Designing immersive surgical training against information technology-related overload in the operating room

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Designing Immersive Surgical Training Against Information Technology-Related Overload in the Operating Room

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Proefschrift ter verkrijging van de graad van doctor aan Tilburg University
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Jon Ragnar Pluyter

geboren op 8 mei 1986 te Breda.

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to Oma Tilburg

for always on my mind
and in my heart

It is tragic when a man outlives his body
Sigmund Freud

Anyone who stops learning is old, whether at twenty or eighty
Henry Ford

Acknowledgments

Writing this section in my office while watching the sunset shining above the forest truly completes the four years of writing my dissertation. The end result lying in front of you fills me with joy and makes me very proud. Even more so I enjoyed the road towards it. I believe that what has been written down in this dissertation reflects no more than five percent of what I have learned in between reading the first paper and writing the last word. Along the way I was lucky to meet and have on my side so many people. People that loved me, supported me, provided me with tools and opened doors that I would never have been able to open myself.

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Gert, onze Ajaxied. Bedankt voor je eeuwige assistentie. Wat hebben we een lol gemaakt met het opbouwen en testen van de simulatie opstellingen in die veel te kleine VR3 ruimte! Zoveel kabels had ik nog nooit eerder bij elkaar gezien. Gelukkig kreeg ik tussentijds promotie naar VR2 en kon ik altijd gebruik maken van jouw kantoor. Bakkie koffie? Sonja, Willem, Angelique, Pieter, bedankt voor jullie gulle helpende handen.

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Abstract

Medical Information Technology (IT) and information delivered by medical IT are rapidly becoming the defining elements of surgical procedures. Several examples include image guided technology, navigation technology, communication and patient record systems and surgical robots, to only name a few. These technologies are designed to advance treatment of diseases. However, information delivered by medical IT also imposes an ever-increasing load on the surgeon. IT-related overload has a detrimental effect on performance and stress of the surgeon and therefore patient safety.

This dissertation outlines the theory-driven design of a basic immersive simulation training program as a means to reduce overload in a safe and controlled setting. As opposed to conventional simulation training, immersive simulation training is performed in a realistic technological and social context similar to the context that is encountered in the operating room. Using controlled experimental testing and subjects with no prior experience with simulation training it is demonstrated that immersive simulation training is beneficial in terms of Emotional-Cognitive Overload (ECO) and stress of the participant. Also immersive training increases parts of surgical performance indirectly through its effect on ECO. This dissertation provides evidence that immersive training has potential to improve patient safety in the operating room.

On a theoretical level, this dissertation demonstrates that the “classical” conceptualization of overload in the field of Information Systems being an excessive amount of information is too simplistic. Based on the Emotional-Cognitive Overload Model by Rutkowski and Saunders (2011) this dissertation outlines the importance of the personal mental organization of Long-Term Memory (LTM) and the congruence of the information stimulus with cognitive schemata encoded in LTM.

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List of frequently used acronyms

Information Systems and Technology

IS = Information System
IT = Information Technology

Surgery and surgical simulation

CAS = Computer Aided Surgery/ Computer Assisted Surgery
IGS = Image Guided Surgery
MAS = Minimal Access Surgery
MI-Su = Minimally Invasive Surgery

Laparoscopic Surgery = IGS using a scope in the abdominal or pelvic cavity

OR = Operating Room

AR = Augmented Reality (surgical simulator)
VR = Virtual Reality (surgical simulator)

Overload and human memory architecture

STM = Short Term Memory
LTM = Long Term Memory
EM = Episodic Memory
SM = Semantic Memory

WM = Working Memory

ECO = Emotional-Cognitive Overload
ECOM = Emotional-Cognitive Overload Model
CLT = Cognitive Load Theory
IP = Information Processing

NFC = Need For Cognition
CA with IT = Cognitive Absorption with Information Technology
encodedECO = experience of ECO encoded in episodic LTM

NASA-TLX = National Aeronautics and Space Administration - Task Load Index

1. Introduction

1.1 Overload with information delivered by medical IT

Surgeons are confronted with a congestion of data screens in the Operating Room (OR). These screens deliver medical information (Bitterman, 2006). The screens are part of videoscopic and image guided technology, information-dense anesthetics machines, navigation technology for brain surgery, communication and patient record systems and surgical robots, to only name a few. Medical Information Technology (IT) and information delivered by medical IT are rapidly becoming the defining elements of surgical procedures (Jakimowicz and Cuschieri, 2005). These technologies are designed to advance treatment of diseases. However, Bitterman (2006) reported that additional screens and displays impose an ever-increasing load on the surgeon. Throughout this dissertation, the term **IT-related overload** is used to characterize overload in the context of IT and therefore in a context where information is delivered by IT. IT-related overload has a detrimental effect on performance and stress of the surgeon and therefore patient safety (Berguer, Smith, and Chung, 2001). Surgical simulation training is a means currently allowing surgeons and surgical residents to improve surgical performance. This dissertation aims to increase simulation training effectiveness by training against IT-related overload under realistic conditions to increase patient safety.

The blooming of new medical IT can be mainly attributed to ceaseless innovation in Image Guided Surgery (IGS). IGS is also referred to as Computer Assisted Surgery and Computer Aided Surgery (CAS), Minimally Invasive Surgery (MI-Su) and Minimal Access Surgery (MAS). These terminologies share the notion of performing surgery with minimal access to the patient (Jakimowicz and Cuschieri, 2005). The surgery is performed based on a monitor depicting the image of the operating area (Buzink, Goossens, Schoon, de Ridder, and Jakimowicz, 2010).

IGS provides an alternative for open surgery where the surgeon has a direct view into the open wound. Open surgery is much more invasive. One well-known IGS procedure is laparoscopic surgery. IGS has obvious benefits for the patient compared to open surgery in terms of minimal tissue damage and shorter hospital stay (Buzink et al., 2010). IGS also has significant financial benefits in terms of significantly reduced hospitalization time and therefore costs. For example Mir, Cadeddu, Sleeper, and Lotan (2011) reported cost savings up to 16% for a minimal access kidney removal over open surgery due to shortened hospital stay.

IGS is performed based on a monitor depicting the image of the operating area (Buzink et al, 2010). The image is generated via a camera or scope within the body (see Figure 1.1) or using imaging technologies from outside the body such as X-ray (see Figure

1.2). It makes IGS rely almost exclusively on information delivered by IT. Laparoscopic surgery is IGS using a scope in the abdominal or pelvic cavity.

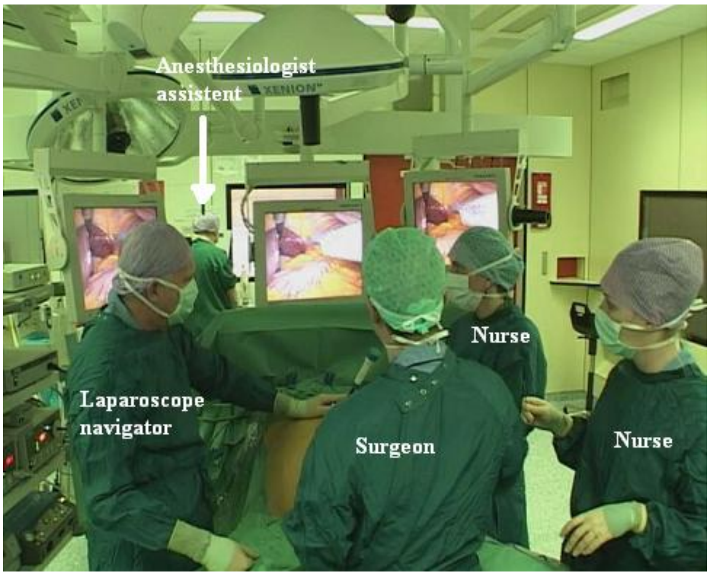

Figure 1.1. Laparoscopic surgery
Laparoscopic surgery requires several small incisions in the abdomen. Surgical instruments and a scope (video camera) are placed into the abdominal cavity. The scope is handled by the laparoscope navigator (see left hand). The scope illuminates the operating field and sends a magnified image from inside the body to the three monitors. The surgeon processes the information delivered by the monitors to perform the operation. He or she manipulates the surgical instruments through the operating field.

Figure 1.2a. Image guided cardiac intervention technology.
This IT is used to treat cardiac disorders such as cardiac arrhythmia. The intervention is performed by the cardiologist using 5 screens depicted on the left. See also the enlargement of X-ray data on the right. The cardiologist is assisted by the cardiologist assistant monitoring 9 additional screens (see Figure 1.2b).
Reprinted with permission of a Top Clinical Hospital.

Figure 1.2b. Image guided cardiac intervention technology.
Subset of screens located in the complementary control room. These 9 screens are monitored by the cardiologist assistant during the cardiac intervention. The enlargements show an X-ray image (left), a control monitor (center), and the electrocardiogram information (right).

While IGS surgery is beneficial for the patient, it is more demanding for the surgeon (Berguer et al., 2001; van Veelen, Nederlof, Goossens, Schot, and Jakimowicz, 2003). For example, depth perception within the operating field is typically lost because the information delivered by the screen is two-dimensional (see Figure 1.1 and 1.2). Also during most procedures the tip of the instrument that is depicted on the monitor moves in the opposite direction to the one which the surgeon or physician manipulates it in. This is referred to as the fulcrum effect. It is caused by the fact that the instruments are inserted through the abdominal wall which acts as a hinge (Botden, Tarab, Buzink and Jakimowicz, 2008). Also tactile information on the tissue delivered by the surgical instruments is reduced (Botden et al., 2008; Buzink, 2010). This requires the surgeon to rely mostly on the visual information delivered by the monitor.

Bitterman (2006) reported that “while these innovative applications are expanding the traditional boundaries of the surgical space and enhancing treatment capabilities, the introduction of additional screens and displays is placing an ever-increasing load [on the surgeon]" (p. 165). The OR is an exceptionally interesting environment to study IT-related overload since the costs of failure are high. The medical staff has to face the cognitive consequences of IT-related overload through medical errors and increased response time. They also face emotional consequences such as stress and irritation (Berguer et al., 2001). These may result from the inability to handle IT properly and process the information delivered by IT to the surgical team (Daniels and Ansermino, 2009). Zheng, Rieder, Cassera, Martinec, Lee, Panton, Park, and Swanstrom (forthcoming) reported that "overloaded surgeons may lose their abilities to maintain patient safety in the operating room" (p.2).

Patient safety: ethical and financial consequences

Patient safety is defined as "non-occurrence of adverse events and the presence of measures to prevent them" (Hoffmann and Rohe, 2010, p. 92). An adverse event is "a harmful event that is due to the treatment rather than the disease; it may be preventable or nonpreventable" (p. 93). A study commissioned by the Dutch government[1] revealed that on average 1.3 million patients are hospitalized annually in the Netherlands (Wagner and De Bruijne, 2007). About 76,000 of these patients suffered from adverse events during their hospital admission. Fifty-four percent of these adverse events occur during surgical intervention in the OR of which 34% can be considered to be preventable. That is 13,954 patients. Human error was included as a primary cause of the adverse event in 58% of the cases, and 61% of these were identified as highly preventable. Human error results from psychological and physiological limitations of humans including cognitive overload (Helmreich, 2000). In 2004 about 42,000 patients passed away during a stay in a Dutch hospital. The death of 1735 of these patients could be related to a preventable adverse event and early death (Wagner and De Bruijne, 2007). A recent follow-up study identified similar numbers (Langelaan, Baines, Broekens, Siemerink, Van de Steeg, Asscheman, De Bruijne, and Wagner, 2010). The exact impact of IT-related overload was not quantified in these reports. However, cognitive overload is generally deemed an important cause of adverse events in surgery (Helmreich, 2000; Berguer et al., 2001; Carswell, Clarke, and Seales, 2005; Prabhu, Smith, Yurko, Acker, and Stefanidis, 2010; Stefanidis, Korndorffer Jr, Markley, Sierra, Heniford, and Scott, 2007). It is also key in other high risk professions involving complex information delivered by IT such as aviation (Helmreich, 2000).

Besides severe personal health-related consequences, these adverse events also have financial consequences. These are of particular interest considering the current worldwide financial situation. Healthcare expenses in the Netherlands were over 87 billion euro in 2010[2].

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[1] Study conducted by NIVEL (Nederlands instituut voor onderzoek van de gezondheidszorg)

[2] Numbers from Centraal Bureau voor de Statistiek (CBS) report *"Zorgrekeningen; uitgaven (in lopende en constante prijzen) en financiering"* [Online] Available at: http://statline.cbs.nl/StatWeb/publication/?VW=T&DM=SLNL&PA=71914NED&D1=0-23,37-45&D2=9-l&HD=101210-0925&HDR=G1&STB=T

This constitutes 14.8% of the Gross Domestic Product (GDP). Hospital care expenses were 22 billion euro. Hospitalized patients in the Netherlands on average spend 7.3 days in hospital. Patients who suffered from preventable adverse damage on average spent ten extra days in hospital. This is a surplus of 136% with an estimated average additional cost of 5600 euro per patient. This comes down to 167 million euro in 2004 which was about 1% of the overall hospital budget (Wagner and De Bruijne, 2007). Taking control of preventable errors is therefore paramount from an ethical and a financial perspective.

Especially novice surgeons are vulnerable to the detrimental effect of cognitive overload causing errors (Hsu, Man, Gizicki, Feldman, and Fried, 2008). Experienced surgeons may have gradually developed strategies to cope with cognitive load imposed by medical IT. In the groundbreaking report “To err is human” preclinical training with new medical IT is considered a prerequisite to prevent excessive load on medical staff (Kohn, Corrigan, and Donaldson, 2000, p. 60). Simulation training is one of the key error management strategies to counter cognitive overload in aviation (Helmreich, 2000).

1.2 Surgical simulation training

Before the simulation era, surgical trainees could only become more proficient by gaining experience on patients. They were trained according to the master-apprenticeship model. This model is also referred to as the “Halsted method”. A senior surgeon supervised a surgeon in training. The surgeon in training learned the tricks of the trade through observation and gradual active participation. Over time the surgical trainee was granted more autonomy. She[3] assisted the senior surgeon during parts of the procedure. Ultimately she performed the entire surgery by herself under the supervision of a senior surgeon. This method served the surgical community well in the open surgery era. Unfortunately surgical errors due to a lack of experience had direct implications on the patient’s health (Jakimowicz and Cuschieri, 2005).

Surgical simulation technology introduced a paradigm shift somewhere near the beginning of the new millennium (Schijven and Bemelmans, 2011). It was inspired by similar efforts in the field of aviation and the military that used simulators to train cognitively demanding tasks (Schijven and Jakimowicz, 2002). Validated surgical simulators allow a surgical trainee to practice in a safe and controlled preclinical environment before performing actual surgery on patients. Simulation training is part of a change in culture from ‘‘blame and shame’’ to a culture that ensures surgical proficiency and transparency to reduce surgical errors (Jakimowicz and Cuschieri, 2005).

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[3] The personal pronouns he (him/his) and she (her) can be used interchangeably throughout this thesis

Simulation training ranges from basic surgical tasks to simulated full procedures (see Figure 1.3). Multiple platforms are available including Virtual Reality (VR) and Augmented Reality (AR) simulation technology (see Figure 1.4).

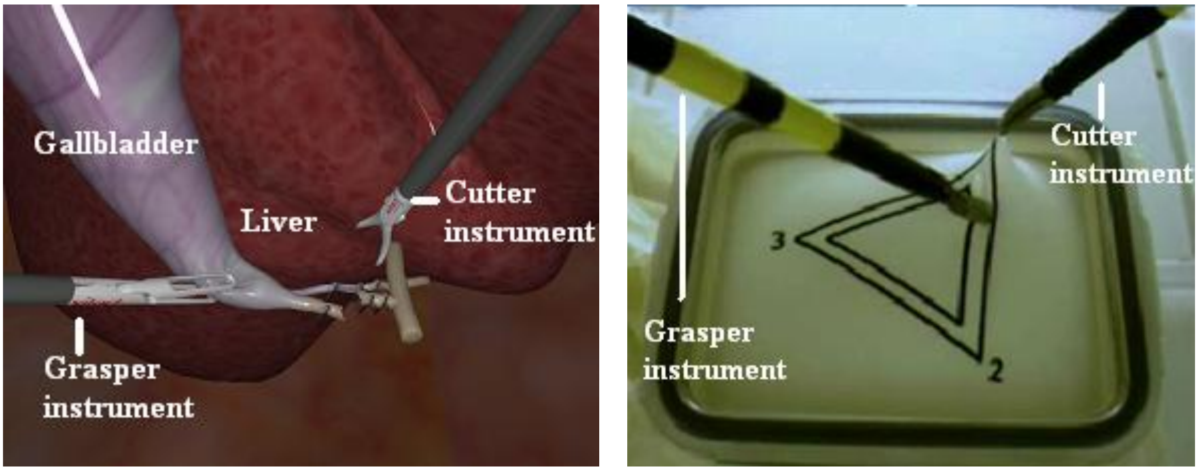

Figure 1.3. Full procedural task (left) and basic surgical task (right). The depicted full procedural task is a simulated laparosopic removal of the gallbladder. The basic surgical task is a component task that is used to train skills required for laparoscopic surgery.

Seymour (2008) defines surgical VR simulation as "the use of a computer to generate an environment with surgical relevance based on mathematical models with which humans can interact by using physical representations of surgical instruments" (p. 182). Alternatively, Augmented Reality (AR) simulators offer combinations of VR simulation and physical objects. AR simulators merge computer graphics and real objects into a single, coherent perception of an enhanced world around the trainee (Botden, Buzink, Schijven, and Jakimowicz, 2007). An illustration and detailed description of the VR and AR simulation technology used in this dissertation is provided in Appendix A, Table A.1.

VR and AR simulation technologies also provide objective assessment of surgical skills. Most simulators track basic performance measures such as time required to complete the procedure. They also assess economy and smoothness of moving the surgical instruments in the operating field. Less economic and less smooth movement may cause damage to healthy tissue. It is therefore considered undesirable. Also long operating times indicate poorer performance. Longer operating time increases the possibility of infections. It is also inefficient in terms of OR utilization and resource allocation (Stepaniak, Heij, de Vries, 2010). More advanced measures such as direct measures of surgical errors and damage to healthy tissue (e.g., cutting the wrong vessel) are also recorded in more recent simulators. VR and AR simulators have the potential to assess performance according to pre-defined benchmarks representing proficient surgical skills. This could potentially be used to define national or worldwide standards representing proficient surgery (Schijven and Bemelmans, 2011; Seymour, 2008). The aviation industry and the military use simulators for certification. All military and commercial pilots must train and be certified in the technical skills that are required for the specific aircraft they will fly (Schijven and Jakimowicz, 2002).

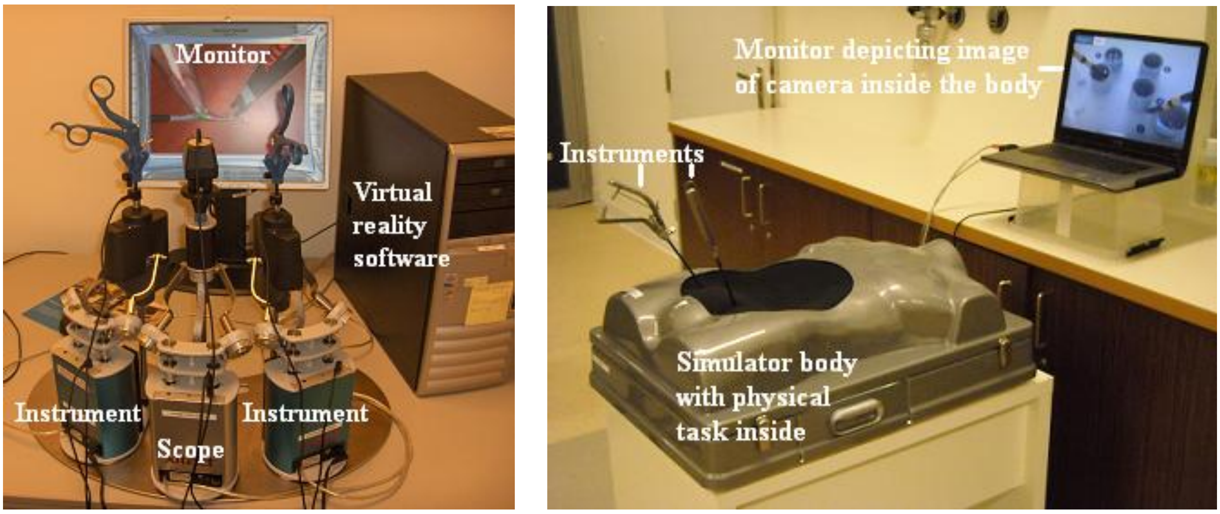

Figure 1.4. Virtual Reality simulator (left) and Augmented Reality simulator (right)

Recent research has demonstrated that surgical simulators improve surgical skills (Schijven, Jakimowicz, Broeders, and Tseng, 2005; Schijven and Bemelmans, 2011; Sturm, Windsor, Cosman, Cregan, Hewett, and Maddern, 2008). Surgical trainees that were trained using simulation technology outperformed trainees that did not receive simulation training (Palter, Grantcharov, Harvey, and MacRae, 2011; Seymour, 2008). Simulation training thus contributes to increase patient safety. VR and AR surgical simulation training are typically provided in isolated and controlled settings in Skills Labs.

Transfer from isolated training to the socio-technological setting of the OR is perceived as cognitively demanding by novices (Prabhu et al., 2010; Stefanidis et al., 2007). The transfer has to be smoothened to decrease IT-related overload in the OR. In other words, simulation training effectiveness needs to be increased. One possible solution is to further integrate simulation into training programs that are closer to clinical practice (Gallagher, Ritter, Champion, Higgins, Fried, Moses, Smith, and Satava, 2005).

1.3 Research objective, scope, approach and expected contribution

The research objective of this thesis is to resolve an issue that is relevant for both practice and theory:

> How can IT-related overload be countered more effectively using surgical simulation training to improve patient safety than is currently the case in surgical training for Minimally Invasive Surgery?

The scope of this dissertation is restricted to the individual level of analysis. Overload at the team level, organizational level (e.g., Galbraith, 1974; Tushman and Nadler, 1978) and societal level (e.g., Davenport and Beck, 2001) are not the focus of this dissertation. Organizational implications at the individual level will be discussed in the general discussion (Chapter 7).

The primary focus is on surgical training. It is a means which can potentially reduce IT-related overload. Surgical training is mostly intended for surgical residents. This dissertation argues that they should be provided the opportunity to develop coping strategies against IT-related overload not on patients, but during simulation training. Experienced surgeons are outside the scope of this dissertation. They may have developed coping strategies during clinical practice (Andersen, Klein, Gogenur, and Rosenberg, 2012). Throughout this thesis the term **immersive training** is used to refer to simulation training in a realistic socio-technological setting that is reproducing and representing situations closer to clinical practice in the OR (see also Stefanidis et al., 2007).

Research approach in subsequent chapters

The remainder of this dissertation is organized as follows. Chapter 2 provides extensive theoretical background for a theory-driven understanding of IT-related overload. Definitions and conceptualizations of overload from the field of Information Systems (IS) are discussed first. Medical IT and information are rapidly becoming the defining elements of surgical procedures. A systematic literature review (n=37 articles) of IT-related overload in the surgical domain is provided. Definitions and conceptualizations, causes and consequences are discussed.

Two comprehensive overload theories are subsequently introduced. First, the Cognitive Load Theory (CLT) developed by Sweller (1988) will be discussed. It is a theory that originates from psychology and has a strong focus on learning. CLT seems a desirable theory for this dissertation that primarily aims to develop effective simulation training. Second, the Emotional-Cognitive Overload Model (ECOM) was developed by Rutkowski and Saunders (2011) based on theory in cognitive psychology. It was recently introduced as the very first comprehensive overload theory in the IS field. It has a specific focus on IT-related overload. Based on these theories a conceptual model is defined. They form the theoretical background on which the subsequent chapters build towards a basic immersive training program (see Figure 1.5).

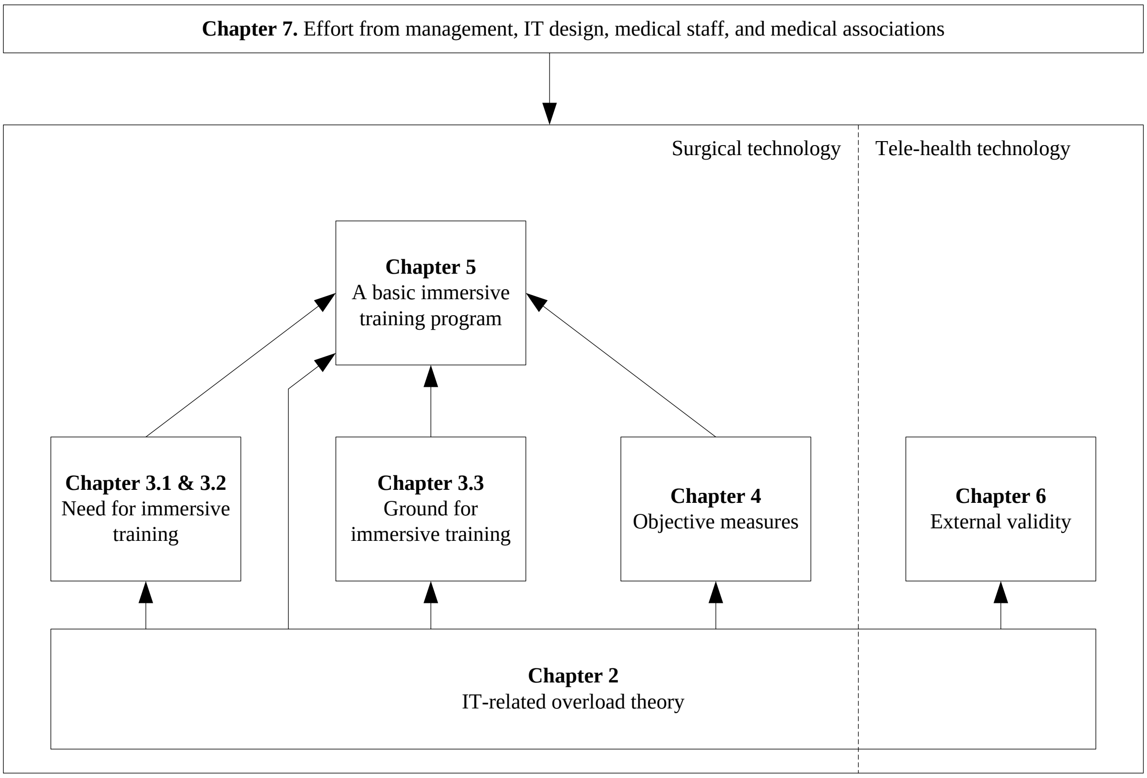

Figure 1.5. Building blocks of the dissertation

Chapter 3 first provides an illustration of medical IT based on observations during a set of twelve surgical procedures. Also an outline of the social context of surgery is provided. Next two experimental studies are presented. Both studies demonstrate that overload imposed by realistic technological and social sources depends on the personal mental organization of Long-Term Memory (LTM). An important implication of this is that IT-related overload can be anticipated using surgical simulation training. In particular, surgical simulation training effectiveness might be increased through training in a realistic context, referred to as immersive training.

Chapter 4 proposes and validates thermal imaging technology as an innovative physiological marker of IT-related overload. It can potentially be used for objective evaluation of training protocols (such as immersive training) aiming to decrease IT-related overload and assessment of surgical trainees.

Chapter 5 combines the effort of the previous chapters into a comprehensive immersive surgical training program. Its effectiveness is demonstrated beyond conventional surgical simulation training in terms of perceived IT-related overload and stress in realistic settings.

Chapter 6 demonstrates that medical IT-related overload is not restricted to medical staff. It is also a threat to potential users (n=1868) of video contact technology for online consultation of their physician. User group targeting based on encoded experience of overload with IT is proposed to help manage such technology driven healthcare innovations. Theoretically it demonstrates the external validity of medical IT-related beyond the surgical domain.

Chapter 7 provides a general discussion on management of IT-related overload. This should be a joint effort of at least the medical staff, hospital management, medical associations and medical IT designers. Immersive surgical training is proposed as a potentially interesting countermeasure that has to be facilitated by management. Cost savings due to improved simulation training are also discussed.

Expected contribution to theory and practice

This dissertation is expected to contribute directly to surgical training practice. It aims to develop an immersive simulation training program which increases training effectiveness and transfer to the high cognitive demands of the OR. Immersive training potentially can be used as a means against medical IT-related overload.

On a theoretical level this dissertation is expected to contribute to research on overload in both Information Systems (IS) and the surgical domain. IT-related overload is considered a delicate issue in both domains (see Eppler and Mengis, 2004; Berguer et al., 2001; Bitterman, 2006). A more theory-driven understanding of medical IT-related overload however is required as will become apparent in Chapter 2. This dissertation aims to fill this gap based on ECOM (Rutkowski and Saunders, 2011) and CLT (Sweller, 1988).

Finally, IT-related overload, commonly referred to as information overload, has also been identified as an important issue across a wide variety of business domains. The results of this dissertation and applications of ECOM (Rutkowski and Saunders, 2011) can inform overload research in the field of managerial decision making (Farhoomand and Drury, 2002), accounting and financial decision making (Rose, Roberts, and Rose, 2004), marketing and consumer behavior (Malhotra, 1984), e-learning (Mayer and Moreno, 2003), computer mediated communication (Hiltz and Turoff, 1985) such as that in public online spaces (Jones, Ravid, and Rafaeli, 2004) and in electronic meetings (Grise and Gallupe, 1999/2000), humanitarian emergency response information systems (Muhren, 2011), police officers using tablets (Allen and Shoard, 2005), car driving (Or and Duffy, 2007), aviation and air traffic control (Seamster, Redding, Cannon, Ryder, and Purcell, 1993), aerospace (Bock, Weigelt, and Bloomberg, 2010) and nuclear power operations (Woods, Patterson, and Roth, 2002).

2. Overload definition and theory [4]

2.1 Definition and conceptualization of IT-related overload in IS

Medical Information Technology (IT) and information delivered by medical IT are rapidly becoming the defining elements of surgical procedures. The Information Systems (IS) domain is primarily concerned with information delivered by IT. It can be expected to have dealt with IT-related overload extensively. The IS overload literature was systematically analyzed in a review by Eppler and Mengis (2004) and Rutkowski and Saunders (2011). An outline of the definitions and conceptualizations of overload in the IS literature is provided below. By far the most popular conceptualization of overload is in relation to information. However, several studies also viewed overload as related to workload.

Information overload

Overload has mostly been defined as an excessive number of inputs delivered by IT. This is mostly referred to as information overload (e.g., Grise and Gallupe, 1999-2000; Hiltz and Turoff, 1985, Schultze and Vandenbosch, 1998) or data overload (Woods, Patterson, and Roth, 2002). Information overload is defined as "the inability of living systems to process excessive amounts of information" (Allen and Shoard, 2005). Data overload implies that "practitioners are bombarded with computer-processed data" (Woods, Patterson, and Roth, 2002, p. 22). Similar terminologies have been used when discussing overload in a specific context such as communication overload and conversational overload. Communication overload is defined as "the delivery of too many communications and to an increase in social density that gives individuals access to more communications than they can easily respond to" (Hiltz and Turoff, 1985, p. 682). Conversational overload is defined as "too many messages are delivered, so that individuals are unable to respond adequately (Jones, Ravid, and Rafaeli, 2004, p. 196). Such conceptualizations of overload deal with having more information input than can be processed by the individual who is receiving the information (see also Chervany and Dickson, 1974; Cook, 1993; Denning, 1982; Farhoomand and Drury, 2003; Nelson, 1994; Payne, 1976 and for an exhaustive list see Eppler and Mengis, 2004). In most cases the overload occurred because of limitations in time or processing capacity. They do not address however, how exactly this information is processed by the individual. Nor do they address how and when it evokes a state of overload.

