieved [97]. Visual-spatial ability appears to be highly relevant for minimal invasive surgery, recent

findings regarding training of that ability offers some promising possibilities of future surgical training.

The results of the first study highlighted the need for customization and the possibility of non-conventional training in order to enhance abilities needed for minimal invasive surgery. Since several previous studies had shown that there is a correlation between both previous video game experience and demonstrated video gaming skill [75, 89] in relation to simulator performance, in study II the aim was to take this information further and synthesize these findings with the discoveries made in study I. In theory video gaming might improve the working memory and visual-spatial abilities needed for high performance. Action gaming has been proven to enhance visual-spatial attention throughout the visual field [98]. Recently it has been shown that playing a first-person shooter video game alters the neural processes that support spatial selective attention and that there is a causal relationship between playing a first-person shooter game and neuroplastic change [99]. The same study stated that individual variations in learning were observed suggesting that not all game players benefit equally [99]. Furthermore, research has implied that training specific cognitive abilities frequently in a video game improves performance in tasks that share common underlying demands, this effect does not transfer to more general cognitive systems [100]. A recent study suggests that visual working memory capacity can be increased after action video game training as compared with training on a control game [101]. Playing an action video game can decrease the gender difference in mental rotation ability [102]. By 10 hours of training with an action video game, subjects increased spatial attention and mental rotation, with women benefiting more than men. Control subjects who played a non-action game showed no improvement [102].

The question was asked whether it is actually possible to improve performances in a surgical simulator by training with a video game. Also, since it was shown that the importance of abilities in relation to simulator performance differed depending on task content, might the same be the case with video game content? Therefore a prospective randomized study comparing the possible transfer effect of a systematic five-week training program in either of two different video games to the performance in two validated virtual reality endoscopic surgical simulators was conducted. Half Life was chosen for one of the experimental groups because it has similarities with virtual endoscopy where navigation is a key element in performance scores. Chessmaster was chosen for the other experimental group because the task is not loaded with visual navigation but rather with general cognitive load and strategy. The training period of 5 weeks was chosen based on the results by Klingberg [85] using the same amount of time and it has been proposed by other authors to enhance sensory discrimination and induce cortical plasticity in sensory and motor cortices [103].

In study II, positive training effects were observed regarding transfer to the MIST-VR task regardless of whether systematic training was performed in the video games Chessmaster or Half-Life. In contrast only the group training Half-Life showed significant improvement in the GI Mentor II variables. The reference group showed no improvement after the 5 weeks

period. The results give rise to two important conclusions; first of all, it is actually possible to get better in surgical simulation simply from playing certain video games, and secondly, video game content is important for the effectiveness of the training period. Once more, findings highlight the need for customization when conducting non-conventional surgical training targeted at the governing abilities important for surgical performance.

The possibility to train minimal invasive surgery through video games opens up for new training regimes. The findings show the potential of video games as training tools to enhance the acquisition of basic technical skills needed in at least virtual reality surgical simulation. Traditional virtual reality simulators for image-guided surgery usually cost millions of dollars to develop and deploy. The cost for video game training would be a fraction of that and with the use of open source engines and alike, development and customization could be easily conducted. The term serious game is used for video games that are designed not with a pure purpose of entertainment, e.g. educational games. In a recent meta-analysis of the effectiveness of serious games, the most frequently occurring outcomes were knowledge acquisition and content understanding, which were typically present in games for learning and affective and motivational outcomes, which were typically present in entertainment games [104]. In another meta-analysis learners in serious games learned more relative to those taught with conventional instruction methods when the game was supplemented with other instruction methods during multiple training sessions working in groups [105]. An interesting issue concerning educational games has been raised recently regarding so called gamer mode, which is described as a tension between adhering to the rules of the game or the fictional aspects of game play [106]. In practice this is represented as either focusing on trying to win the game based on the rules and scoring and on the other hand imagining game play as a real life scenario and acting accordingly [106]. Gamer mode has to be taken into account when training with game like scenarios.

Needless to say, one does not become a surgeon only by playing video games, but study II showed a serious potential of such technical skills training and the importance of customizing the video game training according to content. Video game training could be a supplement to conventional training for the acquisition of certain skills. Recently, a laparoscopic video game for Nintendo Wii has been validated [107]. In relation to the discussion of working memory training and visual-spatial ability training associated with study I, it has been shown in 2013 that by 30 min video game training every day for 2 months with a 3D platform game, there was an increase in gray matter in three different parts of the brain visualized by MRI [108]. The affected areas have been associated with spatial navigation, working memory, motor performance and strategic planning [108]. In study II subjects trained for 5 weeks, 30 min per day. If that amount would lead to gray matter changes remains unanswered since subjects were not scanned.