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[4] This chapter is based on Rutkowski, A.F., Saunders, C.S., & Pluyter, J.R. (forthcoming). Emotional and Cognitive Overload: The Role of Personal Dispositions and Prior Experience. Proceedings of the 72nd Academy of Management Conference 2012: The informal economy, Boston, MA, USA: Academy of Management.

The IT delivering information is a major cause of overload including information push technology (Bawden, Holtham, and Dourtney, 1999) and email (Allen and Shoard, 2005). Other causes are mostly related to the task complexity (Speier, Valacich, and Vessey, 1999) or the individual personality (Allen and Shoard, 2005) and level of experience (Hiltz and Turoff, 1985). In the field of IS scholars typically focus on providing technical solutions (Eppler and Mengis, 2004; Rutkowski and Saunders, 2011). Here IT is used as a mean to reduce overload mostly be reducing or filtering the amount of information presented to the user. Filtering is based on pre-defined personal interest or pertinence of the information (Berghel, 1997; Liang, Lai, and Ku, 2007). Other technical solutions involve autonomous or smart agents. These take over part of the information processing or act as an "external memory". Woods, Patterson, Corban, and Watts (1996) refer to such countermeasures as offloading. They consider individuals and ITs as joint cognitive systems that can share the information processing load. Offloading processing demands to smart agents decreases load imposed on the individual. Also IT can facilitate spreading load over time (Allen and Shoard, 2005).

Workload

Overload is also discusses in relation to workload. Bottlenecks in workload occur "when there are simply too many individual data units to examine them all manually in the time that is available" (Woods et al., 2002, p. 25). Also information overload is related to mental workload. Mental workload is defined as "the degree of processing capacity that is expended during task performance" and "a perceptual construct that attempts to measure 'working hard'" (p. 168). In this view an excessive amount of data or information contributes to excessive workload or mental workload.

Ahuja and Thatcher (2005 p. 435) and Tarafdar, Tu, Ragu-Nathan, and Gagu-Nathan (2007) provide alternative conceptualizations of overload related to workload. Overload in this view has two related dimensions. Quantitative overload is defined as "an individual's perception that they cannot perform a task because they lack critical resources". Qualitative overload is the second type of overload discussed by Ahuja and Thatcher (2005). They define qualitative overload as the situation when "employees perceive assigned work as exceeding their capability or skill levels" (p.436). Tarafdar et al. (2007) also define qualitative and quantitative overload, but they are specifically defined in terms of role overload, or "when the requirements from an individual's role exceed his or her capacity in terms of the level of difficulty or the amount of work (Tarafdar et al., 2007, p. 307). Pennington, Kelton, and DeVries (2006, p. 26), similar to Ahuja and Thatcher (2005) and Tarafdar et al. (2007), define qualitative overload as "a lack of knowledge pressure."

Other conceptualizations

Overload is often considered to be the “number of inputs” (e.g., amount of data, ideas, messages, emails) generated by IT usage such as groupware tools. In one case it is viewed “not necessarily a case of too much data, rather it is an inability to make sense of demands, capabilities, and context as well as data” (Sutcliffe and Weick, 2008). Overload is also described as a paradox. Koeniger and Janowitz (1995) define overload as “we are not receiving enough information, too much information is thrown at us” (p.5). Overload is also defined as a situation with time pressure: for example “too many things to do at once” (Grise and Gallupe, 1999/2000, p.161). Overload is also conceptualized as a consequence of a lack of structure and organization in a system (Hiltz and Turoff, 1985).

Also some authors discuss overload as an output. Tarafdar, Tu, Ragu-Nathan, and Ragu-Nathan (2007) focus on techno-stress. It is defined as stress resulting from the inability to adapt to or cope with new IT in a healthy manner (p. 302). Simpson and Prusak (1995) see overload as a symptom of a failure to create “high quality” information for management use (p. 413). Finally some definitions and conceptualizations specify overload in terms of input and output. Edmunds and Morris (2000) define overload as “too much information for the receiver to process efficiently without distraction, stress, increasing errors and other costs (p. 18 based on definition of Klapp, 1986). Overload is generally associated with impaired performance (Chervany and Dickson, 1974; Faromood and Drury, 2003) and stress (Speier, Valacich, and Vessey, 1999; Tarafdar et al., 2007). Moreover, overload may influence user satisfaction (Liang, Lai, and Ku, 2007) and post adoptive behavior of users (Ahuja and Thatcher, 2005).

In sum, overload has mostly been treated as both input and output in IS. Overload is generally not conceptually differentiating them from its cognitive, emotional and behavioral consequences. Eppler and Mengis (2004) and Rutkowski and Saunders (2011) in their reviews considered this to be the typical conceptualization of overload in the field of IS. Articles rarely address how exactly this information is processed by the individual. Nor do they address how and when it evokes a state of overload. The overload literature in the surgical domain is analyzed next.

2.2 IT-related overload in the surgical literature: a systematic literature review

Overload has been identified as an important issue in the field of surgery (Berguer, Smith, and Chung, 2001; Carswell, Clarke, and Seales , 2005; Prabhu, Smith, Yurko, Acker, and Stefanidis, 2010; Stefanidis, Korndorffer Jr, Markley, Sierra, Heniford, and Scott, 2007, Zheng, Cassera, Martinec, Spaun, and Swanström, 2010). A comprehensive overview of overload studies in the field of surgery however is currently not provided in the surgical literature.

As the next step, a systematic literature review was conducted on IT-related overload in the surgical literature. The literature review initially embraces overload in a broad sense. That is, a priori it does not solely focus on IT-related overload. Rather the role of IT and information delivered by IT is identified a posteriori. This strategy is taken to prevent exclusion of articles that discuss medical IT and information implicitly rather than explicitly. This is likely the case because the field of surgery, as opposed to the field of IS, is not primarily interested in information and IT. Rather surgeons are interested in new procedures and treating patients in a safe and better way. Medical IT and information delivered by medical IT are rapidly becoming the defining elements of surgical procedures. Information and medical IT are therefore implicitly embedded under the more general denominator: surgery. This includes well known aggregated terminologies referring to technology based surgery such as Minimal Access Surgery (MAS), Computer Assisted Surgery and Computer Aided Surgery (CAS), Minimally Invasive Surgery (MI-Su) and Image Guided Surgery (IGS). Medical IT is embedded in many procedures such as laparoscopic and endoscopic surgery. For the same reasons, overload with information delivered by IT may be discussed more implicitly using terminologies such as mental and cognitive workload. After all, the surgeon is primarily concerned about his or her work rather than the information or IT. The literature review will focus on the central elements of “overload” (and related conceptualizations such as mental workload) and “surgery”.

Inclusion/ exclusion criteria and article coding

A systematic literature search was performed using PubMed on April 4, 2012. PubMed is the largest meta-search engine in the medical and surgical field. Over 30,000 unique journals, online books and other (bio) medical scientific outlets are included in PubMed. PubMed was used to search articles with the following keywords in the title or abstract: information load, information overload, cognitive load, cognitive overload, mental load, mental overload, mental workload, cognitive workload, mental strain, cognitive strain, cognitive distraction, mental stress, cognitive stress. The focus of this dissertation is on surgery. An additional constraint was imposed requiring the articles to also contain any of the following keywords in the title or abstract: surgeon, surgery, surgical. This search resulted in a total of 111 articles that met these two criteria. A random sample of the coded articles was also independently coded by a second researcher and irregularities were discussed and unified.

This strategy has some minor limitations, primarily relating to the methodology and scope. One limitation is that other articles that dealt with the issue of overload, but used other keywords in the title and abstract that were not included in the inclusion criteria, are not taken into consideration. This includes studies that discuss overload indirectly, for example by focusing on working memory performance. Also the scope of the review is restricted to articles that are part of PubMed. Inter-disciplinary articles that were published in for example purely technical journals might be underrepresented in the results. It is however unlikely that these articles constitute the core of research on overload in the *surgical* field.

From the 111 results, 39 were identified as actually being related to overload in surgeons or surgeons in training. Excluded articles mainly discussed other types of overload such as “muscle” overload and “iron” overload. Other excluded articles had a patient focus on overload. These discussed for example mental stress of the patient after undergoing surgery, or making decisions about their health such as choosing a specialist from several available alternatives. Also articles discussing overload of team members other than the surgeon (e.g., anesthesiologist) were excluded to maintain a manageable scope. Obviously articles discussing ECO in other members of the surgical team than surgeons would be valuable to consider in future research. Two additional articles were excluded because they were written in languages not familiar to the author of this thesis. The 37 included articles were coded on the following properties:

Article: author(s), journal, year of publication. Full references can be found in the bibliography.

Context: surgical specialism of the study of interest such as laparoscopic surgery.

Terminologies and definition of overload: listing of terminologies including definitions used in the original article to refer to overload. Only terminologies that were dominantly present in the article were listed. These were considered most representative for the content of the original article. Terminologies that were mentioned once or twice in the original article were not reported. Oblique definitions of overload and related terminologies where listed in case overload was not strictly defined in the original article.

Causes: factors that contribute to overload were categorized as characteristics of the information (e.g., amount, modality), IT (e.g., laparoscopic vs. open surgical technology), individual (e.g., experience), role of the individual (e.g., performing role of primary surgeon vs. assistant surgeon), task, team interaction (e.g., performing solo vs. in a team setting) and time. Characteristics of IT also include positioning of the surgeon towards the technology such as side standing or frontal standing position. Secondary task designs and distractions such as arithmetic calculations is categorized as “task” and “information” since additional information relevant for an addition task is presented to the subjects. Several information characteristics vary as a function of the IT that delivers the information. For example image resolution quality can be high or low depending on the ability of the IT to produce such images. Information characteristics that vary as a function of the IT are categorized as both “IT” and “information”.

Information Processing (IP) view: the theoretical model used to explain, predict or discuss overload. One example is the Working Memory (WM) model by Baddeley and Hitch (1974).

Study design: Experimental (within, between, or mixed subjects design), clinical trial, post-hoc analysis, qualitative and observational research, design research, literature-based plea or review. Post-hoc analysis studies are studies that measure constructs of interest without controlled experimental testing or intervention.

Sample: sample size and composition of sample (e.g., surgeons, students).

Tested on Patient (P) or using Simulation (S): refers to the study setting which can be on patients or using simulation on an animal, virtual or augmented model.

Overload measured: measurement instruments used to measure overload or related terminologies such as mental workload. Measures can be categorized as self-reported, physiological and primary/secondary/dual task performance. Physiological measures are mostly based on autonomic nervous system responses to stimuli. Examples include heart rate variability and skin conductance. Dual task performance is typically used to measure "spare mental resources" not allocated to the primary surgical task. Here both primary and secondary task performance are measures.

One self-reported measure that is often encountered in articles included in the review is the NASA-TLX (National Aeronautics and Space Administration Task Load Index)[5]. It is a self-reported scale used to assess task load using five dimensions: mental demand, physical demand, temporal demand, effort, performance, and frustration.

Symptoms and other dependent measures: listing of symptoms of overload and other dependent measures used in the study. Performance is treated as an aggregated collection of time, errors, economy and smoothness of movement and bi-manual coordination.

2.2.1 Conceptualizations of overload

Authors and growing research activity

An overview of the 37 articles and their coding on the above-mentioned properties is provided in Appendix B. Below the main results are discussed. Research activity on overload is not concentrated around just a few authors that serve as "gurus". The 37 articles on overload that were included in this review were co-authored by 178 unique authors. Only 19 authors wrote more than one single paper on overload, of which 7 authors wrote more than

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[5] http://humansystems.arc.nasa.gov/groups/TLX/

two papers. Swanström, Martinec, Klein, Cassera, and Berguer (each 3 articles on overload), and Zheng and Smith (both 4 articles) appear to be the most active authors on overload in the field of surgery.

All but two articles on overload were published in or after 1997. An increasing trend can be observed in the number of articles published on overload in the surgical literature in the last decade (see Figure 2.1). Research activity on overload was boosted a few years after the widespread diffusion of laparoscopy in the mid 90s (Escarce, Bloom, Hillman, Shea, and Schwartz, 1995; Poulsen, Vondeling, Dirksen, Adamsen, Go, and Ament, 2001). Laparoscopy further catalyzed an explosive growth of new Image Guided Surgical (IGS) technologies (Rattner, 1999). Laparoscopy and other IGS technologies have significantly increased cognitive load on the surgeon (Berguer, Smith, and Chung, 2001). The increased research interest in IT-related overload seems a natural response to practical developments in medical IT in the OR.

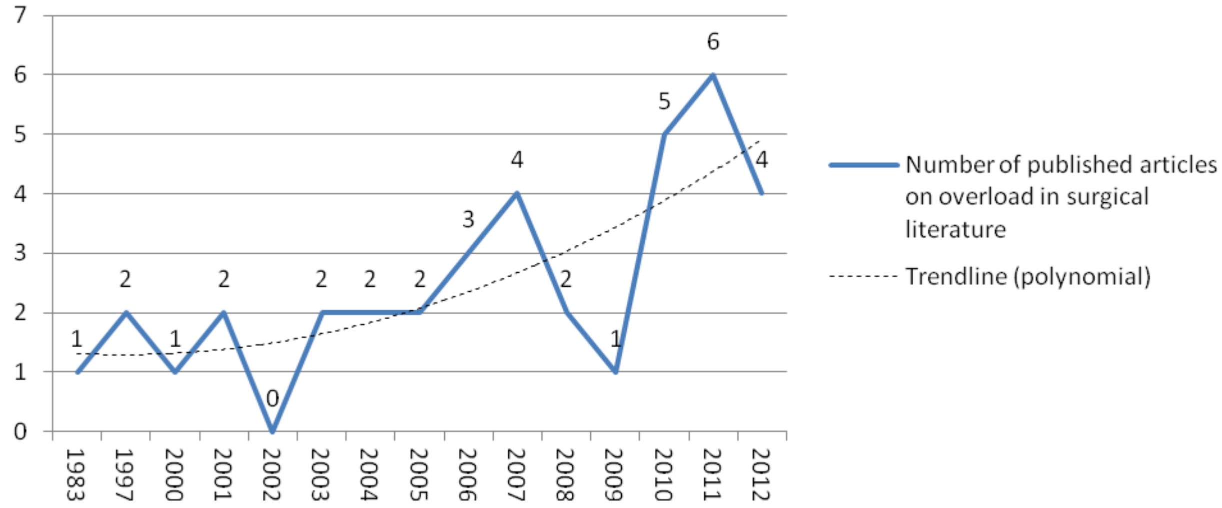

Figure 2.1. Number of articles published on overload in the surgical literature over time [note that the number of 2012 is still pending and includes one article that is in press]

The authors of the articles discuss overload in a variety of contexts. All but one article focus on image guided interventions. Only one article primarily discussed open surgery. This article, by Czyzewska, Kiczka, Czarnecki, and Pokinko (1983), was written in the open surgery era. As discussed before, image guided procedures are highly IT-based by default. They put an increasing cognitive load on the surgeon (Berguer et al., 2001). A total number of 20 articles originate from the field of laparoscopic surgery, 7 from endoscopy and minimally invasive surgery, 2 from cardiac surgery and 2 from rhino/sinus surgery. The focus of the remaining 5 articles is not restricted to a particular context and can be classified under the more general label of surgery (3) and robotic surgery (2). Open surgery was the primary focus of 1 article. Open surgery was also included as a baseline against which alternative minimally invasive surgical technologies were compared in several other articles. One article had a primary focus on the intensive care which patients receive during recovery after surgery.

Overload terminologies, definitions, measures and IP models

Authors use a variety of terminologies referring to overload, as depicted in Figure 2.2. Workload (cognitive or mental) was used in almost half of the articles. Overload was referred to as information overload in only one article. This is in large contrast to the field of IS where information overload is by far the most popular conceptualization of overload (Rutkowski and Saunders, 2011). Arguably this might be because from the practical perspective of surgeons the medical IT and information delivered through IT became inseparable from their task or work (cognitive and mental workload).

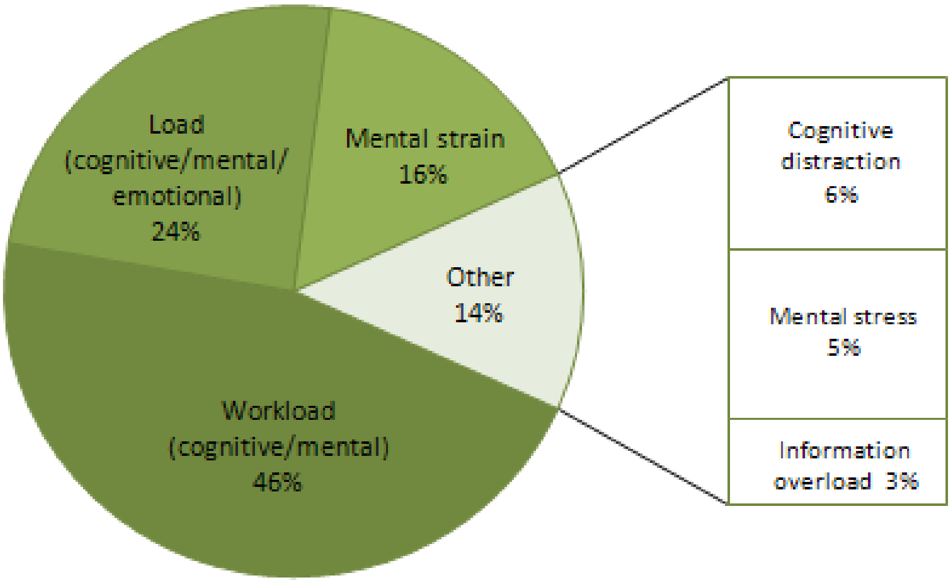

Figure 2.2. Overview of overload and related terminologies used in the surgical literature

Overload was explicitly or obliquely defined in almost 30% of the articles (11 out of 37). Workload was defined as “cost incurred by the human operator to achieve a particular level of performance” (Tomasko, Pauli, Kunselman, and Haluck, 2012, p.38), the inverse of spare mental resources (Zheng, Rieder, Cassera, Martinec, Lee, Panton, Park, Swanström, forthcoming), amount of attentional resources directed to a task at a given moment (Yurko, Scerbo, Prabhu, Acker, and Stefanidis, 2010), the ratio of mental resources required to the total resources available for a given task (Carswell, Clarke, and Seales, 2005), and a finite resource that increases while learning new tasks and performing complex tasks (Zheng, Cassera, Martinec, Spaun, and Swanström, 2010). These definitions share a common element of allocation of attentional, cognitive or mental resources.

Cognitive load was obliquely referred to as allocation of attentional or cognitive resources (Cao, Zhou, Jones and Schwaitzberg, 2007) and multi-tasking (Deka, Kahol, Smith, and Ferrara, 2011). Mental strain was defined as an indicator of the individual response to stress depending on individual coping mechanisms (Böhm, Rötting, Schwenk, Grebe, and Mansmann, 2001). A definition of overload was lacking in the remaining approximate 70% of the articles.

Overload was measured in 30 out of 37 articles. The authors used a variety of measurement instruments including various self-reported scales, physiological measures, and performance measures of the primary and/or secondary task. Self-reported measures were used in 18 studies of which half used the NASA-TLX scale. Physiological measures as well as primary/secondary/dual task performance measures were both used in 8 studies. Sometimes measurement instrument triangulation was performed by including multiple measurement instruments of overload within a single study.

A theoretical Information Processing (IP) view was included in almost one third of the articles (12 out of 37). These authors drew on a wide variety of theories. In fact they used even more different theories than there were articles published with a theoretical model. These were the Theory of Embodied Cognition (defined using Cowart, 2004), the Human Information Processing Model (HIP: Norman and Bobrow, 1975), the Multiple Resource Theory (MRT: Wickens, 1984, 1986), the Systems and Error Theory (Reason, 1990), the Automaticity Theory of Martiniuk (1976) and of Schneider and Shiffrin (1977), the Psychological Refractory Period (PRP: Van Selst, Ruthruff, and Johnson, 1999), top-down and bottom-up theories of attention (Pashler, Johnston, Ruthruff, 2001), the Bottleneck Theory (Welford, 1967), Working Memory and chunking (Baddeley, 2002; Smith and Jonides, 1996), the Theory of Deliberate Practice (Ericsson, Krampe, and Tesch-Römer, 1993), the Multiple Resource Model in Information Processing (Baddeley, 1996), the Hick-Hyman Law (Hick, 1952), effort with distress and strain coping in compensatory control (Frankenhaeuser, 1986; Hockey, 1997), and research linking cardiac arrhythmia and responses of the sympathetic nervous system to mental workload (e.g., Kalsbeek and Ettema, 1963). The remaining two thirds of the articles were a-theoretical with respect to overload and related constructs.

Causes of overload

Seven different categories of causes could be identified that contribute to overload of the surgeon (see Figure 2.3). The authors of the original articles were interested in the impact of these causes on the load and performance of the surgeon. Sometimes multiple causes could be identified within a single article. Causes were sometimes interrelated. For example the articles of Lerotic and Yang (2006, 2007) discussed low or high resolution pictorial information as a function of the ability of IT to produce this information. Here characteristics of IT influence the characteristics of the information it delivers to the individual. In such cases both information and IT were included as a cause. The main four categories of causes are IT (31% of the total causes mentioned was primarily related to IT), information (19%), individual and task (both 17%). The keywords were underlined to improve readability of the text.

IT-related causes often arise from the development of new medical IT (Carswell et al., 2005) such as Minimally Invasive Surgical (MI-Su) technology (Berguer et al., 2001; Böhm et al., 2001; Manukyan, Waseda, Inaki, Torres Bermudez, Gacek, Rudinski, and Buess, 2007; Rieder, Martinec, Cassera, Goers, Dunst, and Swanstrom, 2011; Zheng et al., forthcoming), navigation technology (Strauss, Koulechov, Rottger, Bahner, Trantakis, Hofer, Korb, Burgert, Meixensberger, Manzey, Dietz, and Luth, 2006), surgical robots (Klein, Warm, Riley, Matthews, Doarn, Donovan, and Gaitonde, in press; Lee, Rafiq, Merrell, Ackerman, and Dennerlein, 2005; Rovetta, Bejczy, and Sala, 1997) and communication technology (Reddy Pratt, McDonald, and Shabot, 2003). Also the integration of IT in the OR is considered in studies on display location (Rogers, Heath, Uy, Suresh, and Kaber, 2012; Youssef, Lee, Godinez, Sutton, Klein, George, Seagull, and Park, 2011; Zheng, Janmohamed, and MacKenzie, 2003), monitor integration (Berguer, Loeb, and Smith, 1997; Cheung, Wedlake, Moore, Pautler, and Peters, 2010), monitor quality (Lerotic and Yang, 2006, 2007) and presence of existing IT in the OR (Yurko, Scerbo, Prabhu, Acker, and Stefanidis, 2010)., Considering that a priori this review was not restricted to IT-related overload, it is remarkable that IT forms the largest portion of causes of overload in the surgical literature.

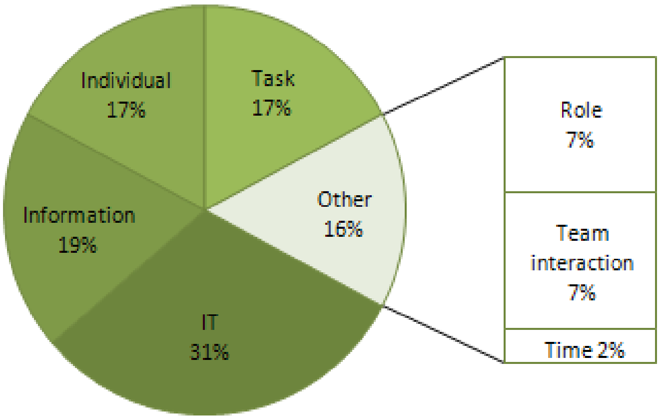

Figure 2.3. Overview of causes of overload mentioned in the surgical literature

Information-related causes arise from meaning of the information (Schuetz, Gockel, Beardi, Hakman, Dunschede, Moenk, Heinrichs, and Junginger, 2008; Zheng Tien, Atkins, Swindells, Tanin, Meneghetti, Qayumi, Neely, and Panton, 2011), information structure (Wadhera, Parker, Burkhart, Greason, Neal, Levenick, Wiegmann, and Sundt, 2010), amount (Reddy et al., 2003; Zheng et al., 2003) and contextuality (Reddy et al., 2003). Several information-related causes interact with other causes, particularly IT and task. Information quality (Lerotic and Yang, 2006, 2007) and modality (Berguer, et al., 1997; Cao, Zhou, Jones, and Schwaitzberg, 2007; Cheung et al., 2010) partially depend on the IT through which the information is delivered. Information relevant to secondary cognitive tasks (Goodell, Cao, and Schwaitzberg, 2006; Hsu, Man, Gizicki, Feldman, and Fried, 2008) exists because the surgeon is confronted with multiple tasks.

Individual-related causes mainly cover gaps in expertise with new or existing surgical technologies and procedures between experts and novices (Andersen, Klein, Gogenur, and Rosenberg, 2012; Berguer et al., 1997; Berguer et al., 2001; Böhm et al., 2001; Cao et al., 2007; Smith, Chung, and Berguer, 2000; Zheng et al., 2010; Hsu et al., 2008; Zheng et al., 2011). Expertise is usually inferred from experience calculated as the number of procedures performed during simulator training or clinical practice. Training is proposed to narrow this gap. Alternatively expertise is inferred from the stage of the career or role of the subject such as medical student, resident, attending surgeon or primary surgeon. One article (Hedman, Klingberg, Enochsson, Kjellin, and Fellander-Tsai, 2007) emphasized individual differences in working memory span and visual-spatial ability. Sleep quality was mentioned as a cause in two articles (Andersen et al., 2012; Tomasko et al., 2012).

Task-related causes are mostly related to the complexity (Czyzewska et al., 1983; Zheng et al., 2003), multi-tasking or distraction (Cao et al., 2007; Deka et al., 2011; Goodell et al., 2006; Schuetz et al., 2008; Youssef et al., 2011), and the reality of the training task (Yurko et al., 2010).

Symptoms and other dependent measures

Various dependent measures were included in the 37 articles that were reviewed. The majority of the authors were interested in the impact of overload on performance. In particular, 24 articles studied the impact of overload on surgical performance. Most of these articles included impaired surgical performance as a manifestation of overload (Rogers et al., 2012; Klein et al., in press; Tomasko et al., 2012; Zheng et al., 2011; Deka et al., 2011; Youssef et al., 2011; McCaskie, Kenny, and Deshmukh, 2011; Zheng et al., 2011; Rieder et al., 2011; Yurko et al., 2010; Cheung et al., 2010; Zheng et al., 2010; Song, Tokuda, Nakayama, Sato, and Hattori, 2009; Schuetz et al., 2008; Hedman et al., 2007; Lee et al., 2005; Berguer et al., 2001; Smith et al., 2000; Rovetta et al., 1997; Berguer et al., 1997). Four articles treated performance on a dual task as a measure of overload (Hsu et al., 2008; Cao et al., 2007; Goodell et al., 2006; Carswell et al., 2005). Two additional articles were interested in communication breakdowns rather than surgical performance (Lingard, Espin, Whyte, Regehr, Baker, Reznick, Bohnen, Orser, Doran, and Grober, 2004; Wadhera et al., 2010).

Emotional manifestations included stress (Klein et al., 2012; Schuetz et al., 2008; Demirtas, Tulmac, Yavuzer, Yalcin, Ayhan, Latifoglu, and Atabay, 2004), anxiety (McCaskie et al., 2011) or emotional response in general (Czyzewska et al., 1983). Eight articles were interested in physiological responses to overload. These studies were Zheng et al. (2011), Song et al. (2009), Carswell et al. (2005), Berguer et al. (2001), Smith et al. (2000), Böhm et al. (2001), Berguer et al. (1997), and Czyzewska et al. (1983).

Physical consequences including physical ergonomics and strain (Andersen et al., 2012; Youssef et al., 2012; Mankuyan et al., 2007; Strauss et al., 2006; Lee et al., 2005), sleepiness and fatigue (Andersen et al., 2012; Tomasko et al., 2012) were measured in 8 articles. Only a few articles measured attitude towards, and perception of IT. These include monitor preference and use (Rogers et al., 2012), ease of use (Rovetta et al., 1997) and general attitude towards IT (Reddy et al., 2003; Rovetta et al., 1997).

Study design, sampling, and test settings

Most studies are quantitative (25 articles). These studies mostly tested the impact of realistic causes of overload on surgical performance in a controlled experiment. Only a few studies are qualitative (7) or literature based (2). Data was collected in a simulation setting in 27 studies and in a patient setting in 11 studies. Some studies used both settings. Three articles did not collect data. Relatively few subjects were included in quantitative studies. The number of subjects in these studies ranged from 1 to 40 with an average of 17 (±11). The cost of simulation technology and the time intensiveness of testing and availability of participants are plausible explanations for the low number of subjects. It is not unusual that Virtual Reality (VR) simulators cost about $100,000 a piece (Newmark, Dandolu, Milner, Grewal, Harbison, and Hernandez, 2007). Subjects have to be tested one at a time if the hospital budget only allows one simulator to be purchased. This makes testing a large number of subjects time intensive.

2.2.2 The need for a theory driven understanding of IT-related overload

The literature review revealed that IT-related overload is a real and relevant issue in the field of surgery. Research on overload in the medical and surgical literature is rather scarce but of growing interest. Research on overload is scattered among almost 180 authors. They restrict their research on overload mostly to one or two articles. This is with the notable exception of at least Swanström, Martinec, Klein, Cassera, Berguer, Zheng and Smith. These authors co-authored three or four articles on overload that were included in this review.

Remember that a priori this review did not solely focus on IT-related overload. Overload is mainly referred to as cognitive or mental workload. Carswell, Clarke, and Seales (2005) give an illustrative definition. They define mental workload as “the ratio of mental resources required to the total resources available for a given task” (p. 80). In fact all definitions of cognitive and mental workload as well as the definition of cognitive load by Cao et al. (2007) share a common element of allocation of attentional, cognitive or mental resources. Presumably from the practical perspective of surgeons, medical IT and information delivered by IT are becoming inseparable from their tasks or work. Therefore load with information delivered by medical IT is referred to as the surgeons' mental workload.

Overload conceptualized as mental workload was measured using self-reported measures and mostly the NASA-TLX scale. Although the measurement scale itself allows mental and physical load to be isolated, several authors did not report the scores on separate dimensions. Rather they include both dimensions in a composite measure of workload. It is recommended that these dimensions are conceptually differentiated and measured separately. They do put a very different load on the individual, where physical load mainly concerns the body and mental load concerns the processing of information in the brain.

Research on IT-related overload is mainly conducted in the fields of laparoscopy as well as minimally invasive surgery and endoscopy in general. These interventions involve information delivered by IT by default as they are forms of Image Guided Surgery (IGS). Also IT and information (mostly delivered by IT) constitute the largest portions of causes of overload in the surgical literature. Rapidly evolving medical IT delivering information on multiple screens and modalities impose new cognitive demands on the surgeon (Berguer et al., 2001; Cao et al., 2007; Cheung et al., 2010). Individual and task were also considered major causes of overload. Authors were mainly interested in the impact of these causes on surgical performance including surgical errors and increased response time. Especially novices may be receptive to the detrimental effects of overload (Hsu et al., 2008; Andersen et al., 2012; Berguer et al., 1997; Berguer et al., 2001; Böhm et al., 2001; Cao et al., 2007; Smith et al., 2000). It is recommended that overload should be carefully considered in surgical training (Carswell et al., 2005).

Definitions of overload and a theoretical IP view on overload were provided only in about one third of the articles. Also there were more different information processing theories used (n=15) than there were articles published with an IP view (n=12). Clearly there is a need for a more comprehensive and theory-driven understanding of medical IT-related overload. Next, two complementary overload theories are introduced and discussed.

2.3 Overload theory

This dissertation considers two comprehensive overload theories. Cognitive Load Theory (CLT) was developed by Sweller (1988). It is a theory that originates from psychology and has a strong focus on learning. Cognitive Load Theory seems an applicable theory for a dissertation that primarily aims to develop effective simulation training. The other theory is the Emotional-Cognitive Overload Model (ECOM), developed by Rutkowski and Saunders (2011). It was recently introduced as the very first comprehensive overload theory in the IS field. It has a specific focus on IT-related overload.

Cognitive Load Theory and the Emotional-Cognitive Overload Model are more applicable in this dissertation than related established theories in the field of IS, particularly Cognitive Fit Theory (CFT: Vessey, 1991) and the theory of Task-Technology Fit (TTF: Goodhue and Thompson, 1995). Cognitive Fit Theory aims to identify the "fit" between the problem representation (symbolic or spatial) and the task (symbolic or spatial). A better fit (e.g., symbolic representation for symbolic task) yields a higher task performance. Cognitive Fit Theory does not focus directly on the individual that is processing the information. The individual dimension is included in the related theory of Task-Technology Fit. Fit is defined as "the correspondence between task requirements, individual abilities, and the functionality of the technology" (Goodhue and Thomson, 1995, p. 218). Fit is explained using a gestalt approach rather than a cognitive approach. The individual dimension is mostly treated as an output without focusing on how information is processed within the cognitive system of an individual. That is, individual performance differs as a function of the degree of Task-Technology Fit.

Perhaps most importantly, Task-Technology Fit Theory and Cognitive Fit Theory primarily focus on "fit". Cognitive Load Theory and the Emotional-Cognitive Overload Model rather focus on "load" and "overload" and particularly on the human memory system of the individual that is processing the information delivered by IT. Cognitive Fit Theory and Task-Technology Fit Theory are valuable theories when studying the fit between technologies and tasks. Cognitive Load Theory and the Emotional-Cognitive Overload Model are more relevant in the context of load and overload as in this dissertation.

Both Cognitive Load Theory and the Emotional-Cognitive Overload Model draw on different models of the architecture of human memory. These are presented in Appendix C. Below a glossary of several important terminologies is provided. Cognitive Load Theory and the Emotional-Cognitive Overload Model are outlined next. Abbreviations are introduced along with the terminology. Throughout Chapter 2 the terminologies are written in full to maintain readability.

- *Cognitive schemata* are cognitive structures that preserve and organize information in Long-Term Memory (LTM) (Piaget, 1951). Cognitive schemata are inherent to the cognitive resources of individuals (Rutkowski and Saunders, 2011).

- *Cognitive resources* are the cognitive "fuel" required for processing information. Processing information stimuli involves a certain level of emotional and cognitive effort and cognitive resources (Rutkowski and Saunders, 2011).

- *Cognitive load* is defined as "the manner in which resources are focused and used during learning and problem solving" (Chandler and Sweller, 1991, p.294).

- *Mental load* is defined as the emotional and cognitive effort, or its appraisal, of processing information stimuli (Rutkowski and Saunders, 2011).

- *Emotional-Cognitive Overload (ECO)* is a state where the personal cognitive resources of an individual are insufficient for handling the mental load that is created from an information stimulus (Rutkowski and Saunders, 2011).

- *Congruence* means that the information stimulus matches emotionally and cognitively with the cognitive schemata encoded in Long-Term Memory. Congruent information is easier to retrieve than non-congruent information (Rutkowski and Saunders, 2011).

Cognitive Load Theory

Cognitive Load Theory (CLT: Sweller, 1988) is mainly concerned with learning and problem solving of complex cognitive tasks. Here the learner is overwhelmed by the number and interaction of information items. Cognitive Load Theory aims to shape conditions where learning aligns with the cognitive architecture of human memory as described in the Working Memory (WM) model of Baddeley and Hitch (1974). Alignment is mainly achieved through design of learning instructions that control situations where load is too high (or low). This inhibits meaningful learning (Paas, Renkl, and Sweller, 2004).

The Working Memory model of Baddeley and Hitch (1974) considers human memory as a structurally integrated system. It is fractioned into three slave systems for temporary storage of information. The slave systems are coordinated by a central executive. The central executive interacts with a separated Long-Term Memory (LTM). The emphasis of this model is on the temporary storage and manipulation of information. The three slave systems for temporary storage of information are the phonological loop, visuospatial sketchpad and episodic buffer. The slave systems are responsible for storage and manipulation of information in different modalities. The *visuospatial sketchpad* deals with temporary storage and manipulation of visual and spatial information. The *phonological loop* deals with the temporary storage and rehearsal of acoustic and speech-based information. The *episodic buffer* was added to the initial WM model by Baddeley in 2000 as a third slave system. The episodic buffer is dedicated to form integrated units of visual-spatial and verbal information.

The *central executive system* controls the limited amount of attentional resources that are attributed to its three subsystems. The central executive interacts with the separate Long-Term Memory for permanent storage of information held in the three slave systems. The central executive thus concerns coordination and attentional control rather than storage (Baddeley, 1998; Baddeley, 2004; Baddeley and Hitch, 1974). Attentional resources allocated by the central executive are limited but only partially overlapping for the three slave systems. That is, part of the limited resources can be attributed to one of the slave systems whereas other parts of the resources can be allocated exclusively to a single slave system. The slave systems can thus be overloaded separately in their limited capacity to process information. This occurs when processing demands exceed the attentional resources allocated to the slave system to process the information.

The limited capacity to process new information by the Working Memory comprises the core of Cognitive Load Theory. Cognitive load is the manner in which resources are focused and used during learning and problem solving (Chandler and Sweller, 1991, p.294). Load becomes too high when one or more slave systems exceed their limited capacity (Paas, Renkl, and Sweller, 2004; Sweller et al., 1998; van Merriënboer and Sweller, 2005).

Cognitive Load Theory assumes that Working Memory capacity is never exceeded when dealing with familiar information. This is information that is stored in Long-Term Memory under the form of cognitive schemata during learning. By constructing and combining schemas, different pieces of information can be treated as a single element in the Working Memory. This drastically reduces the Working Memory load. Existing schemas can be automated through extensive practice. Information can then be processed automatically rather than consciously in Working Memory. This again frees Working Memory capacity. Instructional design should encourage the construction and automation of cognitive schemata (Paas et al., 2004; Sweller et al., 1998; van Merriënboer and Sweller, 2005).

Types of Cognitive Load

Cognitive Load Theory distinguishes between three types of cognitive load. These are intrinsic cognitive load, extraneous cognitive load, and germane cognitive load. The types of load differ based on the nature and contribution to construction of cognitive schemata. *Intrinsic cognitive load* relates to the intrinsic structure of the information. It cannot be influenced by instructional design. Intrinsic cognitive load depends on the number and interaction of information elements that have to be processed simultaneously. Low interactivity allows the Working Memory to process the elements serially. This imposes lower levels of load. High interactivity requires simultaneous processing of information in Working Memory. This imposes higher cognitive load. *Extraneous* and *germane cognitive load* are a function of the way in which information is presented. They are influenced by instructional design and are not an intrinsic part of the information itself. Extraneous load does not contribute to schema construction or automation. It is considered ineffective load. Germane or effective load relates to information and activities that do add to schema construction and automation. Intrinsic, extraneous and germane cognitive load are additive. That is, they draw from the same limited resources. Total load should not exceed available resources for meaningful learning to occur. Cognitive Load Theory prescribes that the total load should be aligned with the cognitive architecture and extraneous load should be minimized (Paas et al., 2004; van Merriënboer and Sweller, 2005).

Cognitive Load Theory has demonstrated that characteristics of the task, information and individual interact. They influence the level of cognitive load and therefore the learning curve and transfer of performance. Task characteristics include task format, complexity, use of multimedia, instructions and time pressure. Characteristics of the information are amount and interactivity of information items. Characteristics of the individual influencing load include her level of expertise and spatial ability (see Paas, Tuovinen, Tabbers, and van Gerven, 2003; Sweller, 1988). For example equal information interactivity imposes different levels of load on the individual depending on his or her level of expertise. Highly experienced individuals process complex and highly interacting elements as a single chunk in the Working Memory. Less experienced individuals confronted with the same information however have less organized schemata and process the information elements as single items in Working Memory. Consequently they experience higher levels of load (Kalyuga, Ayres, Chandler, and Sweller, 2003). These findings have led to several instructional design principles which are outlined in Paas, Tuovinen, Tabbers, and van Gerven (2003).

Emotional-Cognitive Model

The Emotional-Cognitive Overload Model (ECOM: Rutkowski and Saunders, 2011) builds on the modal model (Atkinson and Shiffrin, 1963) of human memory and the associative network theory of Bower (1981). The Emotional-Cognitive Overload Model addresses to both the cognitive and emotional consequences of Emotional-Cognitive Overload. It assumes a cognitive architecture consisting of a limited capacity *Short-Term Memory* (STM) and an unlimited capacity *Long-Term Memory* (LTM). The information stimulus input for the Emotional-Cognitive Overload Model is information delivered by IT (see Figure 2.4). Individuals respond to the information stimulus and place it in Short-Term Memory. The Short-Term Memory can process seven plus or minus two chunks at a time (Miller, 1956). As also proposed by Sweller (1988), information is reloaded from Long-Term Memory into Short-Term Memory to chunk incoming information. Incoming information items are organized into personal pertinent chunks. *Chunking* is the process of encoding, recoding or reorganizing multiple separate information items into personally pertinent units or chunks based on personal meaning (Miller, 1956).

Information chunks are stored in the Long-Term Memory under the form of cognitive schemata. *Cognitive schemata* are cognitive structures that preserve and organize information in Long-Term Memory (Piaget, 1951). Cognitive schemata are crucial when reloading information from Long-Term Memory into Short-Term Memory. Highly organized cognitive schemata increase the number of information items that can be processed as a single chunk in

Short-Term Memory. Put differently, the number of information items that can be processed in Short-Term Memory is fixed to seven plus or minus two. The amount of information conveyed in these items or chunks however is not fixed. Chunk size depends on the personal mental organization of Long-Term Memory under the form of cognitive schemata. Cognitive schemata and chunking thus allow bypassing Short-Term Memory limitations (Rutkowski and Saunders, 2011). The Long-Term Memory is divided into two separated but interrelated memory systems (Tulving, 1972). These are the Episodic Memory (EM) and Semantic Memory (SM). The Episodic Memory stores personal experiences and episodes. The Semantic Memory stores more abstract concepts and acts as a mental thesaurus.

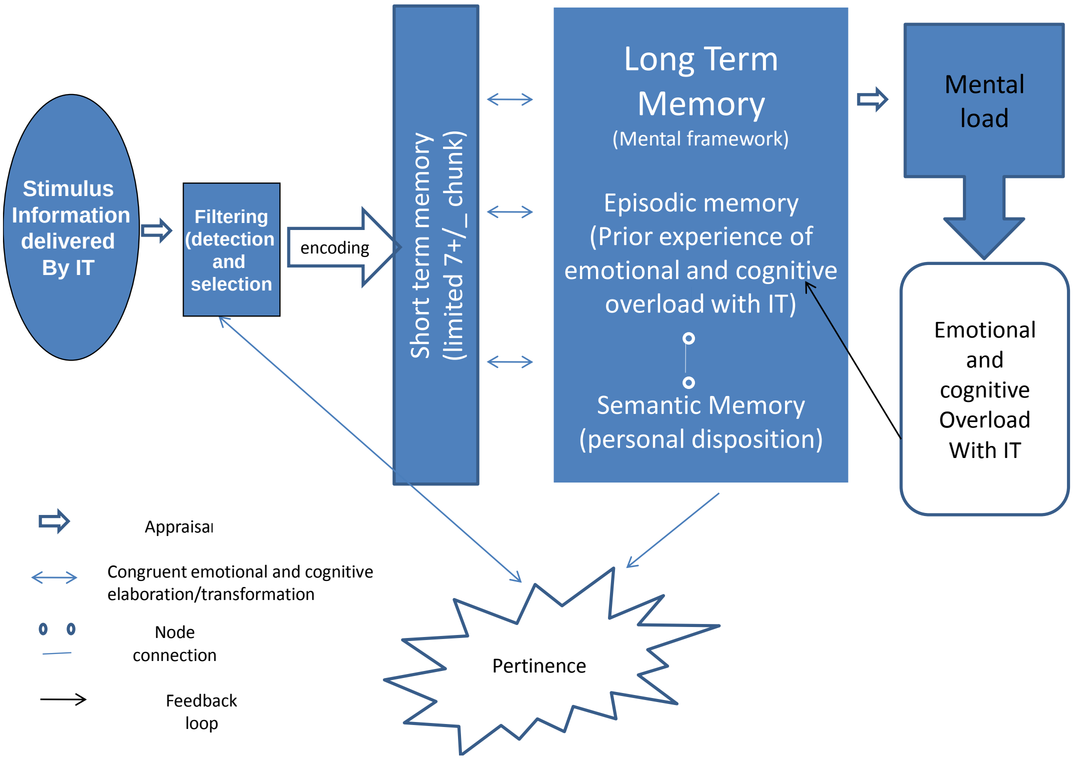

Figure 2.4. The Emotional-Cognitive Overload Model (ECOM). Reprinted from Rutkowski and Saunders (2011).

Cognitive schemata, once encoded in Long-Term Memory, influence the selection of pertinent information that is processed. *Pertinence* is the relevance of a new stimulus based upon a match with an individual's cognitive schemata stored in Long-Term Memory under a personal mental framework. Only when a stimulus is deemed pertinent does it pass through the attentional filter to be encoded in Short-Term Memory. In that case the new information stimulus and the cognitive schemata are congruent. *Congruence* means that the information stimulus matches emotionally and cognitively with the cognitive schemata encoded in Long-

Term Memory. Congruent information is easier to retrieve than non-congruent information (see Rutkowski and Saunders, 2011).

Encoding information in Long-Term Memory under the form of cognitive schemata and retrieval of that information through activation of the schemata is *context-dependent* (Bower, 1981, also see Smith and Vela, 2001 for an overview). Cognitive schemata are easily activated if the context of encoding is reinstated. That is, cognitive schemata are more easily activated in a context that is cognitively or emotionally congruent with the context in which the schemata were constructed. As mentioned before, cognitive schemata improve chunking and decrease Emotional-Cognitive Overload. This effect is amplified when encoding and retrieval context are congruent, as the schemata are more easily activated (Rutkowski and Saunders, 2011).

Cognitive schemata are inherent to the cognitive resources of individuals. *Cognitive resources* are the cognitive “fuel” required for processing information. Cognitive resources are on the one hand fixed and depend on the structure of Short-Term Memory. On the other hand, cognitive resources vary as a function of the personal mental organization of information in Long-Term Memory. Processing information stimuli involves a certain level of emotional and cognitive effort and cognitive resources. *Emotional-Cognitive Overload (ECO)* is a state where the personal cognitive resources of an individual are insufficient for handling the mental load that is created from an information stimulus. *Mental load* is defined as the emotional and cognitive effort, or its appraisal, of processing information stimuli. Responding to mental load involves reloading, activating and matching *personal* cognitive schemata to process information stimuli. Therefore individuals are unequal when facing Emotional-Cognitive Overload with information delivered by IT. Emotional-Cognitive Overload is recognized from its emotional and cognitive manifestations. Emotional manifestations include stress and frustration. Cognitive manifestations include degrading performance and increased errors (Rutkowski and Saunders, 2011).

According to Rutkowski and Saunders (2011), experience of Emotional-Cognitive Overload is encoded in Long-Term Memory as a new cognitive schema. It is referred to as *encoded experience of Emotional-Cognitive Overload* with a particular information stimulus. Experience of Emotional-Cognitive Overload is encoded in the Episodic Memory and is associated with cognitive schemata held in the Semantic Memory. Processing similar information will activate the schema of encoded experience with Emotional-Cognitive Overload. The new information will have a higher chance of not being processed if a negative valence is associated with processing similar information in the past.

The personal mental organization of Long-Term Memory is reflected in personal mental dispositions. Personal mental dispositions embed the notion of stability and permanency implying consistency in behavior over time. Dispositions can be global (trait) or IT-domain specific (state). In this dissertation three important personality traits are included as predictors of IT-related overload or control variables. The Need for Cognition (NFC) is a global personal mental disposition that demonstrates a dispositional tendency to enjoy effortful cognitive activities (Cacioppo and Petty, 1982). It is “a need to structure relevant situations in meaningful, integrated ways” (Cohen, Stotland, and Wolfe, 1955, p. 291). Need for Cognition increases the ability to chunk information meaningfully and therefore decreases mental load. Research has demonstrated that Need for Cognition plays a role in assessing the effectiveness of technology (Tam and Ho, 2005). Anxiety is a second global personal mental disposition used in this dissertation. Anxiety can increase concerns about the ability to process information. Individuals with trait anxiety have a dispositional tendency to process negative affective information (Costa and McGrae, 1992). This reinforces the activation of emotionally congruent cognitive schemata on encoded experience with Emotional-Cognitive Overload in Episodic Memory (Rutkowski and Saunders, 2011).

Cognitive Absorption (CA) with IT is an IT-domain-specific personality mental disposition. It was developed by Agarwal and Karahanna (2000). It is a personal disposition that leads to episodes of total attention where all of an individual’s resources are consumed by the object of attention (p. 673). One important dimension of Cognitive Absorption with IT in the context of IT-related overload is focused immersion. Focused immersion suggests that all of the attentional resources of an individual are focused on a particular task. The cognitive resources make mental effort more efficient and thereby decrease mental load.

2.4 Theory and conceptual model used in this dissertation

The Emotional-Cognitive Overload Model demonstrates the important role of the *personal* mental organization of Long-Term Memory. It deals extensively with pertinence and congruence, emotion, encoded experience with Emotional-Cognitive Overload in Episodic Memory and personal mental dispositions that are part of Semantic Memory. Cognitive Load Theory also stresses the importance of reloading learned information from cognitive schemata encoded in Long-Term Memory to decrease load on the Working Memory. However, and somewhat surprisingly, Cognitive Load Theory does not discuss the structure and personal mental organization of Long-Term Memory. This is surprising because Cognitive Load Theory mainly deals with learning. Learning primarily concerns Long-Term Memory.

This dissertation has a primary aim to improve surgical training. Surgical training aims to construct and organize cognitive schemata in Long-Term Memory (Hsu, Man, Gizicki, Feldman, and Fried, 2008). Therefore this dissertation will draw most extensively on the Emotional-Cognitive Overload Model that underlines the personal mental organization of Long-Term Memory. Also it has a primary focus on IT-related overload. This applies well to the situation of IT-related overload in the Operating Room (OR). Cognitive Load Theory has produced several important instructional design principles which are outlined in Paas, Tuovinen, Tabbers, and van Gerven (2003). These will be further elaborated on in the general discussion on designing medical IT against IT-related overload in Chapter 7.

Conceptual model

Complementary to the definitions of mental load and Emotional-Cognitive Overload (ECO) provided on page 27, the descriptions of Short-Term Memory (STM) and Long-Term Memory (LTM) on page 29-31, and the definition of immersive training outlined on page 10, the following definitions are provided:

- **Information Technology** is defined as "technology used to create, store, exchange, and use information" (Pearlson and Saunders, 2006, p. 14).

- **Information** is "data endowed with relevance and purpose". Relevance and purpose arise from the context in which it is delivered and used (Pearlson and Saunders, 2006, p. 12). An *assumption* related to the conceptual model is that information is processed in the context of a task and role. Particularly throughout this dissertation information is processed by individuals performing the role of a surgical trainee carrying out a set of simulated laparoscopic surgical tasks.

Drawing on the Emotional-Cognitive Overload Model, the following conceptual model is proposed (see Figure 2.5). **Information,** mostly delivered by **Information Technology (IT),** is the primary input. Information is processed in the **individual** human memory system consisting of a Short-Term Memory and Long-Term Memory. The Long-Term Memory is subject to personal mental organization and is therefore differently organized across individuals. These differences are reflected in personal dispositions such as Cognitive Absorption (CA) with IT and Need for Cognition. The cognitive schemata encoded in Long-Term Memory are manipulated through **immersive surgical training**. Since cognitive schemata are inherent to the cognitive resources of the individual, immersive training improves the cognitive resources available for processing and chunking the information. **Emotional-Cognitive Overload (ECO)** occurs when the personal cognitive resources of the individual are insufficient for handling the **mental load** imposed by the information stimulus. Emotional-Cognitive Overload may manifest through its cognitive (e.g., error) and emotional (e.g., stress) manifestations.

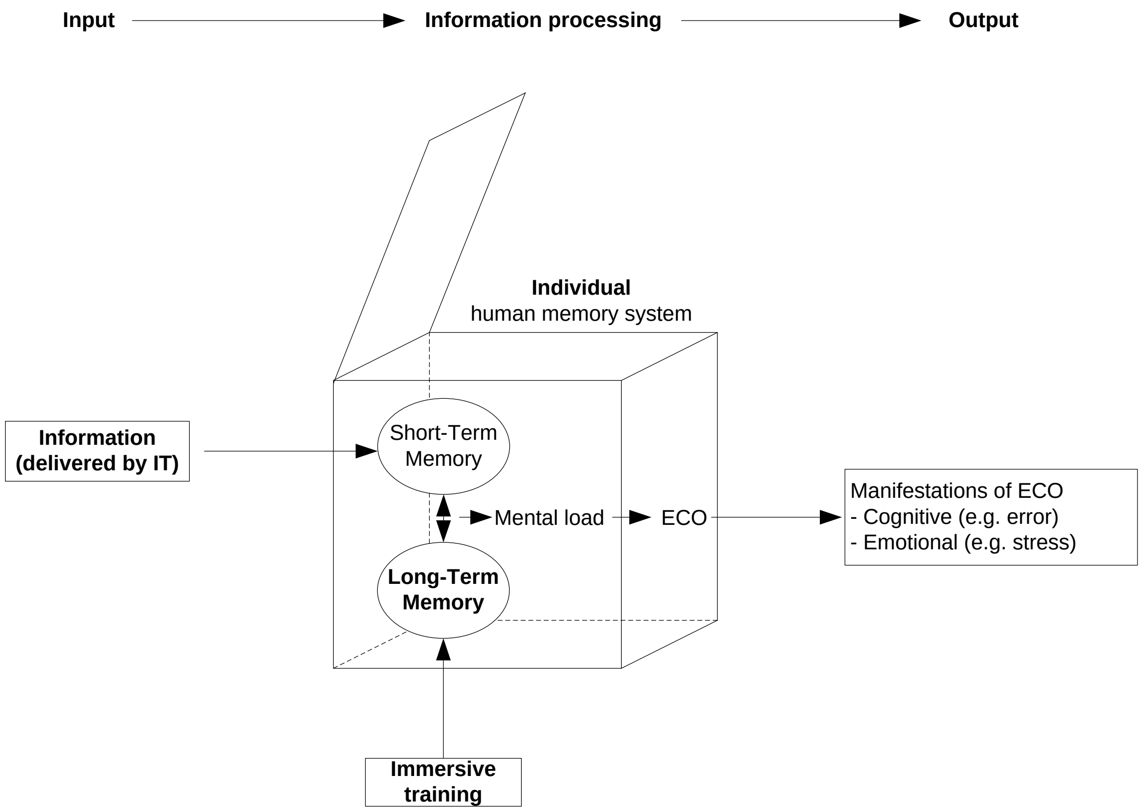

Figure 2.5. Conceptual model used in this dissertation.

The primary contribution of this dissertation lies in the focus on the human memory system in which the information delivered by IT is processed, and particularly on the Long-Term Memory. In this dissertation the cognitive schemata encoded in Long-Term Memory are manipulated through immersive surgical training. In contrast, the human memory system, and particularly the role of Long-Term Memory, is treated as a black box in the "classical" input-output view (see Figure 2.6) on overload used in most previous studies in IS. In that view, overload is mostly defined as an excessive amount of information (for a review see Eppler and Mengis, 2004 as well as Rutkowski and Saunders, 2011) that causes decreased performance (e.g., errors) and stress. Also the role of Long-Term Memory has not been extensively discussed in the surgical literature. Drawing on the Emotional-Cognitive Overload Model and Cognitive Load Theory, this dissertation opens the "black box" of the human memory system by focusing specifically on the Long-Term Memory (see Figure 2.5).

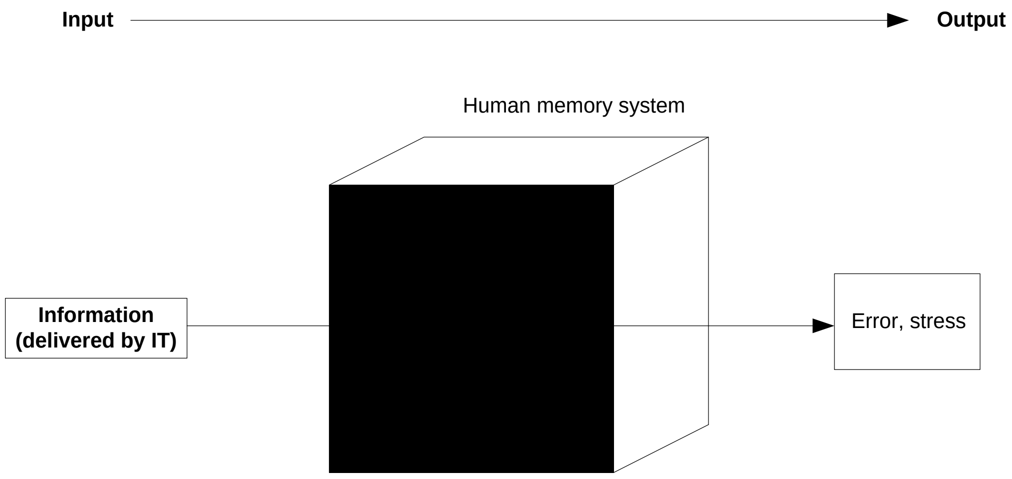

Figure 2.6. The classical view on overload treating the human memory system as a “black box”.

3. Medical IT-related overload: the role of personal mental organization of Long-Term Memory

3.1 The socio-technological setting of the OR

As a next step, observations were conducted during twelve medical interventions in two Dutch hospitals. The goal was to get a more comprehensive insight into medical Information Technology (IT) used during these interventions. Procedures covered the fields of laparoscopic surgery (abdominal and pelvis), interventional cardiology and cardiac surgery (heart), neuro-surgery (brain), and interventional radiology (e.g., stents). These fields are dominated by image guided procedures. An overview of medical IT used during these procedures is provided in Table 3.1. Illustrations of the medical IT are provided subsequently. The overview and illustrations are not intended to be all-embracing. Use of IT varies as a function of the specific procedures performed. It also differs as a function of availability at different hospitals and preference of the surgeon. Rather this overview gives a more comprehensive insight into IT used in the Operating Room (OR).

The main emphasis is put on laparoscopic surgery which is the focus of this dissertation. Other surgical fields are also discussed and demonstrate the high density of medical IT across different medical specialisms.

Table 3.1. Comprehensive overview of medical IT specified by type of intervention

Information Technology	**Laparoscopic surgery**	**Cardiac surgery**	**Neuro-surgery**	**Interventional cardiology**	**Interventional radiology**
Pager /Phone/ Intercom	x	x	x	x	x
Streaming radio technology	x	x		x	
Patient Data Management System*	x	x	x	x	x
Anesthetics technology* - patient vital signs monitor and/or flow monitor	x	x	x	x	x
Scope (e.g., laparoscope, * endoscope, microscope)	x		x		
Computed Tomography (CT) or X-ray *				x	x
Electrocardiograph (ECG) *				x	
Medication dispense technology *	x	x	x	x	
Ultrasound technology *	x	x	x	x	x
Magnetic Resonance Imaging (MRI) *			x	x	x
Heart-lung machine *		x			
Navigation technology			x		

* Illustration provided in Figure 1.1-1.2 & 3.1-3.6

The following pictures of medical IT were taken during observations of twelve surgical procedures and interventions unless mentioned otherwise. Pictures were taken with permission of the medical staff in charge.