In study II two video games with different content were selected in an attempt to analyze the importance of content regarding visual navigation for a transfer effect to occur. Quite surprisingly, in the MIST-VR simulator both the Half Life group and the Chessmaster group

showed a significant transfer effect. These findings could be underpinned by the general cognitive load when training with both Half Life and Chessmaster in contrast to the higher load of visual navigation present only in Half Life that also did improve training in the GI-Mentor II simulator. The finding is interesting in the light of Greens study which was a follow-up to a former study in which they found that gamers had higher visual attention, enumeration ability, spatial distribution, task switching and the ability to take in peripheral details while focusing on a task than non-gamers [98]. In the subsequent study subjects training in either a first person shooter game or the classic 2D game Tetris were tested with the same test. Authors found that both groups actually improved their results, although the first person shooter group had a greater improvement. The improvement in the Tetris group supposedly came from the cognitive workload associated with training [109].

The finding gave rise to the research question asked in study III. If there were a general workload from the video games that can explain improvement in the simulator, would also the workload associated with the acquisition of theoretical knowledge have an effect on simulator performance and vice versa? In study III, simulator performance scores were correlated to examination results.

There was no clear correlation between simulator performance and theoretical knowledge in this study in the general study population. On the other hand, the study might have had a different outcome had it been designed as a training study equal to study II with a randomization process into a study group/non-study group and testing in simulators pre- and post-training. Currently, the selection process for general surgery residents in the US and Canada is somewhat obscure. In a study investigating the orthopedic selection process authors [110] found fair or poor correlations between the residents' initial rankings assessed by four experts, rankings on graduation based by the same four experts, and their USMLE, American Board of Orthopedic Surgery (ABOS), and Orthopedics In Training Exam (OITE) scores. The only relatively strong correlation found was between the OITE and ABOS scores. Despite the faculty's consensus regarding selection criteria, interviewers did not agree in their rankings of residents on graduation [110]. In a recent study authors concluded that although general surgery programs have a wide range of screening/selection criteria, the USMLE Step 1 was the single most important factor for preliminary screening. The interview was the most important factor in determining the final selection, which was rather subjective [111]. The USMLE scores and academic grade performance has been proven to be very predictive of subsequent formalized testing such as American Board of Surgery In Training Examination [112, 113] but poorly predictive of resident clinical performance [113].

It seems that selection criteria for surgeons is characterized to a large extent on academic results, which on other hand has no clear correlation to actual operational skills. On the other hand, to be a good surgeon requires several abilities ranging from knowledge and manual dexterity to judgment and communication. One could argue though that academic record has to be weighed with other factors when recruiting surgeons. It has been suggested that testing for important abilities needed should be conducted already in early stages of medical



education [114] since the impact of aptitude for learning has been proven to be of such importance for learning [67]. In study III medical students was examined and not residents in surgery. The experiment was conducted on surgical novices, and in this context there was no clear correlation between simulator performance and theoretical knowledge.

Although no clear correlations in the general study population were found between simulator performance and examination results, it did give some interesting results regarding gender differences. Performance in the URO Mentor simulator predicted the level of theoretical knowledge in basic surgery in female but not in male medical students. Male students performing worse on the theoretical examination 4–8 weeks after the simulator test performed equally as well in the simulator with male students performing well or excellently on the theoretical test. This contrasts with the results achieved by the female students, where poor simulator results correlated with poor examination results. It is possible that a low performance score in the simulator affects the individual student in a negative way, inducing non-productive learning behavior towards the examination in the basic surgical sciences. In this case, male students did not seem as affected as female students in this aspect. Influence of the tutor's role on the different students can only be speculated about; however, the strength of the study is that every student had the same instructor. The finding implies that an effort to increase female students' simulator performance may affect knowledge acquisition within the basic surgical sciences; the effect of using a male instructor was not controlled for.

Male students had a faster completion time in the urological simulator task. As the simulator test in this study measured only total time and no other metrics such as trauma, smoothness and perioperative bleeding it is possible that female trainees work more slowly but more carefully and with fewer risks reflected in the results.

Motivation may drive the acquisition of surgical theoretical knowledge and practical skills. This would explain the correlation found in female medical students. It could be that highly motivated students achieve higher scores on the surgical simulator test and also study more intensively for the theoretical examination. It was suspected that some of the findings in study III were connected to motivational factors, which led to study IV. The focus of study IV was on motivation as a factor for performance. Motivational work is being conducted in areas such as natural decision-making, wellbeing, social influence and achievement. The area of achievement includes research on activity engagement, learning, and performance. SDT has become a major theory of human motivation in contemporary psychology [87]. SDT distinguishes between different types of motivation based on the different goals that give rise to a specific action. Intrinsic motivation refers to performing an activity for itself and the pleasure and satisfaction following this activity, external motivation implies being engaged not for its own sake but as a means to an end, and finally amotivation alludes to the relative absence of motivation. Social factors (such as rewards, competition, verbal feedback, and choice) can influence individuals' situational motivation and lead to situational consequences that can be affective, cognitive and behavioral in nature [115].