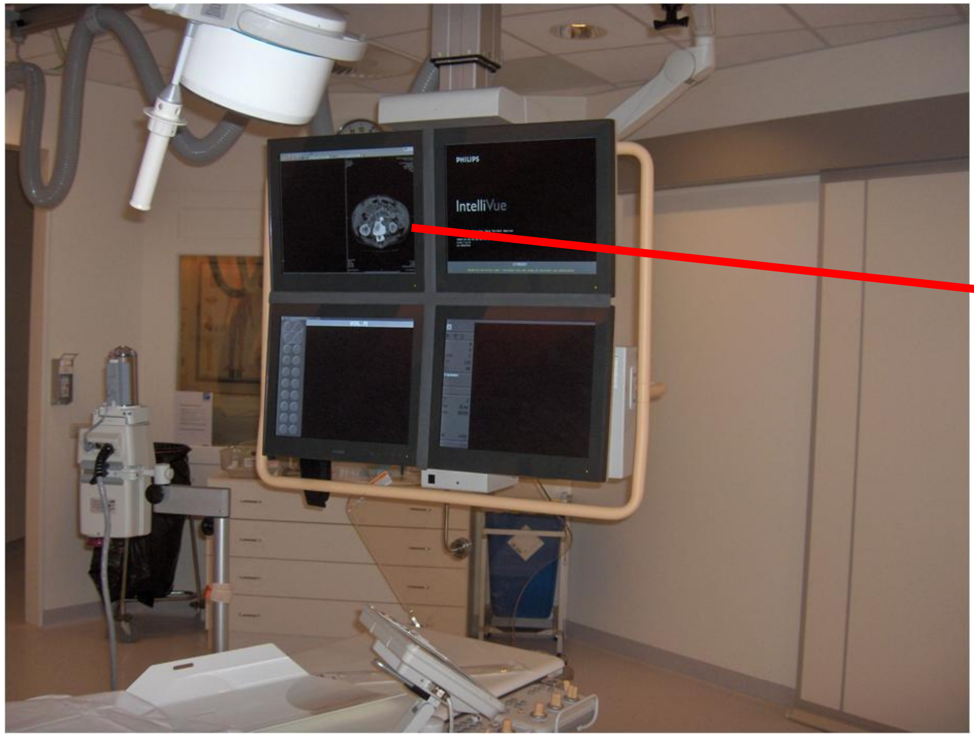

Figure 3.1a. Minimally invasive intervention radiology
Bottom two screens : X-ray images (left = live; right = frozen frame)
Upper right screen: monitoring vital physiological measurements patient
Upper left screen: MRI images, see Figure 3.1b for details

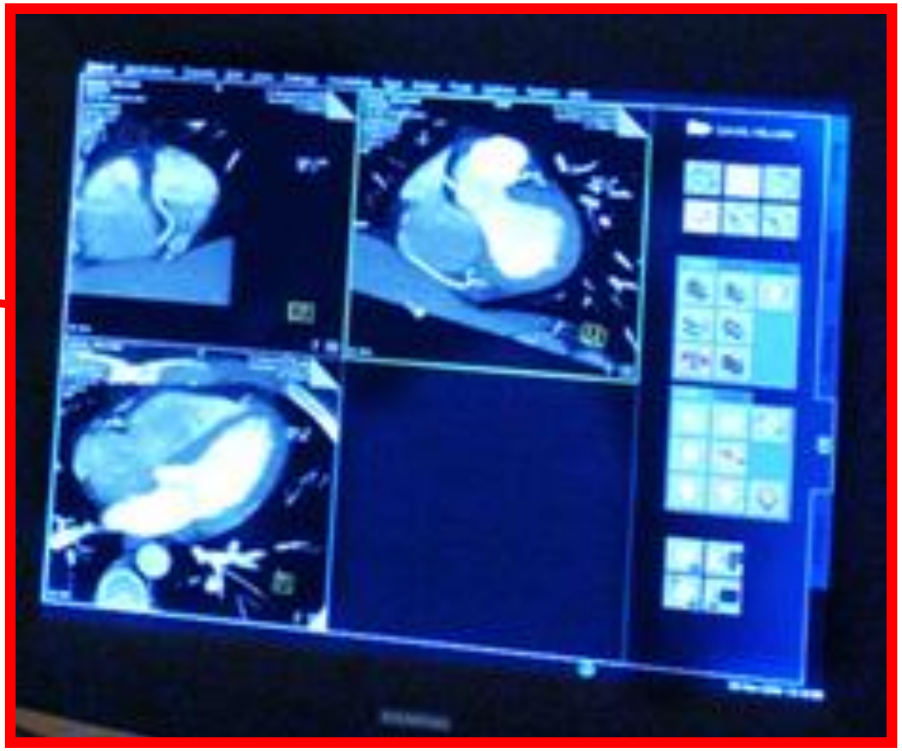

Figure 3.1b. Magnetic Resonance Imaging (MRI)

Figure 3.2. Patient Data Management System

Figure 3.3. Anesthetics technology
Left: flow monitor (monitoring and regulating medication, sedation)
Right: monitoring of vital patient parameters (e.g., heart rate, blood pressure)

Figure 3.4. Echography technology
Medical imaging technology visualizing “weak” tissue such as nerves

Figure 3.5. Medication dispenser technology

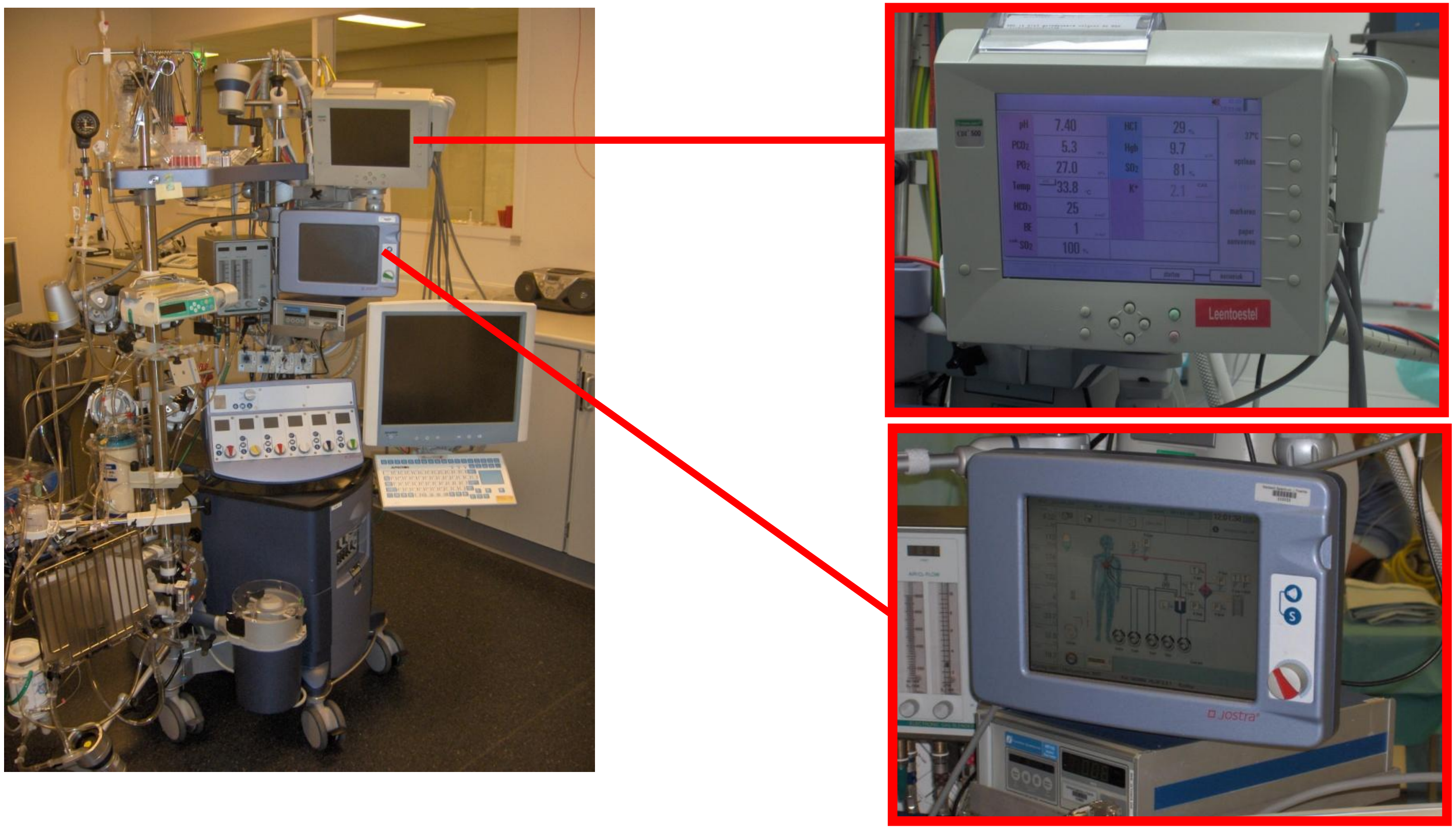

Figure 3.6. Heart-lung machine used during cardiac (heart) surgery.
The heart-lung machine primarily consists of a set of pumps (left) and set of monitors (right). The pumps in conjunction deputize the function of the heart when the heart is shut down during treatment. The monitors are used to continuously regulate and check this process. Information presented on the monitors consists mainly of various blood parameters, blood pressures and blood flow.

The OR as a social setting

The OR is also a social environment. Various members of the surgical team interact, cooperate and collaborate (Wadhera, Henrickson Parker, Burkhart, Greason, Neal, Levenick, Wiegmann, and Sundt, 2010). Surgeons often collaborate with surgeon assistants on a joint surgical task. At the same time surgeons cooperate with anesthesiologists, anesthesiologist-assistants, scrub nurses, circulating nurses, and for specific cardiac interventions with perfusionists. The level of analysis of this dissertation is at the individual level. The focus on the social context is restricted to the impact of the social context on Emotional-Cognitive Overload (ECO) of the individual. ECO on a team level is outside the scope of this thesis as it will require addressing team theory. From an individual level of analysis on IT-related overload the social setting implies that:

(1) Overload can be imposed by poor performance of others

As an example consider a laparoscopic surgical intervention. Laparoscopic surgery is performed using a monitor depicting the image of the camera embedded in the laparoscope (see Figure 3.1). The surgeon processes the information delivered by the monitor. Laparoscope navigation is a task often performed by the least experienced member of the surgical team (Buzink, Botden, Heemskerk, Goossens, de Ridder, and Jakimowicz, 2009). Especially less experienced individuals are vulnerable for overload as they lack a personal mental framework to chunk the information effectively (Hsu, Man, Gizicki, Feldman, and Fried, 2008; Sweller, 1988, Rutkowski and Saunders, 2011). A lack of experience may evoke a state of ECO in the surgeon assistant who consequently delivers an image that poorly represents the operative field. Zheng, Janmohamed, and MacKenzie (2003) indicate that improper laparoscope navigation of the assistant in turn imposes additional mental load on the surgeon. The surgeon has to mentally rotate the image and perform sensori-motor integration. This increases his or her stress level and impairs his or her performance.

(2) Information that is pertinent to an anesthesiologist, nurse or perfusionist may not be as pertinent to the surgeon

The above illustrations show that the OR is packed with medical IT. This IT is used by different members of the surgical team. For example, information delivered by heart-lung machines (Figure 3.6) and flow- and vital-signs monitors (Figure 3.3) may be less pertinent to the surgeon. However processing this information does require allocation of cognitive resources. Zheng, Tien, Atkins, Swindells, Tanin, Meneghetti, Qayumi, Neely, and Panton (2011) demonstrated using eye-tracking technology in a simulation setting that surgeons do attend frequently to vital-signs information.

On top of the cognitive demands imposed by medical IT, surgeons are confronted with conversations not pertinent for the case at hand. These are additional sources of distraction, but mainly of information that require cognitive resources to be processed. It may affect the performance of the novice surgeon (Healey, Primus, and Koutantji, 2007; Sevdalis, Healey, and Vincent, 2006).

3.2 IT-related overload during simulated laparoscopic surgery and the role of personal mental dispositions[6]

Previous studies (Goodell, Cao, and Schwaitzberg, 2006; Hsu, Man, Gizicki, Feldman, and Friend, 2008) have posed arithmetic problems to increase cognitive load in a laboratory setting. These studies assume that the arithmetic problems load on the limited capacity Short-Term Memory (STM). They demonstrated significant adverse effects on surgical performance. Arithmetic problems are used as experimental proxies for realistic sources of overload such as a laparoscope image that poorly represents the operative field, case irrelevant communication and music delivered by streaming radio. According to the Emotional-Cognitive Overload Model (ECOM: Rutkowski and Saunders, 2011) these realistic socio-technological sources might have a different impact on Emotional-Cognitive Overload (ECO). That is, someone may have a high ability to chunk information but may not be able to mentally rotate the image provided by the laparoscope. Similarly he or she may not be able to cope with case irrelevant communication or music delivered by streaming radio.

This is also supported by Cognitive Load Theory (CLT: Sweller, 1988). CLT argues that information presented in different modalities is processed in different slave systems. Images are processed in the visuospatial sketchpad whereas verbally posed arithmetic problems are processed in the phonological loop. These slave systems can be overloaded separately. Overload in the phonological loop does not imply that the visuospatial sketchpad is also overloaded.

Drawing on ECOM, it is assumed in this study that a laparoscope image that poorly represents the operative field, case irrelevant communication among team members and music delivered by streaming radio are potential **realistic** sources of ECO in the OR. This is opposed to an **artificial** setting where operative field representation is optimal and case irrelevant communication and music are absent. Congruent with ECOM, realistic conditions are expected to impose a higher load than artificial conditions. ECO manifests through

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[6] Published as Pluyter, J.R., Buzink, S.N., Rutkowski, A.F., & Jakimowicz, J.J. (2010). Do absorption and realistic distraction influence performance of component task surgical procedure? Surgical Endoscopy, 24(4), 902-907.

impaired performance and stress (Rutkowski and Saunders, 2011). This study aims to assess the impact of these realistic technological and social sources of ECO on performance and stress of the surgical trainee when performing a simulated surgical task. Thereby ECO is measured indirectly through its cognitive and emotional manifestations. If realistic sources of ECO indeed impact performance and stress, then there is a need to manage and train accordingly. In particular, such a finding would identify the need to train under realistic conditions that would allow surgical residents to learn how to cope with realistic sources of ECO (Stefanidis, Korndorffer Jr, Markley, Sierra, Heniford, and Scott, 2007). This study hypothesizes that:

H1. Under realistic high load conditions **surgical performance** is lower than under artificial low load conditions.
H2. Under realistic high load conditions **stress** levels will be higher than under artificial low load conditions.

Additionally, individuals are unequally overloaded as a function of their personal mental dispositions that reflect the personal mental organization of Long-Term Memory (Rutkowski and Saunders, 2011). This study includes the analysis of two personal mental dispositions that were introduced in Chapter 2. These are the Need For Cognition (NFC) and Cognitive Absorption (CA) with IT. NFC is a global personal mental disposition, CA with IT an IT-domain specific personal mental disposition. Congruently the following hypotheses are proposed for performance under realistic high load conditions:

H3a. Participants with high CA with IT will demonstrate higher **surgical performance** than participants with low CA with IT.
H3b. Participants with high CA with IT will demonstrate lower levels of **stress** than participants with low CA with IT.

H4a. Participants with high NFC will demonstrate higher **surgical performance** than participants with low NFC.
H4b. Participants with high NFC will demonstrate lower levels of **stress** than participants with low NFC.

3.2.1 Research method and materials

Participants

In this study, medical trainees (n=12) took part in a 2 (artificial low load vs. realistic high load) within-subject experimental design. All the participants were selected on the basis that they had no simulator or clinical experience performing laparoscopic procedures. This study thus provides a baseline measure[7]. Participants took part on a voluntary basis.

Surgical simulator, tasks and experimental conditions

The Clip and Cut (C&C) module of the Xitact LC 3.0 Virtual Reality (VR) simulator (Xitact SA, Morges, Switzerland) was used in this study. The module simulates part of a laparoscopic cholecystectomy procedure. This is the removal of a gallbladder using laparoscopic surgical technology. Appendix A provides a detailed description of the VR simulator (Table A.1) and simulated surgical task (Table A.2). The trainees were assisted by an assistant navigating the laparoscope.

Participants performed the surgical task in an artificial Low Load (LL) condition and a realistic High Load (HL) condition. Under artificial LL participants were exposed by the laparoscope navigator to a laparoscope image providing an 'optimal[8]' representation of the operative field. Here the cystic duct[9] and cystic artery were presented on different horizontal levels. That is, they were distinguishable from each other without mentally rotating the image. Also participants were not exposed to case-irrelevant communication or music delivered by streaming radio.

Under realistic HL the laparoscope was manipulated using a standardized protocol to provide a laparoscope image that poorly represented the operative field. Here the cystic duct and cystic artery were presented on the same horizontal level. This required mental rotation of the image by the surgical trainee. Additionally participants were exposed to a standardized combination of music representing streaming radio delivered by a laptop computer. It was mixed in parallel with 30 seconds of case-irrelevant communication. Together these represented social sources of ECO. To ensure that all the participants were fully exposed to the case-irrelevant communication, the conversation was placed within the first 70 seconds of the audio file.

All the participants were assisted by the same assistant manipulating the laparoscope. This was an accomplice trained to manipulate the image focus in the standardized and

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[7] Differences in cognitive schemata on medical knowledge about the procedure may still have influenced the level of overload experienced in this study. This is controlled for in subsequent studies presented in this dissertation.

[8] 'Optimal' using standards set by the simulator manufacturer and verified by an experienced surgeon.

[9] The cystic duct is a channel leading from the gallbladder to the common bile duct and carrying bile (gall). The cystic artery lies next to the cystic duct and supplies blood to the cystic duct and gallbladder. For removal of the gallbladder both the cystic duct and artery have to be cut after being pinched off with clips.

controlled way as described above. That was ‘optimal’ representation of the operative field in artificial LL and poor operative field representation in realistic HL. The sessions took place in a separate room to ensure that the participants were not exposed to other sources of information.

Participants performed the surgical task in an artificial Low Load (LL) condition and a realistic High Load (HL) condition. The order of the conditions was fixed in that order. They were not counterbalanced because the carryover effects of the two experimental conditions were expected to be asymmetric. Participants first put in the HL condition would presumably anticipate stress in the subsequent LL condition. Participants put in the reverse order would not anticipate stress in the LL condition. That is because they would not yet be exposed to the high load that increases stress.

Procedure and measures

The participants first completed a pre-test questionnaire (see below) and then received an introduction to the simulator. Subsequently they performed two runs (see Figure 3.7) to familiarize themselves with the simulator and tasks. Each task was explained using a demo video provided by the manufacturer. The video was accompanied by a standardized verbal instruction by the researcher. Then participants completed a second familiarization run without instructions where their baseline performance was assessed. Performance scores were generated by the simulator. These were task completion, task errors, economy of movement, and time required to complete the procedure.

Next, the participants were put in the artificial LL condition. Performance was assessed by the simulator and the participants completed a first post-test (see below).

Finally participants completed the task in the realistic HL condition. Again performance scores were generated by the simulator and participants completed a second post-test (see below).

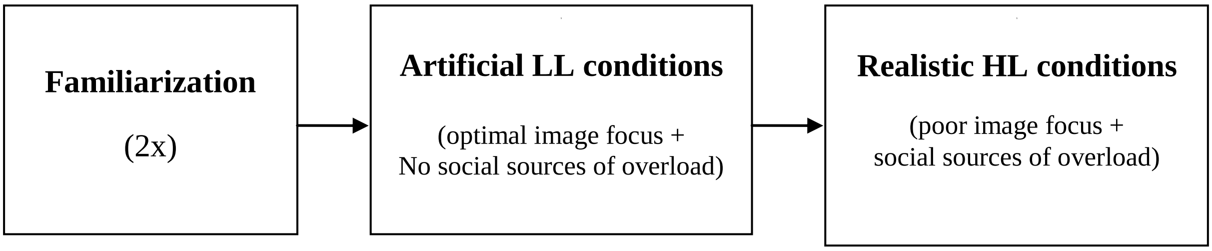

Figure 3.7. Experimental procedure
LL = Low Load, HL = High Load

In the *pre-test questionnaire* the personal mental disposition NFC (Cacioppo and Petty, 1982) was measured using a self-reported scale. It was gathered for post-hoc categorization of performance (recorded by the simulator) and stress (measured in the post-test).
The two *post-test questionnaires* that were administered after LL and HL were identical. They included three stress measures that were gathered using self-reported scales. These were stress toward the noise, stress towards the assistant performing the role of the laparoscope navigator, as well as overall perceived stress (adapted from Cohen, Kamarck, and Mermelstein, 1983; Monroe and Kelley, 1995). ECO was measured only indirectly through its cognitive (surgical performance) and emotional (stress) manifestations. Also the personal mental disposition CA with IT (Agarwal and Karahanna, 2000) was measured in the post-test to obtain an in-context measure of absorption while performing on the surgical simulator. An overview of the scales, items and cronbach alpha scores can be found in Appendix D.

3.2.2 Results

Comparison among conditions

Non-parametric statistics were used in this chapter and throughout this dissertation except from chapter 6. Non-parametric statistics do not make any assumptions about the population distribution of the data. Therefore they are particularly useful to analyze small samples (Pallant, 2007) such as those presented in this dissertation.

The Wilcoxon signed ranks test was used to assess the intercondition (pairwise) comparison between artificial Low Load (LL) and realistic High Load (HL). Table 3.2 provides an overview of the surgical performance measures across the different conditions including familiarization.

Table 3.2. Surgical task performance on the simulator

	Familiarization (run 1)		**Familiarization (run 2: baseline)**		**Low Load (LL)**		**High Load (HL)**	
	M	SD	M	SD	M	SD	M	SD
Task Score	73.00	19.35	115.75	63.02	112.50	59.05	53.92	51.78
Task Completion	91.25	8.29	92.50	11.18	90.42	14.69	82.92	21.69
Task Errors	20.00	15.52	12.50	29.50	7.08	8.908	35.83	30.74
Total Time (s)	124.92	43.52	95.25	25.46	98.67	30.17	111.25	22.19

M = mean, SD = standard deviation
Results based on n=12

The task score was significantly lower (Z = –1.961; p = 0.05) and the task error score significantly higher (Z = –2.162; p = 0.03) in the realistic HL than in the artificial LL condition (Table 3.3). These represent cognitive manifestations of ECO supporting hypothesis 1.

Moreover in realistic HL, the participants were significantly more stressed by the noise (Z = –2.820; p = 0.005) and the assistant performing the role of the laparoscope navigator (Z = –2.263; p = 0.02) than in artificial LL. These represent emotional manifestations of ECO supporting hypothesis 2. Interestingly stress is directed towards both the technological and social sources of ECO presented in visual and auditory modalities. No significant differences could be reported for perceived overall stress, task completion or economy of movement.

Table 3.3. Results of hypotheses 1 and 2

Hypothesis	Dependent variable	Low Load (n=12) Mean (SD)	High Load (n=12) Mean (SD)	Z	p
H1: surgical performance (supported)	Task score Task errors	113 (59) 7 (9)	54 (52) 36 (31)	-1.961 -2.162	.05* .03*
H2: stress (supported)	Stress towards noise Stress towards assistant	1.42 (0.48) 5.58 (2.50)	2.77 (1.63) 7.75 (2.99)	-2.820 -2.263	.005* .02*

p-values based on Wilcoxon Signed Ranks Test (two-tailed): * indicates $p \leq .05$

The results support the hypotheses that participants demonstrate higher cognitive and emotional manifestations of ECO under realistic high load conditions than under artificial low load conditions.

Individual differences in personal mental dispositions

The Mann–Whitney U test was used to assess differences between groups based on their levels of NFC and CA with IT under realistic high load conditions. Categorizing based on CA with IT (medium: n = 6 vs. high: n = 4) showed that medium cognitively absorbed participants (mean rank [mrk] = 7.42) were significantly more stressed by the noise (Z = –2.467; p = 0.01) than were the highly absorbed participants (mrk = 2.63). The remaining two participants were lowly absorbed.

Categorizing based on the NFC (low: n = 7 vs. high: n = 5) showed that in LL the participants with a low NFC (mrk = 8.36) showed a significantly higher level of perceived overall stress (Z = –2.115; p = 0.03) than did the participants with a high NFC (mrk = 3.90). Similar results could be reported for HL (mrk = 8.64 for low NFC and 3.50 for high NFC; Z = –2.44; p = 0.01). An overview of the support for the hypotheses is provided in Tables 3.4 and 3.5.

Table 3.4. Individual differences based on CA with IT when exposed to realistic high load

Hypothesis	Dependent variable	CA medium (n=6) Mean rank	CA high (n=4) Mean rank	Z	p
H3a: surgical performance (rejected)	Surgical performance	-	-	-	NS
H3b: stress (supported)	Stress towards noise	7.42	2.63	-2.467	.01*

p-values based on Mann Whitney U Test (two-tailed): * indicates p≤..05

Table 3.5. Individual differences based on NFC when exposed to realistic high load

Hypothesis	Dependent variable	NFC low (n=7) Mean rank	NFC high (n=5) Mean rank	Z	p
H4a: surgical performance (rejected)	Surgical performance	-	-	-	NS
H4b: stress (supported)	Stress overall	8.64	3.50	-2.44	.01*

p-values based on Mann Whitney U Test (two-tailed): * indicates p≤.05
Results based on n=12

In sum, individuals experience emotional manifestations differently as a function of their global and IT-domain specific personal mental dispositions. These reflect differences in the personal mental organization of LTM.

3.2.3 Discussion

This study demonstrates the adverse effect of realistic sources of ECO on performance and stress during simulated laparoscopic surgery. It identifies a need to train under realistic high load conditions. Overall, the results are in line with previous research demonstrating detrimental effects on performance (Goodell et al, 2006; Moorthy, Munz, Dosis, Bann, and Darzi, 2003).

The ECOM predicted that personal mental frameworks held in Long-Term Memory (LTM) influence chunking of information and therefore ECO. This prediction was supported: participants with high CA with IT and high NFC indicated significantly lower levels of emotional manifestations of ECO in the form of stress. As predicted by ECOM they likely were better able to focus their cognitive resources available for chunking the information delivered by the VR simulator. They could therefore more easily cope with additional load imposed by the realistic sources of ECO. NFC appears an important global personal mental disposition and CA with IT an important IT-domain specific personal mental disposition when studying medical IT-related overload. Interestingly, they had an impact only on the emotional and not on the cognitive manifestations of ECO.

Managerial and clinical implications

The results of this study have three major implications for improving surgical performance and patient safety in the OR. First, the consequences of technological and social sources of overload cannot be underestimated. Managerial effort should be put into increasing the awareness among OR staff to avoid preventable adverse events. This should include untangling the relationship between various *combinations* of overload sources and surgical performance. For example, a laparoscope image that poorly represents the operative field may have a more pronounced adverse effect in combination with case-irrelevant communication. Clarifying these impacts would facilitate the construction of an improved working environment. Of course, more experienced surgeons may have developed strategies to cope with these factors (Hsu, Man, Gizicki, Feldman, and Fried, 2008). Especially novice surgeons may however have not. In fact, half of the surgical residents in Dutch hospitals do not have more hands-on experience with laparoscopic surgery before performing their first laparoscopic cholecystectomy under supervision on a patient than the participants included in this study (IGZ, 2007). Realistic sources of overload may have a similar impact on these residents while they are performing on a patient.

Second, preclinical training of laparoscope navigation seems desirable (Dunkin, Adrales, Apelgren, and Mellinger, 2007; Zheng, Janmohamed, MacKenzie, 2003). This can reduce the need for mental rotation of the laparoscope image by the surgeon, decreasing mental load. Basic skills training should not be restricted to tissue manipulation only. Rather, laparoscope navigation skills should be included in a comprehensive training program.

Finally, individuals are unequal when facing potential sources of overload as a function of their propensity to be cognitively absorbed when using medical IT. Moreover, cognitively complex individuals experience lower levels of stress during simulated surgery under realistic high cognitive load. Personal mental dispositions should be taken into consideration to provide an improved working environment. Personal mental dispositions reflect the personal mental organization of LTM. Further research should focus on the role of LTM when studying overload in the OR. The next chapter focuses on the role of chunking and personal mental organization of LTM under the form of cognitive schemata.

Toward a comprehensive training program

The introduction of myriad new IT in the OR has made information processing a central part of the surgical process. IT-related overload results from inability to handle the IT properly (e.g., providing a laparoscope image that poorly represents the operative field). Improper training in handling new medical IT and information delivered by IT implies introducing potential sources of overload to the surgical process. That is, a lack of laparoscope navigation skills may impose additional mental load on the surgeon (Zheng et al., 2003). Overload also results from inability to process the information that IT and social context (i.e., case-irrelevant communication of team members) brings to the novice surgeon. These factors can be at least partially trained or managed.

Hence, training surgeons and surgical residents to cope with realistic sources of overload in a safe and controlled preclinical setting is paramount. This dissertation introduced immersive surgical simulation training under realistic technological and social conditions as a means to reduce overload. These efforts should complement training of both basic visual-spatial and psychomotor skills, hence providing a comprehensive training program. Immersive training is grounded in the personal mental organization of LTM under the form of cognitive schemata that improve chunking. This will be discussed in the next chapter.

Recommendations for further research

Using medical trainees in this study made it possible to demonstrate the actual impact of realistic social- and technological sources of overload on surgical performance and stress in the absence of coping strategies. It would be interesting to include groups that are trained in different loading conditions. This would allow for objectification of the effect of the proposed comprehensive training program. In such studies, it is recommended to include realistic social and technological sources of overload to obtain relevant results. Also, participants should have no previously encoded cognitive schemata that could interfere with the training intervention. This principle is applied in the remainder of this dissertation to develop and compare immersive training against conventional training programs. Further research could also involve experienced surgeons.

Furthermore, in the minimal setting of this study, it was not possible nor the objective to quantify the impact of the sources of overload in isolation. The participants did indicate that they were stressed by both the laparoscope image that poorly represented the operative field and the social sources of overload. Also the impact of these sources in isolation on cognitive and emotional manifestations of overload is well established in the literature (Sevdalis, Healey, and Vincent, 2006; Moorthy, Munz, Undre, and Darzi, 2004; Mahawar, 2003; Zheng et al., 2003). However, further research should include direct measures of ECO. Validated self-reported measures are introduced in the subsequent chapters. They were not available when this study was conducted. In general, measuring cognitive overload has been a challenge (Paas, Tuovinen, Tabbers and Van Gerven, 2003; see also Rutkowski, Saunders, and Pluyter, 2012). A more comprehensive setting could also provide opportunities for physiological measurement of overload and stress during high load conditions. Chapter 4 introduces a physiological measure of ECO.

3.3 Touching ground for immersive training: the role of chunking and congruence in memory[10]

3.3.1 Introduction and theoretical background

Bitterman (2006) reported a congestion of data screens in the Operating Room (OR) delivering complex medical information. This imposes an ever-increasing load on the surgeon. In the surgical literature presented in Chapter 2, IT-related overload was analyzed almost exclusively for Image Guided Surgery (IGS). These involve complex medical information delivered by medical Information Technology (IT) by default. The OR has become a setting where the surgeon is constantly required to process information. Section 3.1 further illustrated the omnipresence of information delivered by medical IT during surgical interventions. Information is delivered by laparoscopic technology, anesthetic machines and procedural checklists, to only name a few. These ITs constantly bring high amounts of information into the OR. This is referred to in this chapter as a **context of high amount of information delivered by IT**. Even information less pertinent to the surgeon requires allocation of cognitive resources to be processed (Zheng et al., 2003).

This study aims to investigate whether IT-related overload is simply about an excessive amount of information. The previous chapter revealed that individuals are unequally overloaded as a function of their personal mental dispositions. This finding emphasizes the importance of the personal mental organization of Long-Term Memory (LTM). Interestingly, the level of experience or expertise of the surgeon was identified in the surgical literature review as an antecedent of overload. This is in line with Cognitive Load Theory (CLT: Sweller, 1988) and the Emotional-Cognitive Overload Model (ECOM: Rutkowski and Saunders, 2011). Experience underlines the potential role of chunking and cognitive schemata. Particularly, repetitive surgical training and practice increases the level of experience. It allows construction and organization of cognitive schemata in LTM that improve chunking (Rutkowski and Saunders, 2011). Manipulation of chunking through cognitive schemata would open up possibilities to improve surgical training to anticipate overload.

This study tests whether a high amount of information required for laparoscopic surgery can be less overloading than a low amount of information as a function of individual cognitive resources available for chunking the information. The hypotheses are proposed next.

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[10] Parts of this chapter were included in Pluyter, J.R., Rutkowski, A.-F. (2010). Is overload really about too much information? Doctoral Consortium of International Conference on Information Systems (ICIS) 2010, St. Louis, Missouri, US. Doctoral Consortium Chairs Sambamurthy, V. and Tan, B. Admission: forty participants annually selected worldwide.

Hypotheses

This study draws particularly on the ECOM. The model was presented in Chapter 2 on overload theory. This study tests whether a high amount of information required for laparoscopic surgery can be less overloading than a low amount of information as a function of individual cognitive resources available for chunking the information. Chunking is manipulated in this study through construction of cognitive schemata that vary in their degree of congruence with the retrieval context.

Laparoscopic surgery is performed using laparoscopic technology consisting of a laparoscope monitor depicting the image of the camera embedded in the laparoscope. The surgeon processes the information delivered by the laparoscope monitor. Supporting IT such as vital-signs monitors and procedural checklists also constantly feed information into the OR. In other words, laparoscopic surgery is performed in the **context of a high amount of information delivered by IT**. Amount of information delivered by IT is used in this study to manipulate congruence. Cognitive schemata required to perform laparoscopic surgery are presumably more congruent with a high amount of information delivered by IT context **(H_{info})** than a low amount of information delivered by IT context **(L_{info})**. The following hypotheses are presented on ECO and two of its emotional (increased stress) and cognitive (degrading performance) manifestations.

Congruent context

H1a. Participants holding cognitive schemata encoded in a high amount of information delivered by IT context (H_{info} participants) will experience lower levels of **ECO** during simulated laparoscopic surgery than participants with cognitive schemata encoded in a low amount of information delivered by IT context (L_{info} participants).