According to SDT, self-determination involves a true sense of feeling free in doing what one has chosen to do. It suggests that behavioral regulations, in this case reasons for participating in simulator training, can be ordered on a continuum according to the extent to which motivation is self-determined (autonomous). In study IV, measuring students' situational motivation toward their training was in focus.

There were no correlations to performance in the general study population, although there was a significant correlation in the male subgroup. As seen in study III, gender differences were found. One can only speculate why this correlation was found, e.g. if female students need less motivational incentives to perform. The sample when divided into subgroups turns quite small and therefore findings should be interpreted carefully. A recent study concluded that men reports more competitiveness on validated instruments, even in selective sub-populations such as intercollegiate distance runners [116]. In the gender difference study of mental rotation ability by de Lisi, male and female subjects were randomized into video game training either with a video game that had mental rotation characteristics or a video game without these characteristics. Interestingly female subjects in both groups increased their mental rotation ability pre and post testing in contrast to male subjects who only improved results in the group that trained with the first type of video game [66]. Apparently female subjects are affected differently than male subjects by training with the same video game, authors speculate that non-cognitive contextual factors such as the way instructions are given affect visual-spatial performance differently according to gender [66].

As one might assume beforehand, subjects highly interested in becoming surgeons experienced a higher level of self-determination during training. This is quite interesting considering a reference study by Hochberg in which authors conclude "Surgical residents make their career choices at a statistically earlier time than their resident colleagues in emergency medicine, internal medicine, obstetrics and gynecology, pediatrics or psychiatry. The majority of surgical residents have made this decision even before entering medical school. The implications for both future surgeons and surgical educators are important and exciting. Clinical, operative, and research experiences in surgery can be offered to those committed to surgery at an extremely early stage in medical school. The benefit would be that these young men and women would bring enhanced knowledge, skills, and experience to their 1st year of surgical residency" [117]. Furthermore, van Dongen showed in 2007 that when residents are given unlimited training time in a simulator they will not take advantage of the opportunity, a majority explained that they lack time for training due to high work pressure. When adding a competitive element there was only a minimal increase in training time [42]. That finding is interesting in relation to study IV and suggests that medical students interested in surgery take great pleasure in training in a surgical simulator and simulator training increases interest in surgery, but when the student becomes a resident the harsh reality of work environment alters that motivation.

Quite surprisingly, there were no positive correlations between simulator training and motivation from a video gaming experience perspective. In the study the validated MIST-VR

simulator was chosen. The simulator uses very basic anatomical graphics, considering the high degree of realism and extraordinary graphics of current videogames the simulator used in this study might have been a disappointment in light of the putative expectations. Therefore, results might have been different if a simulator with more explicit graphics had been chosen.

In the multivariate analysis visual-spatial ability was proven to be more important than motivation for performance. The importance of visual-spatial ability has been highlighted in various earlier studies [62]. Simulator training made students more interested in choosing surgery as a future specialty, which implies the importance of incorporating simulator training in medical school.

Since a long time ago, in high reliability organizations such as military and aviation, virtual reality simulation is an unquestionable part of training. The constant development of information technology and more advanced surgical techniques will require more sophisticated learning regimes. With the digitalization of the post-modern world, the explosion of social media and the steady implementation of serious games, it is inevitable that medical training in general and minimal invasive surgery training in particular will evolve over the next years to come. Smartphones, online gaming and limitless information have formed the students entering medical programs today. Great difficulties are associated with implementing standardized virtual reality simulator training. In order to meet the requirements of tomorrow's surgeons research must focus on what works and why, taking surgical training to the next level.

Figure 12. Tomorrow's surgeons.



## *Limitations*

A limitation of studies I, II and IV is the relatively limited number of subjects and that only surgical novices were studied, although in study IV there was a selection of highly motivated students. However, the subjects were all novices with a similar background and all attended the medical program at Karolinska Institutet. Medical students were chosen in order to study innate abilities rather than acquired surgical abilities. The aim thus was not to estimate how the variables examined would affect expert performance, since only surgical novices and virtual reality surgical simulators were studied. Another limitation is the fact that surgical simulators were used and not real minimal invasive surgery. Due to this limitation, only validated simulators were used and throughout the thesis the same tasks were used in the different studies.

Furthermore one might raise the question what is really measured in the surgical simulators. Authors have found these metrics to have very limited concurrent validity; differences between experts and novices were found for only 3 of 14 [118] and 2 of 8 analyzed parameters [119]. In both studies, time has been considered to be a validated metric. Time has been included in measuring performance in all three simulators used throughout the thesis.

In study III, time passing between the simulator testing and the final examination was quite long and varied between students. In general, students acquire a great part of their theoretical knowledge during the final weeks before examination.

In study I three different instructors participate, one for each simulator. In the three subsequent studies a single instructor was used. Several studies have shown that role and characteristics of the instructor probably plays a great part for skill retention and motivation. In one study there was no clear evidence that faculty-directed training improved transfer of learned surgical skills to more complex tasks in comparison to self-regulated learning [120]. Earlier studies have shown for example that video-based coaching enhanced the quality of laparoscopic surgical performance on both VR and porcine samples but leads to increased time [121]. Research has proven feedback to be of vital importance [33] and that simulator training without it might have limited effect [81]. Interestingly, procedure-specific qualitative metrics are improved with expert feedback, but non-expert facilitators can also enhance the quality of training [122]. Ahlberg has shown that when teaching laparoscopic skills the single most important factor is the teacher's competence [123]. Although feedback has been proven to be of vital importance, little do we know of how to give feedback in an optimized way [124]. In the conducted studies of this thesis, feedback was limited to a minimum and subjects mainly received their information of progress from the simulator performance scores.

When evaluating the results of these studies one must not forget the importance of knowledge, attitudes, behaviors, and other cognitive factors such as decision-making. In a recent study authors found when examining the attitudes of orthopedic surgeons in Europe, the US and Canada that macho attitudes were fairly prevalent, attitudes that are considered to

be dangerous and associated with greater risk in the aviation industry [125]. Findings of the importance of visual-spatial ability, video gaming skills etc. have to be considered in light of the complex array of abilities that constitute a good surgeon. The key to successful minimal invasive surgery starts with identifying the patient that would benefit from the operation. The old saying “The operation was successful but the patient died”, was coined one hundred years ago and still has relevance. Surgical simulation is a promising technology to offset many challenges, but it is not a total remedy. It represents a complementary tool for clinical training.

### *Future perspectives*

In order to design future training regimes for minimal invasive surgery, one must consider the contextual characteristics associated with different tasks to be trained. Future research could be targeted at the question of why some of the simulator tasks are more 3D challenging than other and whether specific 3D working memory as well as visual-spatial ability challenging training could further improve performance in these tasks. Regarding video-gaming training, future studies could focus on the required amount of time as well as finding the right components needed for a video game to be effective. Furthermore, as a game is characterized by voluntary, nonproductive time in the real world and work is the direct opposite, there will be difficulties in designing an instructional program with game features [126], which could be taken in consideration when designing and validating future training regimes. Further the question whether surgeons should be certified/recertified based on e.g. vision such as in the aviation industry should be discussed, the specific tests could also be a target for future research.

Operating room vision will probably be a future topic considering the difficulties associated with the 2D monitor. Future means of vision could include 3D representations moving vision beyond the boundaries of the conventional monitor.

Since surgical performance is not a one-person effort, OR work consists to a great extent of teamwork, virtual reality simulations incorporating teamwork is an interesting field were the first steps already have been taken [127].

The benefit of this research would be an array of alternate training methods for surgeons, enabling safer surgery for the benefit of patients and thus contributing to health care in the becoming of a high reliability organization.

## Conclusions

-In the first study, it was proven that virtual reality surgical simulation tasks with different content challenge visual-spatial ability and visual working memory differently. Visual-spatial ability in surgical novices, as measured with the MRT-A test, had a stronger correlation with performance metrics in surgical simulators than visual working memory as measured with the RoboMemo computer program. These findings were regardless of simulator task content. The URO Mentor simulator task seemed to be the most challenging regarding visual working memory.

-In the second study, it was shown that systematic video game training for five weeks improved performance in the MIST-VR simulator regardless of whether systematic training was performed in the video games Chessmaster or Half Life. In contrast, only the group training Half Life, a more visual-spatially loaded game, showed significant improvement on the simulator and thus a clear transfer effect regarding performance in the GI Mentor II variables.

- The results from the third study showed that performance in the URO Mentor simulator only predicted the level of theoretical knowledge in basic surgery in female but not in male medical students or the general study population.

-Finally, in the fourth study, there was a correlation among male subjects but in no other subgroup between simulator performance and intrinsic motivation. Visual-spatial ability was proven to be more important than motivation for performance while the latter appeared to be more important than video gaming experience. Subjects more interested in becoming surgeons experienced a higher level of self-determination during training and simulator training increased interest in surgery as a future specialty. There were no positive correlations between motivation to train in a simulator and video gaming experience.

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Figure 13. Future surgical training?

**The Next Level**  
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The advertisement features a central illustration of a surgeon in green scrubs and a surgical mask, holding two laparoscopic instruments. The background is a stylized, high-tech surgical environment with various medical equipment and structures. The text is bold and clear, with a black bar at the bottom containing the platform availability and an orange box for the age rating.