H2a. H_{info} participants will experience lower levels of **stress** during simulated laparoscopic surgery than L_{info} participants.

H3a. H_{info} participants will demonstrate higher levels of **performance** during simulated laparoscopic surgery than L_{info} participants.

Incongruent context

H1b. Participants holding cognitive schemata encoded in a high amount of information delivered by IT context (H_{info} participants) will experience lower levels of **ECO** in a incongruent context than participants with cognitive schemata encoded in a low amount of information delivered by IT context (L_{info} participants).

H2b. H_{info} participants will experience lower levels of **stress** in an incongruent context than L_{info} participants.

H3b. H_{info} participants will demonstrate higher levels of **performance** in an incongruent context than L_{info} participants.

3.3.2 Research method and materials

Participants

Surgeons and surgical residents are likely to have encoded cognitive schemata during previous simulation-based training and clinical practice. These schemata influence the ability to chunk and therefore decrease ECO when learning to use new surgical technology. They are vital to performing complex surgery but do not allow the researchers to control the encoding and activation of schemata and introduce a bias.

Twenty-three undergraduate Information Systems (IS) students were invited to participate in this study to control for this potential bias. These students lack any prior schemata on medical simulation training or practice that could interfere with the experimental manipulation of cognitive schemata. Ahuja and Thatcher (2005) applied a similar strategy involving novice participants to control for differing levels of work experience when studying overload. Compared to medical trainees (see section 3.2) the students demonstrate similar levels of immersion and absorption with medical simulation technology and are similarly interested in learning new technology. These are important antecedents of ECO (Pluyter, Buzink, Rutkowski, and Jakimowicz, 2010).

Surgical tasks and simulation technology

A set of three basic surgical tasks was selected to match the prior knowledge of the participants. These were aiming and translocating, stretching, and cutting simulated tissue. The tasks mimic component tasks needed to perform laparoscopic surgery such as gallbladder removal that is referred to as a laparoscopic cholecystectomy. A detailed description and illustration of the tasks can be found in Appendix A, Table A.2.

The simulated surgical tasks were performed on two platforms: an open-box trainer and Augmented Reality (AR) simulation technology. The AR simulation technology used in this study is the Haptica Promis I simulator (Haptica, Dublin, Ireland). The surgical tasks are performed based on a monitor depicting the image of the camera embedded in the laparoscope. They are thus performed based on information delivered by IT. The open-box trainer is used to train the same skills as the AR simulator. As opposed to the AR simulator, however, it provides a direct view on the operating area without the mediation of a laparoscope and monitor. In other words, information is not delivered by IT. An illustration of the same aiming and translocating task on the two different platforms is provided in Appendix A, Table A.1.

The two platforms differ in their amount of information delivered by IT (low vs. high). That is, the open-box trainer provides the surgeon a direct view on the operating area. The AR simulator provides an indirect view on the operating area through several IT components. These are a monitor depicting the image of the camera embedded in the laparoscope (see Appendix A, Table A.1 and also Berguer, Smith, and Chung, 2001). All other factors such as instruments used during the task, angle of insertion of the instruments, and positioning of participants towards the task was held constant for both platforms. The platforms only differed in their amount of information delivered by IT.

Experimental conditions

Participants (n=23) took part in a 2 (cognitive schemata constructed in low vs. high amount of information delivered by IT context) x 2 (performing in low vs. high amount of information delivered by IT context) mixed subject experimental design. Participants were exposed to a higher amount of information delivered by IT in the H_{info} context than in the L_{info} context. An overview of amount of information delivered by IT in multiple modalities or cues (Dennis and Kinney, 1998) is presented in Table 3.6. Participants in the H_{info} context receive more information in each cue (visual, auditory) than in the L_{info} context. Illustrations and detailed descriptions of these ITs are provided in Appendix A, Table A.3.

Table 3.6. Amount of information delivered by IT

Information delivered by IT	**Modality of information**	**Description of information**	**LOW amount of information delivered by IT context [L_{info}]**	**HIGH amount of information delivered by IT context [H_{info}]**
Primary laparoscope monitor	Visual	The primary laparoscope monitor depicts the image of the camera embedded in the laparoscope.	X	X
Procedural checklist	Visual	Checklist for step-by-step performance of the simulated surgical procedure (e.g., cut tissue).	X (paper based*)	X (computer based)
Auditory pulse-oxy signal	Auditory	Auditory pulse signal varying in speed and pitch. The speed of the pulse represents the heart rate of the simulated patient. The pitch of the signal represents the saturation level of the patient.	X	X
Vital signs monitor	Visual	Monitor providing information on the health condition of the simulated patient (heart rate, blood pressure, arterial blood pressure, consciousness, saturation (i.e., concentration of oxygen in the blood) and body temperature).		X
Supplementary laparoscope monitor	Visual	Monitor delivering the exact same information as the primary laparoscope monitor. It is a duplicate monitor.		X
Pager	Auditory	Personal telecommunication device. The pager "beeps" when it receives a call.		X
Streaming radio	Auditory	Streaming radio signal delivered through a laptop computer.		X

* the paper based and computer monitor based procedural checklist contained exactly the same information in the same font and size

All participants first completed a pre-test questionnaire (see below). Participants were then randomly assigned to a low amount of information delivered by IT context (L_{info}; n=12) or high amount of information delivered by IT context (H_{info}; n=11) context. Participants completed two training runs of the three basic tasks on a surgical box trainer to construct their cognitive schemata in their assigned context (see Figure 3.8).

Participants then completed two runs of the same tasks on the AR simulator instead of the box trainer. Participants were first put in the context equal to that which they were exposed to during box training (**congruent context**). That is, L_{info} participants were assigned to a low amount of information delivered by IT context with the laparoscopic monitor delivering information delivered by IT (L_{info}^{+}). H_{info} participants were assigned to a high amount of information delivered by IT context with the laparoscopic monitor delivering additional information delivered by IT (H_{info}^{+}). H_{info}^{+} is illustrated in Figure 3.9. Surgical performance was recorded by the simulator. Participants filled in a first post-test questionnaire (see below) after completing the tasks.

Finally, conditions were crossed (**incongruent context**). Participants were put in a context that was less congruent with their cognitive schemata, held in their personal mental framework. L_{info} participants were assigned to H_{info}^{+} whereas H_{info} participants were assigned to L_{info}^{+}. Surgical performance was recorded by the simulator. Participants filled in a second post-test questionnaire (see below) after completing the tasks.

All participants were instructed to perform the surgical tasks as economically, smoothly and quickly as possible. They were also instructed to only operate when the heart rate and oxygen level of the simulated patient were stable. Critical limits of stable and unstable were provided upfront and the patient condition could be assessed equally well using the auditory or visual representation of the heart rate and level of oxygen or both.

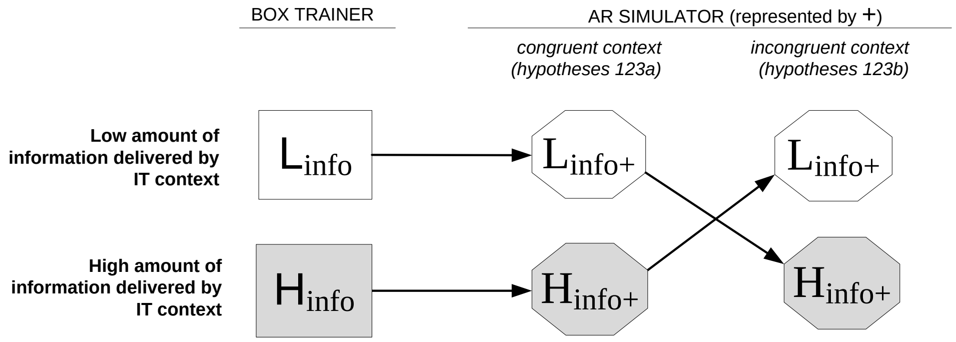

Figure 3.8. Study protocol.

L_{info} = Low amount of information delivered by IT context (white) vs. H_{info} = High amount of information delivered by IT context (grey); Platform: box trainer (boxed shapes) vs. AR simulator (octagons)

Figure 3.9. Illustration of H_{info}^{+} represented by grey octagons in Figure 3.8

Measures

Measures were gathered at three points in time. In the *pre-test questionnaire*, several important control variables and antecedents of ECO were measured. These were experience with car driving-, flight-, or surgical simulation and gaming, encoded experience of ECO with IT (Rutkowski and Saunders, 2010) and Cognitive Absorption (CA) with IT (Agarwal and Karahanna, 2000).

The *two post-test questionnaires* both included the same measures. ECO with information delivered by the laparoscope monitor was measured directly using a validated self-reported scale (Rutkowski and Saunders, 2010). Overall perceived stress was measured using a self-reported scale (adapted from Cohen, Kamarck, and Mermelstein, 1983; Monroe and Kelley, 1993) as an emotional manifestation of ECO.

Surgical performance scores were assessed by the surgical simulator while performing the simulated surgical tasks. The recorded performance scores were: total time required to complete the set of three tasks, economy of movement and smoothness of movement. Higher scores on these parameters indicate poor performance, which is a cognitive manifestation of ECO. Time required to detect changes in heart rate was recorded using a timer. It was used as a control variable to assess whether the streaming radio signal, besides being part of a realistic context, was a source of noise to the participants. An overview of the scales, items and cronbach alpha scores can be found in Appendix D.

3.3.3 Results

Control variables

No differences were found between H_{info} and L_{info} participants on the control variables prior experience with car driving-, flight-, or surgical simulation, encoded experience of ECO with IT, and CA with IT using non-parametric statistics (Mann–Whitney U test). The cognitive schemata of the participants in both experimental conditions can therefore be considered to be equal with respect to these personal mental dispositions. L_{info} participants (mean rank [*mrk*] = 15.13) did report higher levels of experience with gaming (Z= -2.404; p=.019) than H_{info} participants (mrk = 8.59). Higher levels of gaming experience in L_{info} participants could have improved chunking and decrease ECO. However, L_{info} participants were not found to be the better chunkers in this study, as outlined below.

Congruent condition

The Mann–Whitney U test was used to test the set of hypotheses H123a. H_{info} participants (mrk = 7.29) reported a significant tendency towards lower levels of ECO with information delivered by the laparoscope monitor (Z= -1.861; p=.069) when performing on the AR simulator in the congruent condition than L_{info} participants (mrk = 14.50). H_{info} participants (mrk = 8.18) reported significantly lower levels of overall perceived stress (Z= -2.602; p=.009) when performing on the AR simulator in the congruent condition than L_{info} participants (mrk = 15.50). Stress is an emotional manifestation of ECO (Rutkowski and Saunders, 2011). Remember that H_{info} participants were de facto exposed to **more** information than L_{info} participants (see Table 3.6). These results provide partial support for H1a and support H2a (see Table 3.7a).

No significant differences could be found between the training conditions on the three performance indicators. Performance was subsequently compared based on the level of self-reported ECO with information delivered by the laparoscope monitor. The sample was split into two groups using a median split (n =11 participants reporting higher levels of ECO; n=12 participants reporting lower levels of ECO). Performance scores between these groups did not significantly differ.

Time required to detect changes in heart rate was used as a control variable to assess whether the streaming radio signal, besides being part of a realistic context, was a source of noise to the participants. According to the communication model of Shannon and Weaver (1949) noise may interfere with the signal. In this case the heart rate signal may be detected faster in the absence of music forming a source of noise. H_{info} participants (mrk = 17.23) were significantly slower at detecting changes in heart rate (Z = 3.573; p=.001) in the congruent condition than L_{info} participants (mrk = 7.21). This may be an effect of noise because H_{info} participants were exposed to music and L_{info} participants were not. An additional analysis was performed to determine whether this effect was related to ECO. The sample was split into two groups using a median split (n =11 participants reporting higher levels of ECO; n=12 participants reporting lower levels of ECO). Time required to detect changes in heart rate did not significantly differ between these groups. Hence the findings are likely due to noise of the streaming radio which interfered with the heart rate signal. Also from a clinical perspective detecting changes in heart rate is the primary responsibility of the anaesthesiologist-assistant rather than the surgeon.

Table 3.7a. Support of hypotheses 123a

Hypothesis	**Dependent variable**	**L_{info} participants (n=12)**	**H_{info} Participants (n=11)**	**Z**	**P**
H1a (partially supported)	ECO (with information delivered by the laparoscope monitor)	Median = 2.88 Mean(SD) = 3.17 (1.52)	Median = 2.00 Mean(SD) = 2.16 (1.32)	-1.861	.069^{+}
H2a (supported)	Stress	Median = 3.29 Mean(SD) = 3.48 (.61)	Median = 2.86 Mean(SD) = 2.87 (.45)	-2.602	.009*
H3a (rejected)	Performance a. time required to complete tasks	Median = 1032 Mean(SD) = 1074 (346)	Median = 955 Mean(SD) = 994 (268)	-.586	NS
	b. economy of movement	Median = 3698 Mean(SD) = 3798 (1322)	Median = 3510 Mean(SD) = 3535 (965)	-.554	NS
	c. smoothness of movement	Median = 7463 Mean(SD) = 8028 (2785)	Median = 7119 Mean(SD) = 7363 (2073)	-.308	NS

p-values based on Mann Whitney U Test (two-tailed): $^{+}$ indicates p≤.1 * indicates p≤.05

The results demonstrate that cognitive schemata required to perform laparoscopic surgery are more congruent with a high amount of information delivered by IT context (H_{info}) than a low amount of information delivered by IT context (L_{info}). As predicted by ECOM they increase chunking and therefore decrease ECO. This was supported with a significant tendency of the direct self-reported measure of ECO and a significant effect on stress as an emotional manifestation of ECO.

Incongruent condition

Conditions were crossed to explore how participants responded to less congruent information delivered by the IT context. The Mann–Whitney U test was used to test the set of hypotheses H123b. H_{info} participants (mrk = 8.64) reported lower levels of ECO (Z = -2.330; p=.02) when performing in their incongruent condition (L_{info}^{+}) than L_{info} participants (mrk = 15.08) in their incongruent condition (H_{info}^{+}). Apparently H_{info} participants can adapt with low cognitive effort to a context holding a lower amount of information delivered by IT than was previously encoded in their cognitive schemata. For L_{info} participants the incongruent context required cognitive effort to chunk the high amount of information delivered by IT.

No differences were found in stress or surgical performance. Performance and stress were subsequently compared based on the level of self-reported ECO with information delivered by the laparoscope monitor. The sample was split into two groups using a median split (n =11 participants reporting higher levels of ECO; n=12 participants reporting lower levels of ECO). Performance scores and stress between these groups did not significantly differ.

Time required to detect changes in heart rate was used as a control variable to assess whether the streaming radio signal was a source of noise to the participants. No significant differences in time required to detect changes in heart rate were found when comparing H_{info} participants to L_{info} participants or when comparing participants reporting higher levels of ECO to participants reporting lower levels of ECO.

Table 3.7b. Support of hypotheses 123b

Hypothesis	**Dependent variable**	**L_{info} participants (n=12)**	**H_{info} Participants (n=11)**	**Z**	**P**
H1b (supported)	ECO (with information delivered by the laparoscope monitor)	Median = 2.50 Mean(SD) = 2.54 (1.11)	Median = 1.00 Mean(SD) = 1.54 (1.01)	-2.330	.020*
H2b (rejected)	Stress	Median = 3.07 Mean(SD) = 3.00 (.80)	Median = 2.86 Mean(SD) = 2.82 (.84)	-.586	NS
H3b (rejected)	Performance				
	a. time required to complete tasks	Median = 813 Mean(SD) = 834 (217)	Median = 709 Mean(SD) = 790 (210)	-.615	NS
	b. economy of movement	Median = 2926 Mean(SD) = 3091 (1048)	Median = 2436 Mean(SD) = 2796 (753)	-.492	NS
	c. smoothness of movement	Median = 6328 Mean(SD) = 6244 (1664)	Median = 5315 Mean(SD) = 5880 (1638)	-.369	NS

p-values based on Mann Whitney U Test (two-tailed): * indicates $p \leq .05$

Participants holding cognitive schemata encoded in a high amount of information delivered by IT context (H_{info} participants) did experience significantly lower levels of ECO in an incongruent context compared to their congruent context whereas L_{info} participants did not. This supports hypothesis 1b.

3.3.4 Discussion

The results have at least three important implications. First this study demonstrates with a significant tendency that, why, and under which conditions a low amount of information is more overloading than a high amount of information. Participants who initially constructed their cognitive schemata in a context with high amount of information delivered by IT demonstrated a significant tendency towards lower levels of ECO with higher amounts of information while performing simulated laparoscopic surgery than participants holding cognitive schemata constructed in a context with low amount of information delivered by IT.

This contradicts the traditional conceptualization of overload in IS being defined as an excessive amount of information. Rather this study shows that overload is highly dependent on the personal mental organization of LTM. Notably, the difference in ECO was supported with a significant tendency only. This might be due to the relatively low sample size. Also the tasks included in this study were basic surgical tasks. Simulated full procedures may impose higher levels of mental load. Finally a larger difference in context between the two experimental groups could increase the congruence effect of amount of information delivered by IT. A follow up study is presented in Chapter 5. It uses a larger difference in context to reinforce the congruence effect of amount of information delivered by IT. Thereby it demonstrates the significant effect of congruence on ECO.

A second implication is embedded in the joint results concerning H2a and H3a. These indicate that emotional consequences of ECO may manifest in the form of stress even though the cognitive consequences in the form of performance do not. This is in line with Rutkowski and Saunders' (2011) findings that emotion and cognition are linked but independent aspects of ECO. One plausible explanation according to ECOM is that overloaded L_{info} participants increased mental effort when they experience ECO. This allowed them to cope with high mental load and maintain stable performance levels, but this was at the expense of increased stress. Increasing mental effort shows an effective coping mechanism for maintaining stable performance levels when experiencing ECO on the short term. On a long term increasing mental effort might exhaust cognitive resources and cause chronic stress with similar symptoms to burnout and affect performance (Rutkowski and Saunders, 2011). This is of course not desirable for the surgeon or for patient safety.

Finally, from a practical perspective the results suggest that surgeons and surgical residents can possibly anticipate ECO through construction of appropriate cognitive schemata. From a managerial perspective simulation training provides a platform for schemata construction through repetitive practice in a safe and controlled environment. Based on the results of this study, simulation training effectiveness might be increased through training in a realistic context with **high amount of information delivered by IT**. Chapter 5 applies and combines the basic results of this study into an immersive training program.

Limitations and future research

This study demonstrates the important role of chunking, cognitive schemata and congruence. A sample of IS students was used to control for prior differences in cognitive schemata on medical simulation and practice. The effect of chunking on ECO is presumably even greater for surgical trainees or experienced surgeons because they construct an increasing number of interrelated cognitive schemata during surgical training and practice. Thereby they become experts. The question is whether these cognitive schemata should be constructed fully during clinical practice, or at least partially during simulation based training in a safe and controlled preclinical setting. Chapter 5 applies and combines the basic results of this study into an immersive training program.

Further research is required to identify whether the differences in ECO experienced by the participants in the *incongruent* conditions can be solely attributed to cognitive schemata. Chapter 5 provides a follow-up study that compares in a context with *equal* amount of information delivered by IT the effectiveness of different cognitive schemata.

In this study no differences could be found on surgical performance. Performance scores were restricted to the indicators provided by the AR simulator. These were limited to total time, economy and smoothness of movement. Complementary measures such as errors may shed more light on cognitive manifestations of ECO during surgical training and practice. Measurement of clinically relevant performance indicators is a major challenge in surgical simulation training (Satava, 2008). Also stress was measured using self-reported scales. Complementary physiological measures could shed further light on ECO and its emotional manifestations. Neuro-physiological and psychophysiological measures have recently gained attention in the IS field under the label of Neuro-IS. Physiological measures can potentially be used for triangulation of self-reported measures when studying overload (Dimoka, Banker, Benbasat, Davis, Dennis, Gefen, Gupta, Ischebeck, Kenning, Pavlou, Müller-Putz, Riedl, vom Brocke, and Weber, 2011). The next chapter will introduce thermal imaging as an innovative physiological marker of overload.

3.4 Discussion and conclusion

Both studies demonstrate that overload depends on the personal mental organization of LTM. On the one hand, overload is dependent on personal mental dispositions that are relatively stable over time. On the other hand, overload is dependent on cognitive schemata that can be manipulated using simulation technology. In particular:

The study presented in section 3.2 shows lower task scores and higher surgical error scores when a laparoscopic task is performed under realistic high load conditions. General (NFC) and IT-domain specific (CA with IT) personal mental dispositions impact the level of perceived stress. Interestingly all but one participant were medium or highly absorbed and immersed with surgical IT. This allows surgical residents to chunk information delivered by medical IT more easily than average individuals. Even so, they were not immune to the impact of high load conditions on their performance and stress. Technological and social aspects of the working environment in the OR need to be carefully evaluated. Also preclinical training programs should aim to decrease overload delivered by technological and social sources.

The study presented in section 3.3 used IS-students to control for prior differences in cognitive schemata. These students had similar levels of absorption with IT. The study demonstrates with a significant tendency that overload is not simply an excessive amount of information. It shows the important role of chunking and congruence of information delivered by IT with cognitive schemata. Cognitive schemata and their congruence with information stimuli can be manipulated using simulation technology.

This conceptualization of overload has potentially important practical and theoretical implications. Surgical simulation training effectiveness might be increased through training in a realistic context. That is at least a context with high amount of information delivered by IT. This context seems more congruent with the information delivered by IT in the OR as presented in section 3.1. Theoretically it demonstrates with a significant tendency why and when a low amount of information can be more overloading than a high amount of information. This is inconsistent with the typical conceptualization of overload being an excessive amount of information. A follow up study is presented in Chapter 5. It uses a larger difference in context to reinforce the congruence effect of amount of information delivered by IT. Thereby it demonstrates the *significant* effect of congruence on overload.

4. Thermal imaging technology: a physiological marker of Emotional-Cognitive Overload? [11]

4.1 Introduction

Section 3.3 deployed self-reported scales to measure Emotional-Cognitive Overload (ECO). The main advantage is that self-reported measures are relatively easy to obtain. Also they are often the only feasible way to measure variables and constructs. However, self-reported measures are subject to a range of errors and biases. These might threaten the reliability and validity of empirical studies (Campbell and Fiske, 1959; Donaldson and Grant-Vallone, 2002). Indeed self-reported measures reflect the respondents' subjective experience and interpretation of a researched construct. They may therefore lack objectivity (Hufnagel and Conca, 1994).

That is important since response bias is particularly likely to occur when the construct of interest is sensitive in nature (Donaldson and Grant-Vallone, 2002). ECO is often so sensitive that it is not discussed in healthcare settings. It is also not part of the culture of surgeons to accept stress as an inevitable part of practice (Arora, Hull, Sevdalis, Tierney, Nestel, Woloshynowych, Darzi, and Kneebone, 2010). However, it is important to deal with ECO effectively. One way of doing so is to increase the diffusion of simulation technologies to improve surgeon training (Jakimowicz and Cuschieri, 2005). Psychophysiological tools enable the measurement of individuals' responses to the training technology with physiological data. Physiological data is not susceptible to social desirability bias (Dimoka, Banker, Benbasat, Davis, Dennis, Gefen, Gupta, Ischebeck, Kenning, Pavlou, Müller-Putz, Riedl, vom Brocke, and Weber, 2011). It is recommended that cognitive training outcomes such as ECO are objectively measured. Objective measures are becoming even more important when surgical trainees are assessed or even selected on their level of overload (Bass, Silverman, Dowdall, Bourlai, Pavlidis, and Dunkin, 2008; Carswell, Clarke, and Seales, 2005).

The focus of this study is to test thermal imaging as an innovative psychophysiological tool for the objective assessment of ECO during simulation training. The structure of this chapter is as follows. The subsequent section informs the reader on (1) the psychophysiological tools and (2) the importance of efficiently measuring ECO in the

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[11] Published as Pluyter, J.R., Rutkowski, A.F., Jakimowicz, J.J., & Saunders, C. (2012). Measuring users' mental strain when performing technology based surgical tasks on a surgical simulator using thermal imaging technology. In H.R. Sprague Jr. (Ed.), Proceedings of the 45th Hawaii International Conference on System Sciences (HICSS 2012) (p. 2920-2926). Wailea, Maui, Hawaii: IEEE Computer Society Press.

sensitive context of surgical training. The study, results, and possible applications are presented in the next three sections. The discussion section underlines the potential of thermal imaging technology as a non-invasive, safe, comfortable, and relatively cheap physiological measurement instrument. In addition, the data provided by thermal imaging technology is relatively easily-interpretable, uses explicit colors, and does not require extensive knowledge of human brain functioning.

4.2 Psychophysiological tools and Emotional-Cognitive Overload

Using medical measurement tools in healthcare research is relatively common. The literature review presented in Chapter 2 identified studies using physiological measures including skin conductance and eye blink (Berguer, Smith, and Chung, 2001; Smith, Chung, and Berguer, 2000), holters measuring cardiac activity (Böhm, Rötting, Schwenk, Grebe and Mansmann, 2001; Song, Tokuda, Nakayama, Sato, and Hattori, 2009), and electroencephalograms (EEGs) measuring brain activity (as proposed by Carswell, Clarke, and Seales, 2005) to study the impact of new surgical technology, experience and the role of the surgeon on mental workload. Unfortunately holters and EEGs can be relatively invasive. They require a number of electrodes to be attached to the body and connected to a storage device using wires.

Recently, Information Systems (IS) research also started applying neuroscience theories and methods to advance our understanding of IS theories. The term neuro-IS has been coined to describe this new idea (Dimoka, Pavlou, and Davis, 2007). Two main categories of neurophysiological tools exist: psychophysiological and brain imaging techniques (see Dimoka et al., 2011 for details). Psychophysiological tools measure changes in the physiology of the human body. These include changes in cardiac activity, skin conductance and eye movement. Brain imaging tools measure changes in neural activity. Such tools enable the measurement of individuals' responses to Information Technology (IT) with data drawn directly from the human body (see Dimoka et al., 2011 for an exhaustive list of such technologies). Dimoka et al. (2011) explicitly underline the applicability of physiological measures to study overload.

In this chapter a thermal imaging technology is tested as a physiological marker of ECO during training on an Augmented Reality (AR) surgical simulator. Data is collected and analyzed to validate the use of unobtrusive thermal imaging technology to gather physiological information on the potential ECO of individuals learning how to manipulate surgical instruments. Surgical simulation can reduce ECO imposed by medical IT (see Chapter 3.3). Thermal imaging technology can be used to demonstrate the effectiveness of simulation training and foster further diffusion of Augmented Reality training devices in the healthcare curriculum (Gallagher, Ritter, Champion, Higgins, Fried, Moses, Smith, and Satava, 2005; Jakimowicz and Cuschieri, 2005).

Thermal imaging technology

ECO is referred to in the thermal imaging literature as cognitive workload (Stemberger, Allison, and Schnell), mental workload and mental demand (Or and Duffy, 2007), mental effort (Reyes, Lee, Liang, Hoffman, and Huang, 2009), frustration (Puri, Olson, Pavlidis, Levine, and Starren, 2005), and stress (Pavlidis, Dowdall, Sun, Puri, Fei, and Garbey, 2007). These represent cognitive and emotional manifestations of ECO, as categorized by Rutkowski and Saunders (2011). Thermal imaging measures physiological responses to situations of high load but it is difficult to understand what thermal imaging specifically measures. Bass, Silverman, Dowdall, Bourlai, Pavlidis, and Dunkin (2008) identified thermal imaging as a physiological measure that is possibly interesting in a surgical simulation training setting to measure stress reactions resulting from skills acquisition, a mentally demanding cognitive activity.

Episodes of high mental load are associated with temperature changes of specific areas of the human face due to activity alteration of the autonomic nervous system (Or and Duffy, 2007). It triggers subtle increases in the temperature of the skin directly surrounding the periorbital area and also the frontal head (Reyes, Lee, Liang, Hoffman, and Huang, 2009; Stemberger et al., 2010). Facial temperature can be measured unobtrusively with a thermal imaging camera. Prior research has demonstrated that high levels of mental load measured using thermal imaging have been associated with impaired performance (Reyes et al., 2009).

Thermal imaging technology measures infrared radiation naturally emitted by any object. The amount of radiation emitted increases with the temperature of the object (Pavlidis et al., 2007). The thermal imaging camera accordingly constructs a thermographic image of the object such as the human face (see Figure 4.1). Different temperatures are represented using different colors. The thermal imaging camera provides gauges with customizable color ranges. Thereby subtle temperature differences in specific areas can be visualized and subsequently analyzed. Examples include the blue-to-yellow gauge (left) and the black-to-red gauge (right). Here data of the same subject is visualized using different gauges. Thermal imaging of the face is used in other contexts such as overload in car drivers (Or and Duffy, 2007).

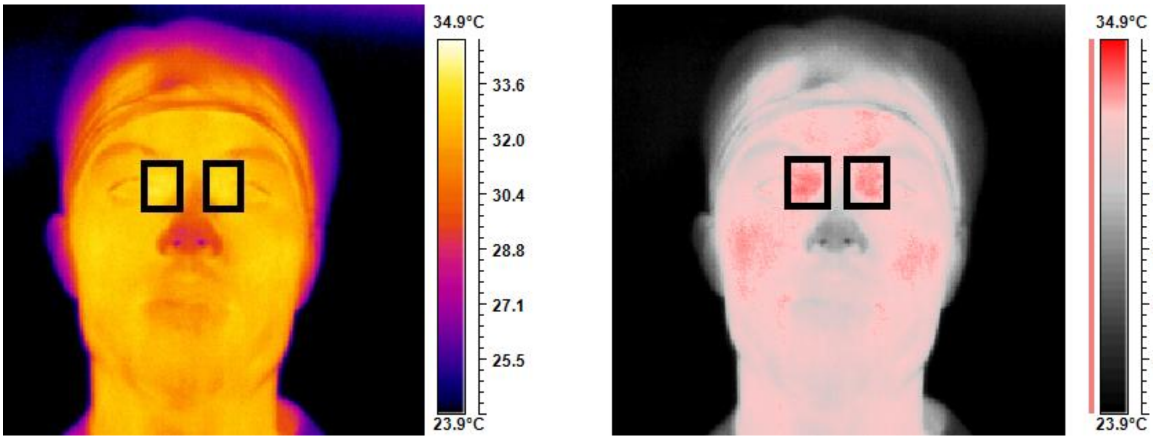

Figure 4.1. Thermographic image; periorbital area marked with rectangle

The Thermoview 8300 infrared thermal imaging camera (Sensor Partners, Drunen, The Netherlands) is used in this chapter to measure the participant’s facial temperature. The camera allows continuous measurement of infrared radiation in the spectral range of 8-14µm with a thermal sensitivity of 0.08 degrees Celsius. This makes it particularly suitable for detecting relatively subtle temperature differences in the human face.

4.3 Research method and materials

Surgical technology

The Haptica Promis I Augmented Reality (AR) simulator (Haptica, Dublin, Ireland) was used in this study. A set of three basic surgical tasks was selected to match the prior knowledge of the participants. These were aiming and translocating, stretching, and cutting simulated tissue. The simulator and tasks were also used in the previous chapter. A detailed description and illustration of the simulator and tasks can be found in Appendix A. Previous research empirically demonstrated that simulated surgery imposes high mental load on the individual (Berguer, Smith, and Chung, 2001).

Participants

Twenty-three participants were invited to an intensive training session on the surgical AR simulator. Participants should have no prior experience with AR, or knowledge of this particular set of basic surgical tasks. If they had, their chunking abilities built through previous experience (Rutkowski and Saunders, 2011) may have biased the results. The participants were IS students who had similar backgrounds regarding IT usage. Medical students were not suitable for this pilot study, because they may have been familiar with AR and the medical tasks that were being performed in the study. This would have increased their level of expertise through cognitive schemata that improve chunking and therefore decrease ECO.

Procedure and measures

Participants were instructed to sit on a chair upon arrival in the temperature controlled training lab. Their *baseline* periorbital temperature was measured 10 minutes after arrival. This period allowed the participants to acclimatize to the training room temperature and to refrain from engaging in complex cognitive activities for a considerable period of time. This is in line with the strategy used by Or and Duffy (2007).

Subjects were first familiarized to the instruments and tasks on an open box trainer. Then participants completed two runs of the set of three surgical tasks on the surgical simulator. During each run the set of three basic surgical tasks was performed once by each of the participants in the same order.

After the first and second run of technology based surgery on the surgical simulator, periorbital skin temperature was measured using the thermal imaging camera. Additional self-reported measures on ECO with the information delivered by the laparoscope monitor (Rutkowski and Saunders, 2010) and overall perceived stress (adapted from Cohen, Kamarck, and Mermelstein, 1983) were gathered using a questionnaire after both runs of technology based surgery. They were correlated to the thermal measures. An overview of the scales, items and cronbach alpha scores can be found in Appendix D.

These measures were selected because thermal imaging was used in previous studies to measure emotional reactions such as stress (Pavlidis, Dowdall, Sun, Puri, Fei, and Garbey, 2007) and frustration (Puri, Olson, Pavlidis, Levine, and Starren, 2005) in a context of high mental load. Also Bass, Silverman, Dowdall, Bourlai, Pavlidis, and Dunkin (2008) identified thermal imaging as a physiological measure possibly interesting in a surgical simulation training setting to measure stress reactions resulting from high mental demand during skills acquisition.

Setting and thermal data analysis software

During the experiment the thermal imaging camera was positioned on a tripod and focused on the face of the participants in a somewhat upward angle to provide an image of the participants' periorbital area. The participants' position and camera angle remained constant throughout the simulator sessions as all exercises were performed using a simulator screen with a fixed position. The study was performed in a temperature-controlled room to minimize the impact of external factors on the skin temperature of the participants.

The thermal imaging data was analyzed using Sensor Partners Infrared Analyzer (SP IR analyzer) software. A screenshot is provided in Figure 4.2. It has a user-friendly interface and relatively simple tools to identify skin temperature of specific areas of the human face. For example it allows drawing ovals, rectangles and spots among other shapes. Maximum, minimum and average temperatures can be identified with a single mouse click. Temperature gauges can also be customized based on preferences of the researcher.

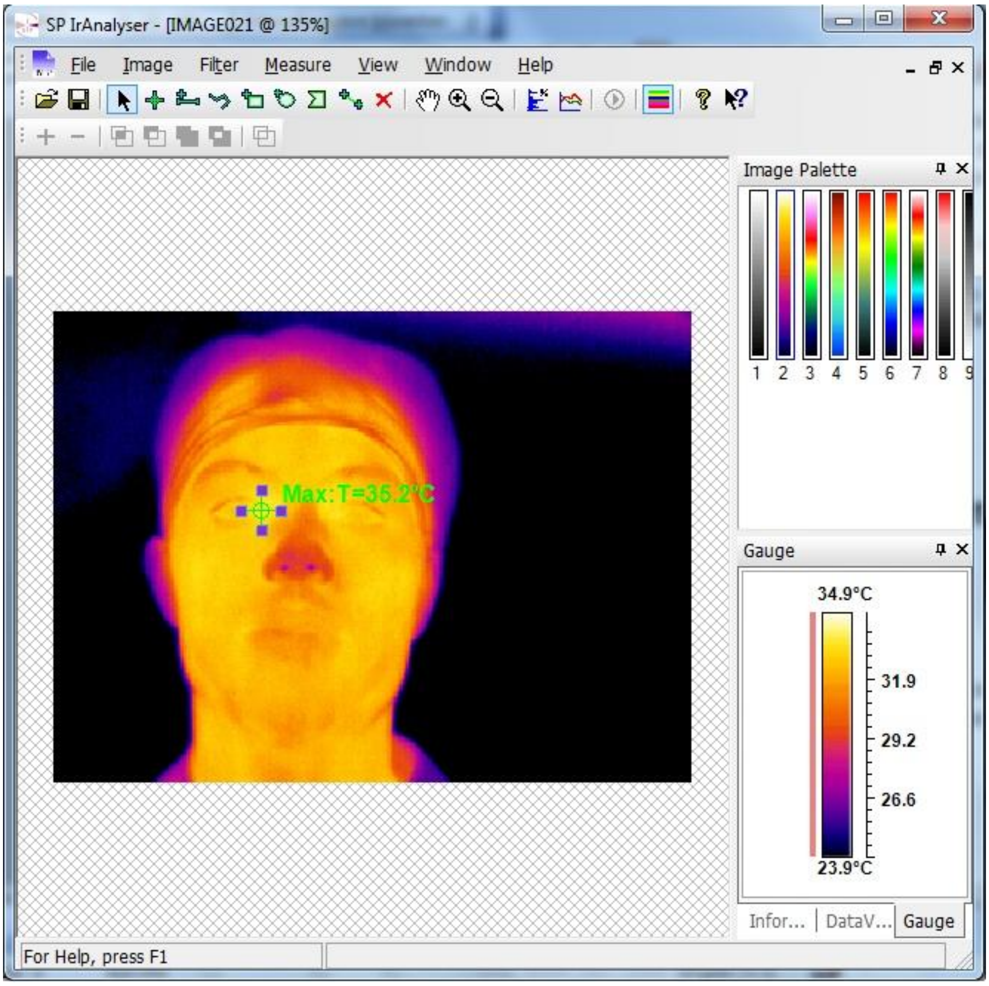

Figure 4.2. SP IR analyzer software

4.4 Results

Periorbital temperature was measured at baseline and after the first and second run of technology based surgery on the surgical simulator. The periorbital area was defined as a 2 cm square centered on the tear duct of each eye. Thermal data could not be recorded for two subjects. Table 4.1 and Figure 4.3 provide an overview of the periorbital temperature at these three points in time. Analysis using the paired sample t-test revealed that periorbital temperature after the first simulator run was significantly higher than baseline (p=.001). Periorbital temperature after the second simulator run was also significantly higher than baseline (p=.0001).

Table 4.1. Periorbital temperature in degrees Celsius at baseline and during surgery on the simulator

	Baseline	**Surgery on simulator (first run)**	**Surgery on simulator (second run)**
Mean (SD)	34.37 (.55)	34.92* (.49)	34.99* (.47)
Min	33.50	34.20	33.90
Max	35.60	35.90	35.70
* significantly different from baseline at alpha=.05 Based on n=21 participants			

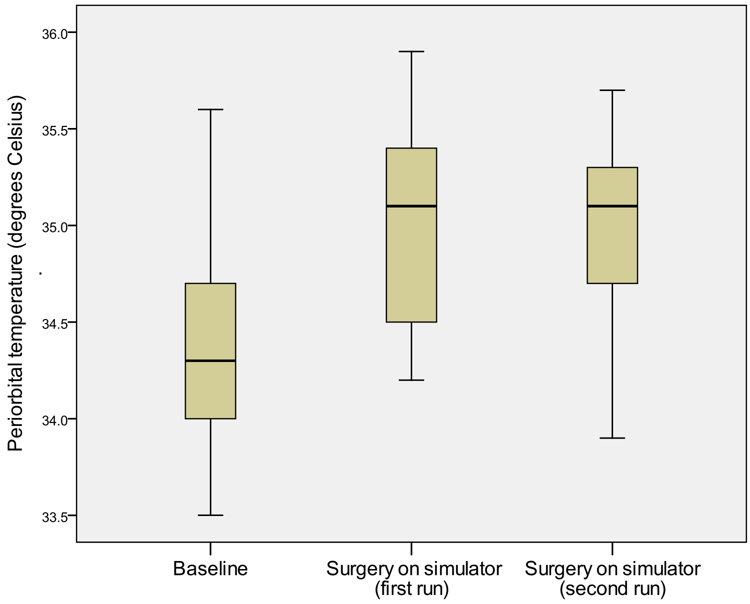

Figure 4.3. Periorbital temperature during baseline and surgery on the simulator
Based on n=21 participants

Periorbital temperature, corrected for differences in baseline temperature, did not significantly correlate with self-reported ECO with information delivered by the laparoscope monitor nor overall perceived stress as an emotional manifestation of ECO (see Table 4.2). A lack of correlation between self-reported and physiological measures is not uncommon. It may indicate that the instruments measure different dimensions of the underlying construct.

Table 4.2. Descriptives of self-reported ECO and overall perceived stress and correlations with thermal data

	ECO with information delivered by the laparoscope monitor		**Overall perceived stress**	
	First run*	**Second run***	**First run***	**Second run***
Mean (SD)	3.29 (1.39)	2.86 (1.38)	3.43 (.82)	3.12 (.67)
Min	1.00	1.00	1.57	1.43
Max	5.50	5.75	4.86	4.17
r. with periorbital temperature corrected for baseline	NS	NS	NS	NS

* First/second run of surgery on the surgical simulator. Correlation based on sample of n=21 due to lack of thermal data of two participants; descriptive based on full sample of n=23.

Considering prior findings on mental and cognitive workload (Stemberger, Allison, and Schnell; Or and Duffy, 2007) it is suggested that the temperature differences possibly reflect mental load rather than the emotional consequences of ECO. This would also be congruent with ECOM, but additional self-reported measures are needed to test this hypothesis. Thermal changes in facial temperature in the remainder of this dissertation are referred to more holistically as a physiological response to mental load (rather than a direct measure of ECO).

4.5 Discussion and conclusion

The results indicate that facial skin temperature measured by the thermal imaging technology is higher during simulated surgery than during baseline. Hence, thermal imaging appears to be a viable technology to gather physiological responses to mental load when using an AR training device. Thermal imaging has several ethical, practical and methodological advantages. The technology can be used to measure skin temperature continuously and unobtrusively without inducing anxiety or stress in the study participants. It can be used to complement and possibly triangulate self-reported measures to increase validity of the study and reduce common method variance.

It extends the set of psychophysiological measures of IT constructs proposed by Dimoka, Banker, Benbasat, Davis, Dennis, Gefen, Gupta, Ischebeck, Kenning, Pavlou, Müller-Putz, Riedl, vom Brocke, and Weber (2011). As opposed to other physiological measures such as functional Magnetic Resonance Imaging (fMRI), thermal imaging is a passive modality. It depends solely on radiation naturally emitted by the subject (Pavlidis, Dowdall, Sun, Puri, Fei, and Garbey, 2007). Hence it does not raise additional health concerns for trainees whose reactions are being measured. Moreover, thermal imaging is non-invasive and unobtrusive. It does not interfere with the tasks performed by the participant, nor does it limit her movement while performing the task. Physiological measures are also often more accurately predicting behavior than self-reported measures (Dimoka et al., 2011). Thermal imaging of physiological responses to mental load has a wide range of potential applications. Several applications are discussed both within and beyond the healthcare domain.

Possible applications in medical training and practice

Thermal responses to mental load could potentially be used to support or accompany training and assessment of surgeons' and surgical residents' performing simulated Image Guided Surgery (IGS). It can help assess the negative impact on performance and stress that the surgical staff is typically reluctant to recognize (Arora, Hull, Sevdalis, Tierney, Nestel, Woloshnowych, Darzi, and Kneebone, 2010). This technology could be used as a complementary assessment tool evaluating the effectiveness of curriculum protocols in handling overload and resulting stress. Also surgical residents demonstrating excessive physiological responses to mental load when performing basic surgical tasks could be instructed to follow additional simulation training before to operate on patients (see also Bass, Silverman, Dowdall, Bourlai, Pavlidis, and Dunkin, 2008). Determining when surgical residents can proceed from training to clinical practice, according to technical and cognitive measures including overload, is currently of very high interest in the field of surgery (Carswell, Clarke, and Seales, 2005). One could think of similar applications in other high-tech and high-risk professions such as aviation and electronic auctions. Indeed, thermal imaging fulfills a similar role by assessing excessive mental load of car drivers (Or and Duffy, 2007).

ECO during surgery and other high-impact professions resulting in impaired performance may have far reaching consequences. Thermal responses to mental load could be used interactively with the individual to improve performance (Pavlidis et al., 2007). For example, thermal imaging could potentially detect excessive levels of mental load imposed by IT during technology based surgery, office work (Arnetz and Wiholm, 1997) or technology-mediated auctions. The IT user can be notified and instructed to take a cool down period in order to avoid ECO. ECO might result in surgical errors, degraded performance levels on the cognitive level, and burn-out on the emotional level (Rutkowski and Saunders, 2011).

Furthermore, theoretical contributions arise for the overload literature in both the IS and surgical fields. An interesting paradox in the IS field is that while concerned with technology, IS researchers principally use self-reported measures to investigate IT use. At least 57% of the empirical studies conducted on use of IT primarily rely on self-reported measures (Dwivedi, Williams, Lal, and Schwarz, 2008). Increasing emphasis in the IS discipline has been placed on improving instrument quality and IS theory rigor. Still, Straub, Boudreau and Gefen (2004) report that "IS positivist researchers still have major barriers to overcome in instrument, statistical and other forms of validation" (p. 5). Also thermal imaging did not appear as a measurement instrument in the literature review on overload in the surgical literature that was presented in Chapter 2.

Psychophysiological measures such as thermal imaging should be complementary to existing measures including self-report measures and brain-imaging tools. Multiple sources of measurement allow triangulation and might shed light on different dimensions of the construct of interest. For example, thermal imaging can extend the assessment of the body's physiological response to mental load when confronted with technology. Brain imaging tools can shed light on associated brain activity. Self-reported measures can be used to gather data on the subjective experience and perception of ECO. All measures can inform the researcher on different aspects of ECO imposed by IT. They also counterbalance part of each other's methodological weaknesses and reduce the impact of common method variance.

Limitations and future research

This lab-setting study is aimed at testing the appropriateness of thermal imaging as a physiological response to mental load to help identify ECO during simulated surgery. Therefore simulated surgery was only compared against baseline. It would be interesting to experimentally manipulate ECO on various levels (low-medium-high) as covered in the subsequent chapter. This also allows further specification of the sensitivity and specificity of the thermal imaging technology measuring ECO. Future studies should also attempt to identify correlations between physiological measures of ECO and self-reported measures. One possibility is the use of multi-trait multi-method analysis to identify the specificity of thermal imaging as a physiological correlate of various self-reported measures (e.g., mental load, ECO, stress as an emotional manifestation of ECO). Also, it would be interesting to use thermal imaging technology within a real setting[12] with experienced surgeons, or with advanced medical students.

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[12] Ethically, subjects have to be informed that they are being monitored and researchers need approval from the Institutional Research Board when deploying the measurement instrument in real settings.

Like any other measure, the use of thermal imaging technology raises challenges that require attention. From a data analysis perspective it is rather difficult to delineate the exact region of interest. Various authors used different areas of the human face including the forehead, periorbital and nose. Also, currently there is no consensus about the unit of analysis. Authors use measures such as mean and standard deviation (Reyes, Lee, Liang, Hoffman, and Huang, 2009), or hottest pixels (Pavlidis et al., 2007) to represent the temperature of the region of interest. Further research is required to identify the delineation and unit of analysis that best represents the construct of interest. Particularly Multi-Trait-Multi-Method (MTMM) analysis is recommended. MTMM allows determining discriminant and convergent validity of constructs measured using multiple measurement tools (e.g., psychophysiological, brain imaging, self-report) against related constructs. It could also be used to reach consensus on the region of interest (e.g., frontal head, periorbital area) and unit of analysis (e.g., maximum value, average value, standard deviation). MTMM could potentially be used to identify response biases in further research. However this requires multiple measurement tools to measure the same dimension of each construct. This also makes it easier to identify self-reported correlates.

From a data collection perspective, thermal imaging of the face requires a relatively stable position of the subject. Moving subjects can however be traced using a motion tracking system (see Pavlidis et al., 2007). Finally, thermal imaging requires a temperature controlled room to control the impact of external sources (e.g., direct sunlight, heating, air-conditioning) on body temperature.

Concluding, self-reported measures are subject to several errors and biases that might threaten the reliability and validity of the study. These include response bias and common method variance. This study empirically demonstrates that thermal imaging provides a promising complementary physiological measure. Psychophysiological measures can be used to uncover different dimensions of IT constructs explaining IT-related overload (Reyes et al., 2009). Finally, they can be used to triangulate results of self-reported measures and brain imaging tools to reduce common method variance. Thermal imaging additionally has multiple practical applications. These include diffusion and use of simulation technology in healthcare curricula.

The thermal camera has three main advantages that make it worthwhile to consider. First of all it does not require a large budget or extensive knowledge to interpret the data. Ethically speaking, it can be used without disturbing the subjects or causing any potential damage to their health. This could be especially useful when conducting research in a real (vs. lab) setting, such as the operating room or surgical training. Third, the interpretation of the results is computerized and based on visualization effects. In this respect, use of the technology is rather straightforward. This study is among the first to use thermal imaging to efficiently map ECO during surgical simulation. It could be a good tool to investigate and improve programs of surgical simulation training and stress coping strategies.

5. Immersive Surgical Training to Decrease Emotional-Cognitive Overload in the OR

Towards Narrowing the Gap Between Simulation Training and Clinical Practice

5.1 Introduction and theoretical background

Recent research has demonstrated that surgical simulators improve surgical skills (Schijven, Jakimowicz, Broeders, and Tseng, 2005, Schijven and Bemelmans, 2011, Sturm, Windsor, Cosman, Cregan, Hewett, and Maddern, 2008). Thereby they contribute to increase patient safety. Virtual Reality (VR) and Augmented Reality (AR) surgical simulation training is typically provided in isolated and controlled settings. Transfer from isolated training to the socio-technological setting of the Operating Room (OR) is perceived as cognitively demanding by novices (Prabhu, Smith, Yurko, Acker, and Stefanidis, 2010).

Inability to cope with technological and social demands may result into a state of Emotional-Cognitive Overload (ECO). This may cause impaired performance and increased stress (Rutkowski and Saunders, 2011; Hsu, Man, Gizicki, Feldman, and Fried, 2008). On the social level ECO also leads to breakdowns in the interaction of surgeons, surgeon assistants, anesthesiologists and nurses (Wadhera, Henrickson Parker, Burkhart, Greason, Neal, Levenick, Wiegmann, and Sundt, 2010). The consequences of ECO in the OR are recognized factors hampering operating room safety (Tollner, Riley, Matthews, and Shockley, 2005; Zheng, Rieder, Cassera, Martinec, Lee, Panton, Park, and Swanstrom, forthcoming).

Simulation-based training curricula should be designed to smoothen the transfer from training to clinical practice (Gallagher, Ritter, Champion, Higgins, Fried, Moses, Smith, and Satava, 2005). This may reduce adverse effects of overload for novice surgeons and surgeons in training. In other words, they should be provided with an improved training environment. This chapter builds on the results of Chapter 3 and 4 to define a comprehensive simulation training program. Chapter 3.2 demonstrated the impact of *realistic* technological and social sources of ECO on performance and stress. It also demonstrated that highly immersed and cognitively complex individuals may be less prone to emotional manifestations of overload. However, they were equally susceptible to degradations in surgical performance. The second study presented in Chapter 3.3 demonstrated the important role of chunking and congruence through the manipulation of cognitive schemata. In particular, cognitive schemata required for laparoscopic tasks are more congruent with a high (vs. low) amount of information context. This context is deemed more *realistic* than a laboratory training setting. These findings provided grounds for further increasing the effectiveness of simulation to decrease ECO. Chapter 4 introduced thermal imaging as tool to measure physiological responses to mental load. It is potentially a valuable tool for evaluation of the effectiveness of simulation training programs. It also has the potential to be included in assessment of cognitive training outcomes (Bass, Silverman, Dowdall, Bourlai, Pavlidis, and Dunkin, 2008).

Based on these results, the current chapter proposes and tests training under simulated realistic OR conditions. It reproduces and represents situations closer to clinical practice (Stefanidis, Korndorffer Jr, Markley, Sierra, Heniford, and Scott, 2007). Reality is embedded in both the technological context (which was pre-tested in Chapter 3.3) and the social context. Such training is referred to in this dissertation as **immersive training**. Specifically, the current study is a first step toward defining an improved training program. It is based on the hypothesis that training effectiveness should be increased and hence that overload, stress and adverse events should be decreased in a safe OR. Thermal imaging technology is used to measure physiological responses to mental load. It is a complementary measure used to test the effectiveness of the training.

The remainder of this chapter is organized as follows. First, a basic minimal paradigm immersive simulation training program is presented. It is based on the previous chapters and theoretically grounded in the Emotional-Cognitive Overload Model (ECOM: Rutkowski and Saunders, 2011). The next section presents the results of an experimental study comparing the immersive training program to conventional simulation training in terms of ECO, stress, and surgical performance of the trainee. The potential and the further development of immersive training as part of surgical training curricula are discussed in the final section.

5.2 A Basic Immersive Training Program

Immersive training is defined as training in a realistic socio-technological context that reproduces and represents situations closer to clinical practice. The socio-technological context includes both technological (i.e., medical Information Technology (IT) used in the operating room) and social aspects (e.g., social interaction). The level of analysis of this dissertation is at the individual level. The focus on the social context is restricted to the impact of the social context on ECO of the individual. The social setting is treated as a source of overload to the individual, as was done in Chapter 3.2. ECO on a team level is outside the scope of this thesis as it would require addressing team theory. Immersion is “the subjective impression that one is participating in a comprehensive, *realistic* experience” (Dede, 2009; p. 66, italics added).

Immersion can be beneficial for anticipating ECO through surgical training in at least two ways. First, training in a realistic immersive context could foster context-dependent learning and context-congruent retrieval. Information is more easily activated and retrieved from Long-Term Memory (LTM) than incongruent information (see also Chapter 3.3).

Second, immersive training allows trainees to learn to cope better with realistic sources of overload that might disrupt their state of focused immersion in the OR.

VR and AR surgical simulation training is typically provided in isolated and controlled settings with only a trainee training on a simulation device. Such conventional isolated training settings are not congruent with the cognitively demanding socio-technological context of the OR. However this is the current training environment typically deployed for simulation training (Prabhu, Smith, Yurko, Acker, and Stefanidis, 2010). During immersive training the realistic context is encoded in LTM. It may improve retrieval of congruent schemata during clinical practice in the OR.

Technological and social training context

Immersive training aims to provide training in a realistic technological and social context. The **technological context** (see Table 5.1) in a conventional setting consists only of a box trainer or surgical simulator with one laparoscope monitor. In this study it is complemented with a paper based checklist describing the procedural steps, and an auditory pulse-oxy signal for experimental control. An immersive training context is proposed where trainees are additionally surrounded by a supplementary laparoscope monitor, a vital signs monitor, a personal computer with web access, a pager, streaming radio, and a computer based checklist instead of the paper based checklist (but containing exactly the same information). These technologies increase the reality of the technological context that is encoded as part of the cognitive schemata during training. Participants in the immersive training context receive more information in each cue (visual, auditory) than in the conventional training context. Illustrations and detailed descriptions of these ITs are provided in Appendix A, Table A.3.

The technological context was pre-tested in Chapter 3.3. It demonstrated with a significant tendency that “*more* information delivered by IT is *less* overload” when a high amount of information delivered by IT fosters retrieval of congruent cognitive schemata encoded under high amounts of information delivered by IT.

Table 5.1. Technological context specified per training condition

Information delivered by IT	**Modality of information**	**Description of information**	**Conventional Training Context [CTC]**	**Immersive Training Context [ITC]**
Primary laparoscope monitor	Visual	The primary laparoscope monitor depicts the image of the camera embedded in the laparoscope.	X	X
Procedural checklist	Visual	Checklist for step-by-step performance of the simulated surgical procedure (e.g., cut tissue).	X	X
Auditory pulse-oxy signal	Auditory	Auditory pulse signal varying in speed and pitch. The speed of the pulse represents the heart rate of the simulated patient. The pitch of the signal represents the saturation level of the patient.	X	X
Vital signs monitor	Visual	Monitor providing information on the health condition of the simulated patient (heart rate, blood pressure, arterial blood pressure, consciousness, saturation (i.e., concentration of oxygen in the blood) and body temperature).		X
Supplementary laparoscope monitor	Visual	Monitor delivering the exact same information as the primary laparoscope monitor. It is a duplicate monitor.		X
Pager	Auditory	Personal telecommunication device. The pager “beeps” when it receives a call.		X
Streaming radio	Auditory	Streaming radio signal delivered through a laptop computer.		X
Personal computer with web access	Visual	Internet computer available to the co-actor performing the role of the anaesthesiologist-assistant in training. The co-actor was left free to (not) use the computer.		X

The **social context** in a conventional setting consists of the surgical trainee training by him- or herself. For immersive training a more realistic dyadic setting is proposed where the surgical trainee is accompanied by a co-actor performing the role of an anaesthesiologist-assistant in training. The co-actor increases the reality of the social context that is encoded as part of the cognitive schemata during training. The co-actor is instructed to monitor the vital signs of the simulated patient. He or she is instructed to only interact according to a predefined protocol with the participant performing the role of surgeon in training when abnormalities occur in the vital signs. Abnormalities are manipulated by the researcher equally for every participant.

This realistic technological and social training context is encoded in LTM and may improve retrieval of congruent schemata during clinical practice in the OR. Immersive training in a realistic technological and social context is depicted in Figure 5.1. Overall immersive training assumes that schemata constructed in the proposed technological and social context are more *congruent* with the demanding context of the OR compared to conventional training.

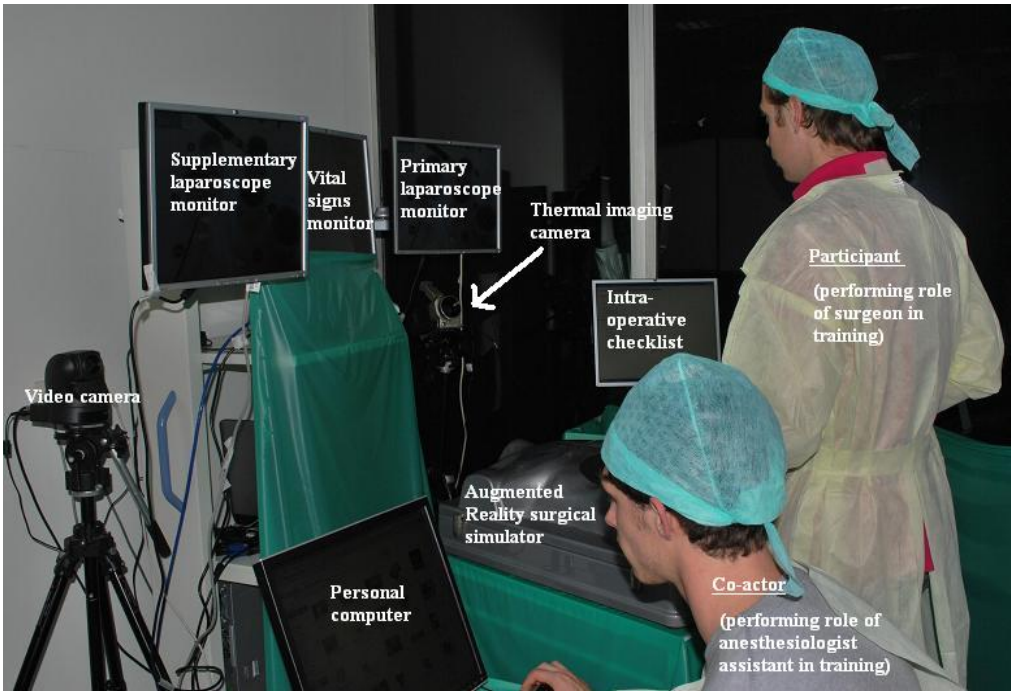

Figure 5.1. Immersive training in a realistic technological and social context

5.3 Research method and materials

In this section the basic Immersive Training Context program (ITC) outlined in the previous section is compared to the Conventional Training Context program (CTC).

Trainees

Immersive training is designed for training surgical trainees. The next step towards validation of this basic immersive training program again requires different types of participants. Surgeons and surgical residents already have encoded cognitive schemata that would interfere with the manipulation of cognitive schemata in this study. They would introduce a bias when comparing the basic immersive training program with the conventional training.

Forty-six undergraduate Information Systems (IS) students were invited to participate in the study presented in the subsequent section to control for this potential bias. These students lack any prior schemata on medical simulation training or practice that could interfere with the training conditions. Compared to medical trainees these students demonstrate similar levels of immersion and absorption with technology and are similarly interested in learning new technology. These are important antecedents of ECO and transfer (Rutkowski and Saunders, 2011). This sample allows comparing the basic immersive training program against conventional training without introducing bias of existing cognitive schemata. Testing this is required before proceeding towards training surgical trainees.

Surgical simulator and tasks

For this basic immersive training program a set of three basic surgical tasks were selected. These were aiming and translocating, stretching, and cutting simulated tissue. These tasks can be performed on a box trainer and Augmented Reality (AR) simulator (Haptica Promis I, Haptica, Dublin, Ireland). Illustrations and detailed descriptions of the tasks, the AR simulator and box trainer are provided in appendix A. The essential contribution of immersive training however lies in the training context. The training task can therefore be easily expanded towards for example simulated full procedural laparoscopic cholecystectomies.

Training conditions and roles

The sample of 46 students was randomly split into two groups, each performing a different role in this study. One group (n=23) performed the role of surgical trainee. This group is further referred to as *participants*. The other group (n=23) performed the role of anaesthesiologist assistant in training and are referred to as *co-actors*. Participants were randomly assigned to the Conventional Training Context (CTC: n=12) or Immersive Training Context (ITC: n=11) condition. Participants in both training conditions performed exactly the same surgical tasks outlined in the basic immersive training program (see above). The only difference between the two conditions was the technological context in which the training was performed (see Table 5.1).

Procedure

Participants were instructed to sit on a chair upon arrival in the temperature controlled training lab. Their *baseline* frontal head temperature was measured 10 minutes after arrival. This period allowed the participants to acclimatize to the training room temperature and to refrain from engaging in complex cognitive activities for a considerable period of time. This is in line with the strategy used by Or and Duffy (2007). Participants subsequently completed a pre-test questionnaire (see below).

Training started with two runs of the set of tasks presented in the previous section on a box trainer in a solo setting to familiarize themselves with the surgical instruments and tasks (see Figure 5.2). This was followed by one run of the same tasks on the Haptica Promis I Augmented Reality (AR) simulator (Haptica, Dublin, Ireland) in a dyadic setting with a co-actor. The social context was gradually scaled up equally for both training conditions from a solo setting to a more realistic dyadic setting in order not to overload participants from the start.

Participants finally performed one assessment run after completing all training runs. Assessment of all the participants was performed on the simulator in a dyadic setting in ITC as this setting is closest to reality (see Figure 5.2). It is therefore the most suitable to assess the relative effectiveness of the two training curricula. Measures were collected using a post-test questionnaire (see below) and surgical performance scores recorded by the simulator (see below). Also frontal head temperature was assessed.

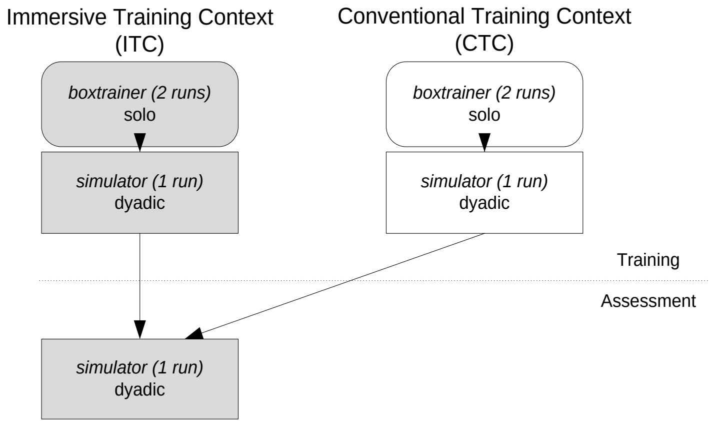

Figure 5.2. Protocol
White boxes (conventional isolated setting) vs. *grey* boxes (immersive setting);
Curved boxes (solo setting) vs. *angular* boxes (dyadic setting)

Measures

Measures were gathered using three different measurement instruments: a set of two questionnaires, performance scores recorded by the simulator, and physiological measures using the thermal imaging camera.

The *pre-test questionnaire* included important control variables and antecedents of ECO. These were experience with simulation or gaming, encoded experience of ECO with information technology (Rutkowski and Saunders, 2010), CA with IT (Agarwal and Karahanna, 2000), and social relationship with the co-actor. These represent factors that might interact with the training conditions influencing the training outcomes. For example Chapter 3 demonstrated that highly absorbed participants demonstrated a lower impact of realistic sources of overload on surgical performance and stress.

In the *post-test questionnaire* Emotional-Cognitive Overload (ECO) with information delivered by the laparoscope monitor was measured using a validated self-reported scale (Rutkowski and Saunders, 2010). Levels of perceived overall stress and stress towards the co-actor (both adapted from Cohen, Kamarck, and Mermelstein, 1983; Monroe and Kelley, 1993) were measured using validated self-reported scales. They represent emotional manifestations of ECO. Details on the measurement scales used in the pre- and post-test can be found in appendix D.

Performance scores were assessed by the surgical simulator during the assessment run. These were total time required to complete the set of three tasks, economy of movement and smoothness of movement.

The thermal imaging camera tested in the previous chapter was used to measure physiological responses to high mental load. The Thermoview 8300 infrared thermal imaging camera (Sensor Partners, Drunen, the Netherlands) was used to measure the participant's facial temperature. Frontal head temperature (see Figure 5.3) was used as the region of interest (Reyes, Lee, Liang, Hoffman, and Huang, 2009; Stemberger, Allison, and Schnell, 2010) due to the lack of correlation found in Chapter 4. Temperature was measured before the training started (baseline) and after the final assessment run was completed (post-assessment). The camera was positioned on a tripod in a temperature controlled room and was focussed on the participant's face.

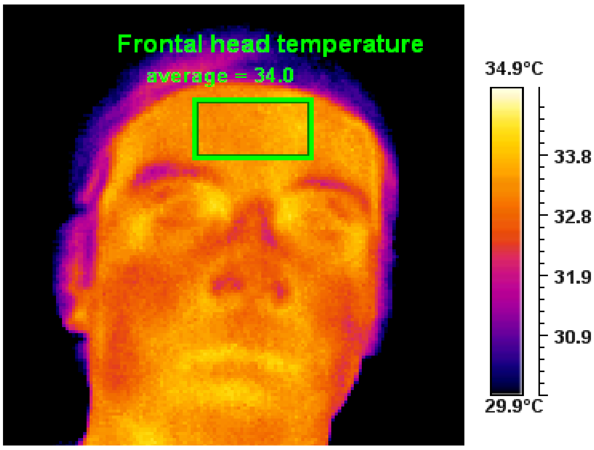

Figure 5.3. Thermographic image with average frontal head temperature in degrees Celsius

5.4 Results

Thermal imaging data could not be recorded for one participant in each condition. These two subjects were excluded from analysis of the thermal imaging data. Two co-actors were unable to participate and were replaced by an accomplice who was instructed to act in a standardized and controlled way. No differences between the two conditions were found on all control variables using the Mann-Whitney U Test. These were: encoded experience of ECO with IT, CA with IT, experience with car driving-, flight-, or surgical simulation and social relation with co-actor.

Results of the self-report measures: ECO and stress

The effects of the training conditions were compared in the final assessment run performed in ICT on a simulator in a dyadic setting using the Mann-Whitney U Test (see Table 5.2). Participants trained in CTC (mean rank [mrk] = 14.83) experienced significantly more ECO according to the self-reported scale (Z = -2.103; p= .035) than participants trained in ITC (mrk = 8.91). Participants trained in CTC (mrk = 15.04) also reported significantly higher perceived overall stress levels (Z = -2.258; p= .024) than participants trained in ITC (mrk = 8.68). Participants trained in CTC (mrk = 14.33) reported a significant tendency towards higher perceived stress towards the co-actor (Z = -1.831; p= .067) than participants trained in ITC (mrk = 9.45).

Results of the performance scores

No significant differences could be found between the training conditions on the three performance indicators. Performance was subsequently compared based on the level of self-reported ECO. The sample was split into two groups using a median split (n =11 participants reporting higher levels of ECO; n=12 participants reporting lower levels of ECO). Participants reporting higher levels of ECO (mrk = 15.36) demonstrated longer path length of the left surgical instrument (Z = 2.277; p= .023) than participants reporting lower levels of ECO (mrk = 8.92). Longer path length represents less economic movement of the surgical instrument in the operating field. This increases the potential of damaging healthy tissue. It is therefore a sign of poor performance. Considering that ITC decreases ECO, these results demonstrate that ITC has an indirect effect on performance that runs over the effect of ITC on ECO. That is, participants trained in ITC experience lower levels of ECO and therefore demonstrate higher performance levels in terms of more economic movement of the surgical instrument.

Table 5.2. Between subjects comparison of self-reported measures: ECO, stress, and performance

	Conventional Training Context (CTC; n=12)		**Immersive Training Context (ITC; n=11)**	
	Median	Mean (SD)	Median	Mean (SD)
Emotional-Cognitive Overload	3.88	3.48 (1.41)	2.00 *	2.20 (1.06)
Overall stress	3.43	3.41 (.57)	3.00 *	2.78 (.64)
Stress towards co-actor	1.70	2.00 (1.16)	1.00 ^{T}	1.24 (.40)
Total Time (seconds)	708.26	726.02 (234.41)	779.09	738.04 (208.01)
Smoothness of movement	5729.50	5619.92 (1811.32)	6163.00	5819.55 (1825.50)
Path length of movement (total)	2396.66	2562.55 (878.53)	2669.92	2566.64 (551.25)
	Higher levels of ECO (n=11)		**Lower levels of ECO (n=12)**	
Path length of movement (left)	278.37	277.61 (57.73)	200.54 *	217.55 (45.94)

* significant difference (two-tailed) at alpha <.05

^{T} significant tendency (two-tailed) .05< alpha <.07

Between subjects comparison based on Mann-Whitney U Test

The results indicate that a realistic socio-technological setting with high amounts of information delivered by IT and presence of other individuals impose higher levels of ECO and stress for participants that were trained in a conventional rather than an immersive training context. Also individuals reporting higher levels of ECO demonstrated lower performance scores than individuals reporting lower levels of ECO. Immersive training improves performance indirectly by decreasing ECO.

Results of the thermal measures

Analysis of the thermal imaging data revealed that differences in post-assessment temperature were found only when taking into account the baseline temperature. Therefore the thermal imaging data was compared within subjects using the Wilcoxon Signed Ranks Test (see Table 5.3: baseline versus post-assessment). In the CTC condition, post-assessment frontal head temperature was significantly higher (Z = -2.229; p=.026) than baseline temperature. This indicates that CTC participants demonstrated a stronger physiological response to the mental load imposed by performance in the immersive context compared to their baseline. In the ITC condition, post-assessment frontal head temperature was not significantly different from baseline (Z = -.415; p = .678). This indicates that ITC participants demonstrated an equal physiological response to the mental load imposed by performance in the immersive context compared to their baseline. There was no significant difference between baseline frontal head temperature of the two training conditions. Also frontal head temperature corrected for baseline did not significantly correlate with the self-reported measures of ECO and stress. These results also support the hypothesis proposed in the previous chapter that facial temperature might be a physiological indicator of mental load.

Table 5.3. Within subjects comparison of thermal responses to mental load

	Conventional Training Context (CTC; n=11)				**Immersive Training Context (ITC; n=10)**			
	Baseline		**Post-assessment**		**Baseline**		**Post-assessment**	
	Median	M(SD)	Median	M(SD)	Median	M(SD)	Median	M(SD)
Frontal head temperature	33.45	33.37 (.49)	33.80 *	33.75 (.69)	33.50	33.65 (.65)	33.30	33.53 (.74)

M(SD) = Mean (Standard deviation)
* significant difference (two-tailed) at alpha <.05
Within subjects comparison (baseline vs. post-assessment) based on Wilcoxon Signed Ranks Test

The results of the thermal data coincide with the self-reported measures of stress as an emotional manifestation of ECO. The self-reported measures and thermal imaging data demonstrate the potential of immersive training over conventional training in terms of ECO and its emotional manifestation in the form of stress.

5.5 Discussion and conclusion

The current study is to the best of our knowledge the first study to demonstrate the potential of a basic immersive surgical training program to decrease Emotional-Cognitive Overload (ECO) and resulting stress. Immersive training, through its effect on ECO, also has a positive effect on performance. This study integrates various lines of previous research in the field of surgery. The first stream of research includes studies identifying overload as an important cognitive issue in surgery (Berguer, Smith, and Chung, 2001; Carswell, Clarke, and Seales, 2005; Stefanidis, Korndorffer Jr, Markley, Sierra, Heniford, and Scott, 2007; Tollner, Riley, Matthews, and Shockley, 2005; Zheng, Cassera, Martinec, Spaun, and Swanstrom, 2010). These sparked off the quest for interventions that allow anticipating overload. The second stream of research covers “VR to OR” studies discussing the transfer of surgical skills from Virtual Reality simulation training to clinical performance in the OR (Moulton, Dubrowski, MacRae, Graham, Grober, and Reznick, 2006; Seymour, 2008). These efforts coincide with a third stream of research covering efforts aimed at embedding simulators in more comprehensively designed training curricula with appropriate technical and cognitive training outcome measures (Jakimowicz and Cuschieri, 2005; Jakimowicz and Fingerhut, 2009).

Few studies have integrated these efforts, with the notable exception of at least the study by Stefanidis et al. (2007). Their study focused on training under realistic conditions as a possible mean to smoothen the transfer from training to clinical practice with special attention for workload. However the benefit of realistic training could not be demonstrated in their study. This is possibly due to the fact that final assessment in their study was not performed in the most realistic setting that the participants were trained in.

The present study also makes a theoretical contribution to the IS literature. In particular, (1) it demonstrates that individuals are unequally overloaded when facing the same amount of information delivered by IT; (2) this is due to the personal mental organization of the LTM under the form of cognitive schemata rather than simply the fixed limited capacity of STM. Participants were randomly assigned to the training conditions and demonstrated equal scores on the control variables. The different outcomes must reflect the schemata that were developed during training. Finally (3) it also exploits the potential of thermal imaging technology as an innovative psycho-physiological instrument to measures physiological responses to mental load.

The practical contribution of this chapter for anticipating ECO in novice surgical trainees using surgical simulation-based training curricula is twofold. First the results of this study demonstrate the potential of a basic immersive training program using a realistic context. Immersive training allows surgical training in a social context with a high amount of information delivered by medical IT that is more congruent with cognitively demanding OR. It also allows trainees to learn to cope with these cognitive demands during training rather than during clinical practice. In this study immersive training appears beneficial in terms of the trainees' experience of ECO, overall stress level and, with a significant tendency, stress towards colleagues. Also it was demonstrated that immersive training through its effect on ECO leads to higher levels of surgical performance. This study is an important step towards immersive surgical training curricula to reduce ECO including its emotional manifestations in the form of stress. Immersive simulation training may further smoothen the transfer from training to the OR.

Interestingly the immersive socio-technological context in this study was constructed with relatively simple and inexpensive means. The effectiveness of immersive training may look intuitive but practically this form of immersive training in a realistic context is rarely applied. After further validation involving surgical residents, this form of training might be an appealing way to embed simulators into elaborately design training programs that are engaging and increase the effectiveness of simulation training.

Second, this study exploits the potential of thermal imaging in the field of surgery (Pluyter, Buzink, Rutkowski, and Jakimowicz, 2012) to measure physiological responses to mental load. Evaluation of cognitive aspects of surgery is crucial to assess the effectiveness of surgical training curricula (Carswell et al., 2005, Gallagher, Ritter, Champion, Higgins, Fried, Moses, Smith, and Satava, 2005; Kahol, Vankipuram, and Smith, 2009). Interestingly, thermal imaging technology is often already present in a hospital for patient diagnosis. This lowers the barriers that might arise from the availability and lack of knowledge of the technology. In this study significant differences on the thermal data could only be reported when taking into account the baseline temperature of the participants. This was true even though baseline temperature did not significantly differ between the conditions. Baseline should be taken into account for thermal imaging as is also the case for other physiological measures such as fMRI (Dimoka, Banker, Benbasat, Davis, Dennis, Gefen, Gupta, Ischebeck, Kenning, Pavlou, Müller-Putz, Riedl, vom Brocke, and Weber, 2011).

Limitations and future research on immersive training

This study demonstrates the potential of a basic immersive training program constructed based on the memory congruence stipulated by ECOM (Rutkowski and Saunders, 2011). It is a first step towards an improved surgical simulation training program. Students with no existing cognitive schemata on surgery and surgical simulation were included to allow full control over the manipulation of cognitive schemata in the two training conditions. The immersive setting should be tested on surgical trainees and surgeons as a next step in the validation process. Three possible directions are proposed, of which some are currently in progress:

(1) *Replicate with surgical trainees*: further research is required to test whether the results of this study can be applied to surgical residential training in an even more realistic socio-technological context than was presented in this study. Part of this research will be covered in the second stage of this study, which is currently in progress. This second stage focuses on the manipulation of both technological and social context to train surgical residents in teams of three using merely simulation inside a real OR. A simulated operating room might foster the transfer of surgical skills from training to clinical practice (Jakimowicz and Fingerhoot, 2009). Implications for design of immersive simulation are discussed in the general discussion provided in Chapter 7.

(2) *Identify impact of social context on ECO:* further research could isolate the impact of the social context that is embedded in the immersive training program on ECO. This could be done if the social context is manipulated in a separate training condition. In the current study the social context was manipulated equally in both conditions.

(3) *Identify impact of immersive training on performance:* in this study three basic surgical tasks were used. Significant differences between the training conditions for the three performance indicators could only be found through the effect of immersive training on ECO. This is possibly due to limited amount of performance parameters and basic nature of the tasks. Further research could focus on more realistic tasks (e.g., full procedural training) and simulators that measure a complementary range of advanced performance indicators. This could include bleedings, inappropriate cutting and clipping of tissue, too much pressure put on tissue, and inappropriate cauterization, among other measures.

In the second stage of this study Virtual Reality (VR) simulation of a full laparoscopic cholecystectomy procedure will be used to further increase realism of the task. Assessment of performance will be further expanded with a range of clinically relevant performance parameters including surgical errors. These could possibly further identify the potential of immersive training in decreasing impaired performance resulting from ECO.

Concluding, this study demonstrates the potential of a basic immersive surgical training program using simulation to reduce IT-related overload and consequent stress and stress towards colleagues. These findings were supported by physiological data collected using thermal imaging. Immersive training allows novices to build appropriate cognitive schemata and coping strategies that are required to cope with the cognitive demands in the OR. Immersive training could smoothen the transfer from training to clinical practice in the OR. Ironically immersive training uses a context of high amount of information delivered by IT to decrease ECO. As already recommended, this study is a first step towards an improved surgical simulation training program. Further research on immersive training of medical trainees in an even more realistic context is required. This will be partially covered in a second stage of this study.

6. Recent developments in healthcare technology: my physician @ home[13]

6.1 Introduction

Tele-health is a recent development that coincides with the rapid blooming of Information Technology (IT) in the Operating Room (OR). It is part of a new culture of communication that has been implemented in the healthcare domain (see Noorani and Picot, 2001; Wilson, 2003). Tele-health is "the use of communications and information technology to deliver health and health care services and information over large and small distances" (Noorani and Picot, 2001, viii). It provides a growing range of connectivity options between physicians and their discharged patients. Tele-health is supported through Video Contact (VC) technology. It provides patients the opportunity to consult medical professionals. It is used by patients and physicians to exchange and discuss synchronously medical information such as laboratory test results and medication prescriptions. For example, patients suffering from diabetes can use it to exchange the results of their blood levels. Thereby it is a substitute for physical meetings. It provides potential benefits for geographically dispersed patients and physicians. The patient does not have to travel for miles to interact with a physician. Care can be improved through regular checks of physiological data (Peddle, 2007).

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However this new technology may challenge the cognitive system of the patient. The average patient can be expected to lack important cognitive schemata holding relevant medical information. This applies even more when the patient was recently diagnosed with the disease rather than years back. They may also lack the technical skills to handle the VC technology. Chapter 3 and 5 demonstrated that a lack of appropriate schemata can impose higher levels of Emotional-Cognitive Overload (ECO). Also the average person is not as cognitively complex and highly absorbed as some surgical trainees are. And even such trainees are not immune for the impact of realistic sources of overload on their performance and stress.

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[13] This chapter is based on Rutkowski, A.F., Saunders, C.S., & Pluyter, J.R. (forthcoming). Emotional and Cognitive Overload: The Role of Personal Dispositions and Prior Experience. Proceedings of the 72nd Academy of Management Conference 2012: The informal economy, Boston, MA, USA: Academy of Management.

Figure 6.1. Video contact technology on a mobile device

ECO with information delivered by video technology lies in wait. Again the cognitive and emotional costs of failure are high. Erroneous interpretation of the information may result in incorrect medication dispensing or treatment strategies. Also patients using such technologies are already ill. Stress resulting from ECO may be particularly harmful under delicate health conditions such as cardiac disorders. This chapter aims to study the attitude of patients towards having video contact with their physician. In particular, it aims to find out whether patients expect to be overloaded with the information delivered by VC technology (see Figure 6.1).

The contribution of this study to the overall dissertation is twofold. On a practical level it tests whether overload with medical IT exists beyond the medical staff. It may be a relevant issue for patients that face new developments in healthcare technology. Such innovation should be properly managed in order not to produce a fiasco and a waste of money. Identification of different types of patients based on their encoded experience of ECO and personal mental dispositions could be important to target different user groups. The theoretical goal is to demonstrate the external validity of overload with information delivered by medical IT beyond surgical training. The focus of the study is on the patient’s attitude towards VC technology. It does not focus on diffusion of the technology itself or on overload from the physician’s perspective.

6.2 Theoretical background

This chapter builds on the Emotional-Cognitive Overload Model (ECOM: Rutkowski and Saunders, 2011). In this study the personal mental framework of individual participants is shaped through the interaction of encoded experience of ECO in Episodic Memory (EM) and two important personal mental dispositions. These are the Need For Cognition (NFC) and trait anxiety. These were introduced in Chapter 2 on overload theory. NFC can help in processing the information delivered by IT (see also Chapter 3). Anxiety can increase concerns about the ability to process medical information. Based on the ECOM it is argued that experience of ECO remains as a residual in the LTM, encoded in Episodic Memory. It can affect the perceived ECO with information delivered by video technology (ECO-video). The research model is displayed in Figure 6.2.

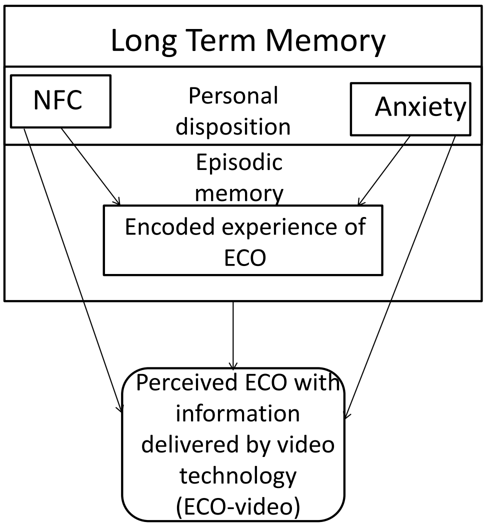

Figure 6.2. Research Model

High mental load may dissolve as soon as it has been experienced if the individual has the cognitive resources to process the input stimulus. The individual may deal effectively with the stimulus by chunking it well. Alternatively he or she may not have the appropriate emotional and cognitive resources to chunk it efficiently. The subjective experience of ECO remains encoded in LTM as a positive or negative valence. Dealing successfully with high mental load does not necessarily imply a positive valence. The individual may have perceived ECO with information delivered by IT as negative because of concerns about making mistakes (Rutkowski and Saunders, 2011).

If the individual was dissatisfied with the consequences of processing the information delivered by IT, the encoded experience related to that processing may have an embedded negative valence. On the other hand, if the mental load was processed without difficulty, the overall impression would be good. A positive valence would be embedded with the memory of the encoded experience of ECO in the individual’s mental framework. The chances of a negative valence increase with the number of encoded experiences of ECO not emotionally and cognitively handled by the individual. That is because it is not only likely that the overload situation had not been handled well cognitively, but also because of the likelihood that the emotional experience would have been negative. In that case there had been any frustration, stress, or other perceived negative consequences of the overload situation (Rutkowski and Saunders, 2011).

This paper presents the results of a panel survey (n=1868). Participants were invited to evaluate perceived ECO with information delivered by a VC technology. This technology allowed potential patients to discuss health matters with specialists online. It was mentioned that the VC technology was also applicable for discussing other sensitive information such as financial information with bankers. The following hypotheses are proposed:

H1. Individuals reporting higher levels of encoded experience of ECO in EM will report higher levels of ECO with information delivered by VC technology than individuals with lower levels of encoded experience with ECO.

The lower an individual’s NFC, the more likely he or she would experience a high mental load situation as an ECO situation. The individual would not find the situation to be pleasurable if he or she could not handle it properly. In such situations, he or she may experience more frustration and make more errors. Such individuals are likely to have encoded the situation into their memory as a negative experience of ECO. Similarly, individuals who are more anxious likely remember high mental load situations as ECO situations. These are situations in which they were frustrated or performed poorly because they had to struggle to process the stimulus information. Hence, it is hypothesized that:

H2a. NFC will be negatively related to encoded experience of ECO in EM.
H2b. Anxiety will be positively related to encoded experience of ECO in EM.

H3a. NFC will be negatively related to perceived ECO with information delivered by video technology.
H3b. Anxiety will be positively related to perceived ECO with information delivered by video technology.

6.3 Research method

Participants and Procedures

A sample of 2538 Dutch participants was invited to fill in the online survey. Participants completed self-reported questions on NFC (Cacioppo and Petty, 1982), anxiety (Costa and McCrae, 1992) and encoded experience of ECO (Rutkowski and Saunders, 2011). Subsequently the VC technology was introduced and its possibilities in terms of synchronous communication with physicians were outlined. Illustrations of the VC on a mobile device and television were provided (see Figure 6.1) to give the participants a comprehensive view. Participants were subsequently asked to evaluate their concerns about ECO with information delivered by the online VC technology (Rutkowski and Saunders, 2011). The VC was designed to support online interaction with physicians and exchange of similarly sensitive financial information. Details on the measurement scales of NFC, anxiety, encoded experience of ECO and concerns about ECO with information delivered by the VC technology can be found in appendix D.

The response rate was 73.6%. The participants ranged in age from 16 to 93 years old with 4.8% below 24, 29.7% aged 25-44, 43.2% aged 45-64 and 22.3% older than 64. Participants from all age groups reported to be overloaded with information delivered by IT (see also Rutkowski and Saunders, 2010). The total sample consisted of 1017 males. Participants worked in a wide range of industries including government (7.2%), retail (6.2%), healthcare (9.4%), industry (9.4%), service (7.2%), education (7.2%), financial institutions (3.2%), transportation (2.5%) and agriculture (1.3%).

Analysis and Results

Path model and identification

In this study Structural Equation Modeling (SEM) is conducted to test the hypotheses and the path model (Figure 6.3) that was derived from the research model (Figure 6.2). AMOS 19.0 was used to conduct SEM using a maximum likelihood estimation procedure, which is the default estimation procedure in SEM (Kline, 2005). AMOS is widely used to conduct SEM (Kline, 2005, p.6). The independent variables are Need for Cognition (NFC), anxiety, and the latent variable encoded experience of ECO. Encoded experience of ECO has two reflective indicators: cognitive manifestations and emotional manifestations. The dependent variable is perceived ECO with information delivered by the VC technology (ECO-video).

NFC and Anxiety are represented in the path model (see Figure 6.3) as observed variables. NFC and Anxiety can be expected to correlate. Both variables influence encoded experience of ECO (encodedECO) which is represented as a latent factor. It is measured through its observable emotional and cognitive consequences. These observable consequences are included in the model as reflective indicators of encodedECO. They are encodedE (emotional consequences) and encodedC (cognitive consequences). NFC, Anxiety and encodedECO influence ECO-VIDEO that is represented as an observed variable. All endogenous variables by default have a unique associated disturbance term e_n. Several assumptions apply to the disturbance terms: (1) their expected value is zero, (2) error variance is constant for all units, (3) error terms for different units are independent, (4) error terms are independent of the related observed variable, and (5) error terms are normally distributed (Kline, 2005). The path model and corresponding hypotheses are depicted in Figure 6.3.

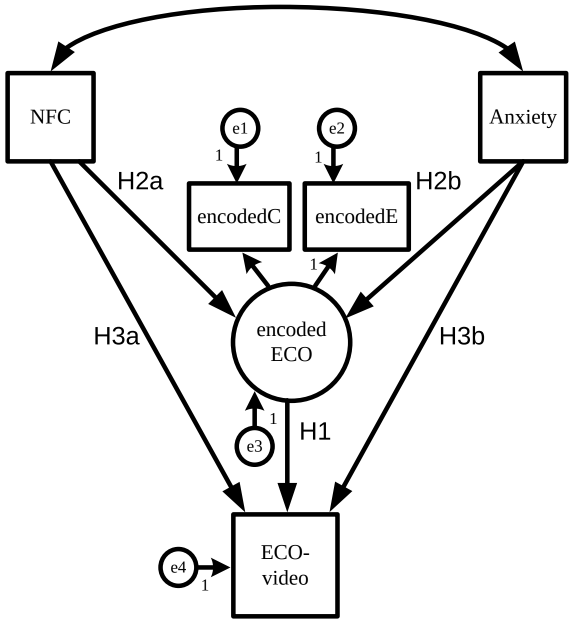

Figure 6.3. Path Model

Hypotheses are denoted by H_n in the path diagram. It is recommended to assess the identifiability of the measurement model and structural model a priori (Boomsma, 2000). To identify the model both the measurement model and structural model should be identified. In the measurement model, indicators are used to assess constructs or latent variables. For the measurement model to be identified, five conditions labeled A through E must hold (Kenny, Kashy, and Bolger, 1998). Only the composition of the latent construct encodedECO and its indicators encodedC and encodedE are part of the measurement model. First the latent variable was scaled by fixing the path coefficient of the direct path from encodedECO to encodedE to 1 (condition A). Any latent variable needs to be scaled in SEM. Fixing the path coefficient is the common approach taken, especially when the latent variable is part of a structural model (Kenny et al., 1998) as was the case in the path model of this study.

The latent construct encodedECO has two indicators whose error terms are uncorrelated, and the construct encodedECO, is correlated to at least one other construct (condition B). No paired constructs are in the measurement model (condition C). The indicators of encodedECO are uncorrelated (condition D) and there are no double loadings of the indicators (condition E). The measurement model satisfies all conditions to be identified. Also the structural model is identified. Condition A and condition B are satisfied, and, hence, condition C is not applicable (Kenny et al., 1998). The measurement model and structural model were estimated at once.

Data Screening

SEM requires several assumptions to be met before it is possible to fit the model to the data. These assumptions apply to the normality, outliers, multicollinearity, missing data, linearity and homoscedasticity of the data (Kline, 2005; Boomsma, 2000).

SEM assumes normality and is robust against violations of the normality assumption when a large sample size is used. Inspection of the Q-Q plot suggested that all variables were normally distributed. Further inspection of the skewness-index and kurtosis-index of the variables was performed (see Table 6.1). All variables showed an absolute value of the skewness-index < 2, and absolute value of the kurtosis-index < 7. The data followed an approximately normal distribution, which is appropriate for applying SEM (Kline, 2005, p. 49-51). Seven subjects were excluded based on extreme scores on anxiety. Outliers were defined as scores more than three standard deviations beyond the mean. No missing data could be reported on the variables of interest. That is because the questionnaire was administered electronically using constraints that required the participants to fill out the entire questionnaire.

No pairwise multicollinearity was detected. All bivariate correlations were below .80 (See Table 6.2) and tolerance statistics were not below the threshold of 0.1 (Keller and Warrack, 2003). Inspections of the bivariate scatterplots suggest moderate linear relationships among the independent and dependent variables. Exponential, quadratic and logarithmic data transformations were performed but did not substantively increase bivariate linearity or homoscedasticity. Therefore the original scores were used as input for the SEM analysis in AMOS. Using the original scores also simplifies the interpretation of the path model. This is desirable in this paper that aims to explain.

Table 6.1. Descriptives

	encodedC	**encodedE**	**NFC**	**Anxiety**	**ECO-video**
Mean	3.12	2.92	4.44	2.72	3.73
SD	1.64	1.61	1.36	1.14	1.53
Skewness	.454	.550	-.489	.441	.131
Kurtosis	-.489	-.467	-.172	-.331	-.430

Table 6.2. Correlation Matrix

	NFC	Anxiety	ECO-video	encodedE	encodedC
NFC	1				
Anxiety	-.262	1			
ECO-video	-.263	.270	1		
encodedE	-.252	.326	.271	1	
encodedC	-.178	.230	.192	.705	1

Overall Model Fit

The standardized solution of the estimated model is depicted in Figure 6.4.The overall fit of the model was assessed using statistical tests and fit indices. X^2 and CMIN are both equal to 5.065 with df=2 and $p \geq .080$ indicating the model is not rejected at a 5% nor 1% α-level. Indeed this logic is backward from the usual reject-support of statistical tests (Kline, 2005, p. 136; Steiger and Fouladi, 1997). Two absolute fit indices are used: the adjusted goodness-of-fit index (AGFI) and root mean square error of approximation (RMSEA). An AGFI ≥ .95 and RMSEA ≤ .05 generally indicate the data is well-reproduced by the research model. The model fit scores of the research model AGFI ≥ .992 and RMSEA ≤ .029 indicate a good absolute fit. The Tucker-Lewis Index (TLI) was used to test the incremental fit of the model. The TLI compares the fit of the proposed path model to the fit of the independence or null model where all variables are unrelated. The TLI ≥ .992 is higher than the required threshold of .95 indicating a good fit of the path model. Overall the statistical tests and fit indices demonstrate a good model fit.

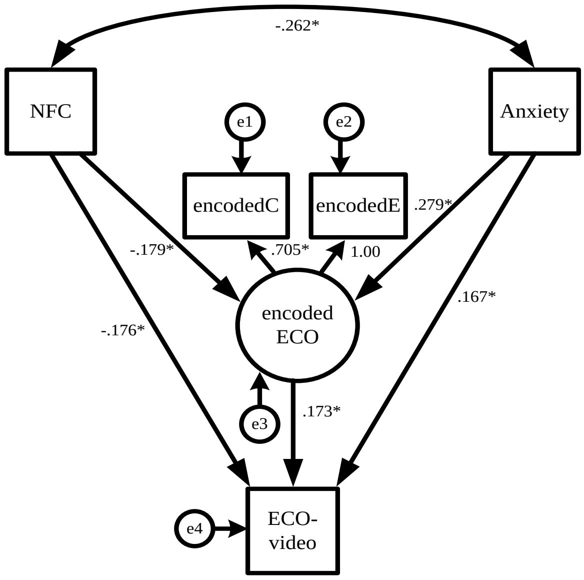

Figure 6.4. Standardized Solution of Estimated Path Model
* indicates significance of free parameter at α=.001

The standardized residual covariance matrix and modification indices do not suggest adding additional paths or correlations. Neither can the model be made more parsimonious as all parameters of the estimated model are significant (see Table 6.3).

Table 6.3. Unstandardized Estimates

Independent variable$^+$	**Dependent variable**$^+$	**Relation**	**Estimate**	**Standard error**	**z**	**p**
NFC	encodedECO	Regression weight	-.213	.027	-7.979	≤ .001
Anxiety	encodedECO	Regression weight	.396	.032	12.472	≤ .001
encodedECO	encodedC	Regression weight	.716	.042	17.183	≤ .001
encodedECO	encodedE	Regression weight	1.000			
Anxiety	ECO-video	Regression weight	.225	.032	7.125	≤ .001
NFC	ECO-video	Regression weight	-.198	.026	-7.686	≤ .001
encodedECO	ECO-video	Regression weight	.164	.024	6.753	≤ .001
Anxiety	NFC	Covariance	-.405	.037	-10.895	≤ .001

$^+$ Variable1 and Variable2 in case of covariance, instead of Independent and Dependent variable.

The theoretical model should be compared to competing models if such models can be drawn up based on valid theoretical arguments (Boomsma, 2000; Kline, 2005, p. 64). First, alternative models with curvilinear relationships of NFC and Anxiety on the dependent variables were tested as a result of the moderate bivariate linearity detected in the data screening. These models did not yield a better fit than the research model.

Second, it could be argued that encodedECO should be treated as an exogenous variable as it represent episodes encoded in Episodic Memory as a part of LTM. This would produce the following competing model (see Figure 6.5) to the path model derived from the research model proposed in Figure 6.3. The research model and competing model are equivalent models that yield the same covariances with a different configuration of paths. They also have equal model fit and can thus only be compared on theoretical arguments. The research model is as parsimonious as the equivalent model. The modeled relationships are based on theory where NFC and Anxiety represent personal mental dispositions that have a direct impact on encodedECO rather than only being associated with it as is the case in the equivalent model. EncodedECO reflects an experience that is encoded in LTM after previous experiences with overload accumulated over time. All three constructs are part of the mental framework of the individuals assessing perceived ECO with information delivered by the VC technology.

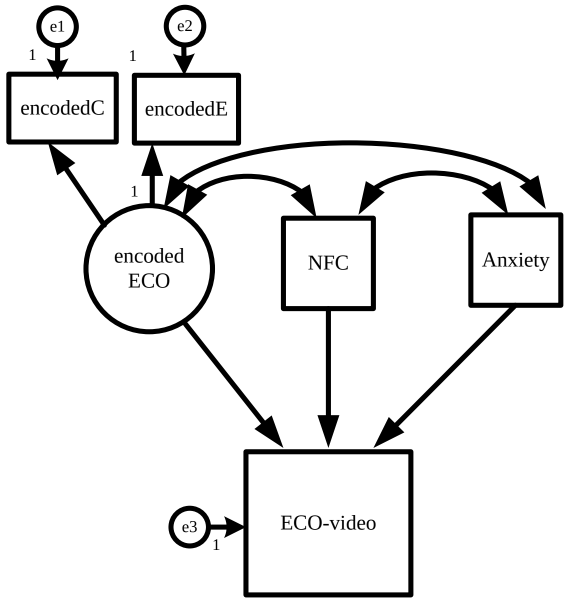

Figure 6.5. Equivalent model

Based on these theoretical arguments the equivalent model is rejected in favor of the path model derived from the research model (see Figure 6.3). There are no theoretical arguments to treat the state of ECO-video as an independent variable to predict personal mental dispositions encoded in LTM.

Tests of Hypotheses

Inspection of the unstandardized estimates and z-scores of the regression weights (see Table 6.3) reveals that all hypotheses are supported. Here p values are reported although it is recognized that p values are less informative because parameter estimates are mutually dependent (Boomsma, 2000). Acceptance or rejection of the hypotheses is therefore based on the z-scores of the unstandardized estimates. An estimated regression weight with z-score ≥ 1.96 suggests acceptance of the accompanying hypothesis.

The direct path from encodedECO to ECO-video was estimated at .164 (standard error [se]=.024) with a Z = -6.753. This confirms Hypothesis 1. The direct path from NFC to encodedECO was estimated at -.213 (se=.027) with Z = -7.979 confirming Hypothesis 2a. The direct path of Anxiety to encodedECO was estimated at .396 (se=.032) with Z = 12.472 confirming Hypothesis 2b. The direct path of NFC to ECO-video was estimated at -.198 (se=.026) with Z = -7.686 confirming Hypothesis 3a. The direct path from Anxiety to ECO-video was estimated at .225 (se=.032) with Z = 7.125 confirming Hypothesis 3b. Hence, all hypotheses were supported.

Taken together, these results imply that individuals reporting higher levels of encoded experience of ECO report higher levels of ECO with information delivered by VC technology than individuals with lower levels of encoded experience with ECO. NFC is negatively related and anxiety is positively related to encoded experience of ECO as well as to ECO with information delivered by the VC.

6.4 Discussion and conclusion

The results, in line with ECOM (Rutkowski and Saunders) indicate that encoded experience of ECO is a crucial factor in estimating individual attitudes towards VC technology for healthcare purposes. Encoded experience of ECO is embedded in the individual's mental framework. It differs for each individual. The results demonstrate that encoded experience influences appraisal of the potential ECO with information delivered by the proposed VC technology. ECO in that sense is "cumulative" as it feeds into the episodic memory to influence appraisal.

The results also demonstrate the role of anxiety and the NFC, two personal mental dispositions. In particular they influenced experience of ECO in the past. They also influence concerns about ECO with information delivered by the proposed VC technology. Participants high in NFC are cognitively complex individuals with a dispositional tendency to enjoy effortful cognitive activities (Cacioppo and Petty, 1982). Their need to structure information meaningfully (Cohen, Stotland, and Wolfe, 1955) increases the ability to chunk information. As predicted by ECOM this decreases their concerns about being unable to resolve a state of high mental load imposed by the VC technology. This was also demonstrated in the surgical setting in Chapter 3.2.

Anxiety increases concerns about the ability to process information. Individuals with trait anxiety also have a dispositional tendency to process negative affective information (Costa and McGrae, 1992). This reinforces the activation of emotionally congruent cognitive schemata on experience with ECO encoded in episodic memory (Rutkowski and Saunders, 2011). This was demonstrated in this study through the impact of anxiety on encoded experience of ECO and their impact on concerns about ECO with information delivered by the VC technology.

Implications for management and theory and limitations

The contribution of this study is twofold. On a practical level it demonstrates that IT-related overload in healthcare exists beyond the surgical domain. It is a relevant issue for patients that face new developments in healthcare technology. While individuals may accept that they experience IT-related overload at the workplace, they may not do so in their homes. It should be remembered that not everyone is able to emotionally and cognitively handle the information delivered by the IT. It is likely that patients who are concerned about being overloaded with the information delivered by VC technology may prefer physical consultations. ECOM (Rutkowski and Saunders, 2011) predicts that these individuals will blame the VC technology to explain their attitude.

Such innovation should be properly managed. Identification of different types of patients based on their encoded experience of ECO and personal mental dispositions could be important to target different user groups. Overloaded patients may need tailored instructions, specific training or simply physical meetings. Also they may benefit more from VC technology if they are given the opportunity to practice during healthy conditions rather than under urgent conditions of illness. That would allow them to develop appropriate cognitive schemata in a relatively safe setting.

As opposed to surgeons and surgical residents, discharged patients are not embedded in an organization where management can support their interest and facilitate their needs. As demonstrated in this study not everyone is equally able to handle information delivered by technological innovations. Ethically it is important to identify who is responsible for educating patients about healthcare technology.

Theoretically, this chapter demonstrates the external validity of medical IT-related overload beyond surgical training. The study is based on rigorous SEM analysis of a large sample of n=1868 respondents. Thereby it contributes to a more theory-driven understanding of IT-related overload.

This study has two limitations. First, the SEM analysis is performed using cross-sectional data. Hence, causality cannot be confirmed. The analysis however is performed on a large sample and the path diagram is constructed based on strong theoretical arguments. When compared with alternate models, the model displayed better indices of fit. It is suggested that further research should attempt to obtain follow-up data gathered using randomized controlled experiments. This would help to further assess the appropriateness of the causal order in the research model. The magnitude of the path estimations might be underestimated in this study due to modest evidence of linearity identified in the data screening.

Second, only two personal mental dispositions were included. CA with IT (Agarwal and Karahanna, 2000) was identified as an important personal mental disposition in Chapter 3. CA with IT as well as other dispositions such as self-efficacy (Compeau and Higgins, 1995) could also impact perceptions of overload. These could further help to target potential user groups more specifically. Future research could contribute by studying other personal mental dispositions.

Concluding, this research describes the test of a model that refines the concept of IT-related overload. It incorporates emotional and cognitive aspects related to encoded experiences with IT-related overload. It also demonstrates that personal mental dispositions, most notably NFC and anxiety, impact how individuals perceive IT-related overload and therefore assess potential mental load. In particular, individuals with a high NFC or low anxiety levels are less likely to perceive encoded experiences negatively. They are also less likely to experience ECO when dealing with information delivered by proposed VC technology. Such innovations should be managed properly by for example targeting user groups based on their level of encoded experience of ECO.

7. General discussion – managing overload

7.1 Reflection on research objective

The focus of this thesis is on an issue relevant for both practice and theory. It was posed in the introduction as the main research objective of this dissertation:

> How can Information Technology (IT) -related overload be countered more effectively using surgical simulation training to improve patient safety than is currently the case in surgical training for Minimally Invasive Surgery?

The literature review revealed that IT-related overload is indeed a real and relevant issue in the field of surgery, although it is mostly referred to as mental workload. Medical IT and information delivered by medical IT are rapidly becoming the defining elements of surgical procedures. Medical IT delivering complex information on multiple screens and modalities impose new cognitive demands on the surgeon (Berguer, Smith, and Chung, 2001; Cao, Zhou, Jones, and Schwaitzberg, 2007; Cheung, Wedlake, Moore, Pautler, and Peters, 2010). Especially novices may be receptive to the detrimental effects of overload on surgical performance and stress (Hsu, Man, Gizicki, Feldman, and Fried, 2008; Andersen, Klein, Gogenur, and Rosenberg, 2012; Berguer, Smith, and Chung, 2001; Böhm, Rotting, Schwenk, Grebe, and Mansmann, 2001; Smith, Chung, and Berguer, 2000). Appropriate simulation training is required (Carswell, Clarke, and Seales, 2005; Jakimowicz and Cuschieri, 2005).

In this dissertation a basic **immersive** surgical simulation training program was developed and tested step-by-step using a theory-driven approach. In particular, immersive training was embedded in the Emotional-Cognitive Overload Model (ECOM: Rutkowski and Saunders, 2011), which underlines the role of *congruence* of personal cognitive schemata. Immersive training provides surgical training in a context that is more congruent with the cognitively demanding Operating Room (OR). Particularly it embeds reality in both the technological and social context. It allows trainees to learn to cope with these cognitive demands during training rather than during clinical practice.

Compared to conventional simulation training, immersive training was shown to be significantly more effective in terms of the trainees' decreased experience of Emotional-Cognitive Overload (ECO), overall stress level and, with a significant tendency, stress towards colleagues. Lower levels of ECO were also associated with higher performance levels in Chapter 5. Subjects undergoing immersive training are better able to process the information delivered by medical IT. Immersive training is an important step towards training curricula that reduce IT-related overload in the OR. Immersive simulation training may further smoothen the transfer from training to the OR. Thermal imaging was included as a physiological indicator of mental load as a complementary assessment tool.

7.2 Practical contributions

This dissertation has several key practical implications to increase patient safety in the OR. In this section it is argued that reducing overload should be a joint effort of at least medical staff, hospital management, medical associations, and medical IT design industry. Their specific contributions will be discussed subsequently. The discussion is centered on two general themes that require contribution from multiple stakeholders including hospital management, hospital staff, the medical IT design industry, and medical associations (see Table 7.1). The general themes arose from the results of Chapter 2 to 5. Chapter 2 identified that IT-related overload is a real issue in the field of surgery that requires a theory-driven understanding. Chapter 3 demonstrated that realistic social and technological sources of overload impact performance and stress. Social and technological sources of overload should be actively **managed to improve patient safety in the operating room**. Chapter 3 and 5 demonstrated the role of cognitive schemata constructed through simulation training. Especially Chapter 5 demonstrated that embedding simulators into elaborate **preclinical simulation training programs** is desirable. Immersive training was found to be a potentially promising training program allowing participants to increase chunking abilities of information delivered by medical IT.

The remainder of the discussion focuses on these two general themes: improving preclinical training (1) and pro-active management of patient safety in the OR (2). It builds primarily on the results provided in the previous chapters and summarized above. The discussion is further grounded in reality using three additional sources of information:

1. A recent report by the Dutch national institute of public health[14] on safety during laparoscopic surgery. It is used to frame the results into a broader societal context. Information from this report is referred to as (IGZ, 2007).

2. A set of quotes from the medical staff collected during twelve surgical procedures in two Dutch hospitals discussed in Chapter 3. They are not the basis for substantive arguments for the implications but will be merely used to illustrate the practical context of the implications. They are presented *"within double quotes and in italics"*. The role of the anonymous respondent is denoted [between brackets].

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[14] Inspectie Gezondheidszorg (IGZ)

Table 7.1. Recommendations per stakeholder

	PRIMARY CONTRIBUTING PARTY			
	Hospital management	**Medical staff**	**Design/ industry**	**Medical associations**
Improve preclinical training (to anticipate ECO and develop coping mechanisms)	Facilitation and control process of preclinical training	Participate in preclinical training to construct cognitive schemata reducing ECO	Design of surgical simulation technology and programs	Setting standards for training curricula including both technical and cognitive (including ECO) measures and assessment criteria.
Proactive management of patient safety in the Operating Room (with embedded awareness of-, and countermeasures to ECO)	*(1)* Strategic level: defining safety strategy with specific attention to preclinical as a countermeasure to ECO *(2)* Tactical/operational level: facilitate and control safety culture	(1) Recognition of impact of ECO on surgical performance and stress (2) Raising awareness of this impact among colleagues	Design medical IT against ECO by aligning the design with the cognitive architecture of human memory (Short-Term Memory, Long-Term Memory).	Setting and controlling standards

3. A cost analysis of surgical training in a pre-clinical simulation setting versus “training on the job” in the OR. The data was collected from multiple data sources, but mainly from the report of Van Baalen and Bosman (2011).

7.2.1 Improving preclinical training

Hospital management and facilitation of preclinical training

This dissertation underlines the importance of preclinical **simulation training** to construct cognitive schemata required to perform complex surgical tasks. Cognitive schemata are an inherent part of an individual’s cognitive resources (Rutkowski and Saunders, 2011). Cognitive resources are required to cope with high mental load during surgery (see Chapter 3 and 5). Preclinical simulation training allows construction of cognitive schemata in a safe and controlled environment (Schijven and Jakimowicz, 2004).

The role of management is primarily to facilitate preclinical training through allocation of resources. Laparoscopic surgical training facilities are present in only 35% of Dutch hospitals. Also less than half of these training facilities (15.4% of the hospitals) offer full laparoscopic training programs. In fact it is noted that “training facilities are randomly and diversely present” as opposed to being structurally present (IGZ, 2007, p. 30). When these facilities are present, the degree of actual capacity utilization could be improved (IGZ, 2007). Notably, 49% of the surgical residents in Dutch hospitals did not follow any hands-on preclinical training course in laparoscopic surgical skills before performing their first laparoscopic gallbladder removal under supervision (IGZ, 2007, p. 52).

This is remarkable since surgical simulation training has advantages from an ethical as well as a cost-perspective. Surgical simulation training allows a surgical trainee to practice in a safe and controlled environment before performing actual surgery on patients. Simulation training increases surgical proficiency preclinically and errors made during simulation training have no effect on patients (Jakimowicz and Cuschieri, 2005). This is in contrast with “training” on the job where errors due to a lack of experience have direct implications on the patient’s health (Jakimowicz and Cuschieri, 2005).

Simulation is not intended to fully replace “training” in the clinical environment. However it aims to improve preparation for the clinical setting to improve patient care and safety (Maran and Glavin, 2003). Recent research has demonstrated that surgical trainees that are trained using simulation technology outperform trainees that do not receive simulation training (Palter, Grantcharov, Harvey, and MacRae, 2011; Seymour, 2008). Improved preparation in a simulated setting also has cost advantages. Firstly, training on the job is costly because it takes place in the OR. The OR is a capital intensive environment where delay resulting from surgical training generates considerable costs (Van Baalen and Bosman, 2011). Secondly, higher probability of conversions from laparoscopic to open surgery associated with lower levels of experience (Aggarwal, Hance, Undre, Ratnasothy, Moorthy, Chang, and Darzi, 2006) are not only harmful for the patient but also costly for the hospital.

A cost analysis of based on costs of delay is provided first. Here preclinical simulation training is compared to “training on the job”. The focus of training and the cost analysis is restricted to surgical residents. This is congruent with the delineated scope presented in the introduction of this dissertation that does not include experienced surgeons. Also the analysis focuses exclusively on costs of training.

Table 7.2 outlines the costs of a tutored preclinical simulation training program for basic laparoscopic skills certified by the European Association for Endoscopic Surgery (EAES). Surgical simulation is embedded in a comprehensive training program that allows surgical residents to train their basic laparoscopic skills. The costs per hour (€115) are calculated by dividing the total course costs (€500) over the total amount of hours of the training program (16) and adding up the hourly adjournment costs (€50) and daily subsistence allowance per hour of training (€272/8) of the surgical resident. The course costs of the training course are the subscription costs which include depreciation of simulation technology, costs of the training facility and personnel. Adjournment costs are defined as compensation received by trainees for loss of income due to their participation in the training. Daily substance allowance is based on the rates given by the United Nations Development Program (UNDP). Opportunity costs are not included in the calculation because it is part of the resident’s curriculum to follow training programs.

Table 7.2. Costs of preclinical simulation training

Head of expenditure	**Unit**	**Cost per unit**	**Total costs**
Costs of 2-day training course[1] (euro)	1 course	€500 per course	€500
Hourly adjournment cost[2] (euro)	16 hours	€50 per hour	€800
Daily subsistence allowance[3] (euro)	2 days	€272 per day	€544
Costs of 2-day training course (euro)			€1,844
Costs per hour of 2-day training course (euro)			**€115**

[1] Based on two-day (16 hours) European Association for Endoscopic Surgery (EAES) certified and tutored preclinical simulation training course for laparoscopic skills. The costs include depreciation of simulation technology, costs of the training facility and personnel.
[2] Adjournment costs based on Van Baalen and Bosman (2011) and rounded off upwards to tens.
[3] Based on rates of UNDP

When surgical residents are not trained in a preclinical simulation setting, they are **“trained” on the job** during actual surgery in the OR. The surgical resident performs (part of) a surgical procedure under supervision of the faculty surgeon (Bridges and Diamond, 1999). Thereby additional costs (costs of delay) are generated in addition to the regular costs of surgery. The costs of delay are due to additional time spent in the OR. In line with Bridges and Diamond (1999) it is assumed that the surgical resident is added to the surgical team rather than replacing a team member. Thereby additional wage costs are generated by the surgical resident. Revenue gained for a procedure is equal regardless of whether it involves on the job training or not. That is, the hospital receives equal compensation for the surgical procedure by the health insurance company.

Table 7.3 provides an overview of the costs of on the job training. This benchmark is based on a sample of two Dutch Top Clinical Hospitals. The data was provided by Van Baalen and Bosman (2011). The benchmark presented in Table 7.3 is a weighted average of the two hospitals. The weighted average is based on the proportion of total delay per hospital. The numbers per hospital are not presented to preserve anonymity of the contribution of the individual hospitals. Only costs of delay and the resident's wage are taken into consideration.

Table 7.3. Costs of "on the job training" in the Operating Room

Head of expenditure on the job training in the OR	**Benchmark based on weighted average of 2 Dutch Top Clinical Hospitals**
Total costs of delay (euro) [4]	€156,727
Total number of hours spent by surgical resident on training in the OR (hours) [4]	704
Delay due to on the job training (as percentage of total number of hours spent by surgical resident on training in the OR) [4]	34%
Total delay due to on the job training (hours)	251
Total costs of on the job training (excl. hourly wage of surgical resident)	€222
Hourly wage of surgical resident [4]	€50
Total costs of on the job training per hour spent in the OR (euro)	**€272**

[4] Numbers based on Van Baalen and Bosman (2011)

The total costs of delay, that is the costs generated in addition to the regular costs of surgery, are €156,727. The total costs of delay are generated over 704 hours of which 34% (251 hours) accounts for delay. On the job training is however provided during the total number of hours that the resident spends in the OR (704). Therefore each hour of on the job training on average generates (€156,727 / 704 =) €222 additional costs on top of the regular costs of surgery. Additional wage costs of €50 per hour are generated by the surgical resident. The total costs of on the job training per hour spent in the OR are €272.

From a cost-perspective, simulation training is a promising alternative to "on the job training". Effectiveness of these two training methods should also be taken into consideration. Training is considered effective if it increases surgical proficiency. Proficiency includes technical (e.g., manipulation of surgical instruments) as well as cognitive aspects of surgery such as dealing with overload and stress (Carswell et al., 2005, Gallagher, Ritter, Champion, Higgins, Fried, Moses, Smith, and Satava, 2005; Kahol, Vankipuram, and Smith, 2009). Previous studies demonstrated that simulation training is more effective than no training at all (Schijven, Jakimowicz, Broeders, and Tseng, 2005, Schijven and Bemelmans, 2011, Sturm, Windsor, Cosman, Cregan, Hewett, and Maddern, 2008, Palter, Grantcharov, Harvey, and MacRae, 2011; Seymour, 2008). This implies that individuals undergoing simulation training are better prepared for the clinical setting than individuals that solely do on the job training.

Further research is required that directly compares the relative effectiveness of simulation training to training on the job (Sturm, Windsor, Cosman, Cregan, Hewett, and Maddern, 2008). This was also the aim of Gerson and Van Dam (2003). Unfortunately they did not control the training time allowed for the two training groups. As proficiency generally increases with training time (Schijven and Jakimowicz, 2004) irrespective of the training method, the results of their study were not conclusive. Further research is required to assess the relative effectiveness of simulation training which from a cost perspective appears to be a promising alternative to training on the job. Such research should also aim to identify which part of on the job training could be covered by simulation training. For example, previous research has demonstrated that for surgical trainees that are susceptible to simulation training, the first 25 training repetitions are crucial to reach proficiency in laparoscopic technical skills (Schijven and Jakimowicz, 2004). Simulation is not intended to fully replace training in the clinical environment. However it aims to improve preparation to improve patient care and safety (Maran and Glavin, 2003).

A second potential cost- and ethical advantage of simulation training resides in a possible reduction of conversions. Improving laparoscopic surgical skills through elaborately designed training programs may reduce the number of conversions from surgeries that started laparoscopically and have to be converted to open surgery (Aggarwal, Hance, Undre, Ratnasothy, Moorthy, Chang, and Darzi, 2006). The number of cholecystectomy (gallbladder removal) procedures performed annually in the Netherlands is provided in Table 7.4. The numbers are based only on cholecystectomy procedures that account for about 3% of the total number of surgeries performed in the Netherlands.

Table 7.4. Number of occurrences

	Laparoscopic Cholecystectomy	**Open Cholecystectomy**
Number of procedures performed annually in the Netherlands [5]	21,898 procedures	2,853 procedures
Number of procedures converted from laparoscopic to open cholecystectomy annually in the Netherlands[6]	2,190 procedures (=10% of all laparoscopic cholecystectomies)	

[5] According to most recent data recorded by the Centraal Bureau voor de Statistiek (CBS) Available [online] at http://statline.cbs.nl/StatWeb/publication/?DM=SLNL&PA=80386NED&D1=a&D2=0&D3=0&D4=a&D5=l&HDR=T&STB=G4,G1,G2,G3&VW=T

[6] According to data recorded by the Inspectie Gezondheidszorg (IGZ, 2007)

Open cholecystectomy procedures have higher total costs compared to laparoscopic cholecystectomy procedures. This is mainly due to longer hospitalization time required after open surgery. An overview of costs of laparoscopic- and open cholecystectomy procedures is provided in Table 7.5. The total costs per patient of an open cholecystectomy are more than twice the costs of a laparoscopic cholecystectomy with a difference of €3,570.

Table 7.5. Overview of costs related to cholecystectomy procedures (per patient)

	Costs of Cholecystectomy[7]	
Head of expenditure	**Laparoscopic Cholecystectomy (LC)**	**Open Cholecystectomy (OC)**
Hospital stay (days)	€1,200	€3,800
Operating Room	€1,560	€1,950
Physician consultation	€170	€240
Lab examinations	€120	€280
Lab-samples	€40	€110
Radiological examinations	€50	€140
Miscellaneous actions	€50	€160
Materials	€10	€90
Total costs per patient * * excluding physician costs	**€3,200**	**€6,770** (surplus of €3,570)

[7] Average costs (excluding physician costs) based on Dutch hospital benchmark (Top Clinical Hospitals) (n > 15) Only clinical procedures included. Data provided by Chief Financial Officer (CFO) of a Top Clinical Hospital.

Table 7.6 provides a scenario analysis of potential cost-savings from a decrease in need for conversions due to simulation training. Simulation training improves surgical skills that are needed to complete a surgery laparoscopically instead of converting to open surgery (Aggarwal, Hance, Undre, Ratnasothy, Moorthy, Chang, and Darzi, 2006). These cost-savings could be allocated to facilitate preclinical simulation training. The numbers are based on the convergence rates provided in Table 7.4. They are extrapolated to a national level using three hypothetical scenarios. The scenarios represent the percentage of conversions that is reduced due to improvement of skills during simulation training. The 'medium impact scenario' assumes a 3% decrease of conversions from laparoscopic to open surgery due to improved simulation training. This comes down to 65 conversions (which is 3% of 2,190 conversions performed annually in the Netherlands as presented in Table 7.4) with associated cost savings of €232,050. That would allow 178 surgical residents to follow a certified two-day training course based on the costs (€1,844 per participant) presented in Table 7.2.

Table 7.6. Re-allocation of cost savings due to reduced number of conversions

	Reduction in number conversions (low, medium, high)		
	Low **(1%)** 21 procedures	**Medium** **(3%)** 65 procedures	**High** **(5%)** 109 procedures
Total cost savings (à €3,570 per procedure) available for training	€74,970	€232,050	€389,130
Number of surgical residents that can receive an additional simulation training course (à €1,844) [8]	40 surgical residents	125 surgical residents	211 surgical residents

[8] Based on two-day (16 hours) European Association for Endoscopic Surgery (EAES) certified and tutored preclinical simulation training course for laparoscopic skills. The costs include depreciation of simulation technology, costs of the training facility and personnel (see Table 7.2).

To put this into perspective note that 49% of the surgical residents did not follow any hands-on training course in laparoscopic surgical skills before performing their first laparoscopic gallbladder removal under supervision (IGZ, 2007, p. 52). The two cost-analyses presented above illustrate potential cost savings that can be used by management to facilitate simulation training. They demonstrate that simulation has both ethical- and financial advantages. Further research on the relative costs, effectiveness, and errors (e.g., preventable conversions to open surgery) associated with simulation training and on the job training is highly recommended to provide a cost-effective and high quality preparation for the cognitively demanding OR to surgical residents.

Medical association’s standardization

The IGZ (2007) noted that preclinical surgical training is in desperate need of at least national standardization of training programs and training assessment criteria. Standardization can only be achieved with involvement of medical associations that bring together regional initiatives.

Assessment criteria should evaluate both psychomotor and cognitive aspects of surgery including overload (Carswell et al. 2005). This dissertation proposes self-reported and physiological measures that can be used as indicators of ECO and mental load. The literature review presented in Chapter 2 identified several physiological measures including skin conductance and eye blink (Berguer, Smith, and Chung, 2001; Smith, Chung, and Berguer, 2000), holters measuring cardiac activity (Böhm, Rötting, Schwenk, Grebe and Mansmann, 2001; Song, Tokuda, Nakayama, Sato, and Hattori, 2009), and electroencephalograms (EEGs) measuring brain activity (as proposed by Carswell, Clarke, and Seales, 2005) as physiological indicators of mental workload. Chapters 4 and 5 demonstrated the potential of thermal imaging technology as an innovative psycho-physiological tool.

As noted in Chapter 4, physiological measures enable the measurement of ECO with physiological data that is not susceptible to social desirability bias. That is important since response bias is particularly likely to occur for a sensitive construct such as ECO. Overload is often so sensitive that it is not discussed in healthcare settings. It is also not part of the culture of surgeons to accept stress as an inevitable part of practice (Arora, Hull, Sevdalis, Tierney, Nestel, Woloshynowych, Darzi, and Kneebone, 2010). Objective measures are becoming even more important when surgical trainees are actually assessed or even selected on their ability to cope with situations of high mental load (Bass, Silverman, Dowdall, Bourlai, Pavlidis, and Dunkin, 2008; Carswell, Clarke, and Seales, 2005).

Standardized training should be performed using integrated simulation training programs. This dissertation demonstrated the potential of an immersive training program in Chapter 5. Also it should be carefully considered which surgical skills should be trained. Chapter 3 demonstrated that poor navigation by the laparoscope navigator in the face of social sources of overload impairs performance of the surgeon in training. Laparoscope navigation is a task often performed by the least experienced member of the surgical team (Buzink, Botden, Heemskerk, Goossens, de Ridder, and Jakimowicz, 2009). Such skills should also be considered in a standardized training program. A runner nurse mentioned during laparoscopic surgery:

> *"This is a good one [surgical resident navigating the laparoscope of which the information is presented to the surgeon via the laparoscope monitor], sometimes you really get seasick"* [Runner nurse during laparoscopic surgery]

Medical staff participation

Surgical trainees are highly dependent on the training infrastructure (surgical simulators, standardized training programs and curricula) provided to them. They should exploit the possibilities of preclinical surgical training provided to them.

Design of comprehensive simulation training programs

This dissertation demonstrated using subjects with no prior encoded cognitive schemata on simulation training that immersive training in a realistic context with high amounts of information delivered by technology in a social setting can increase training effectiveness. Particularly Chapter 5 demonstrated that basic immersive training decreases the experience of IT-related overload and consequent stress in a realistic setting. It responds to a call that surgical simulators should be embedded in elaborately designed simulation training programs (Jakimowicz and Fingerhoot, 2009). The importance of elaborately designed training programs is also recognized by the public health association (see IGZ, 2007).

The basic immersive context developed throughout this dissertation was constructed using means commonly present in a Skills Lab. An overview of the materials, facilities and personnel required for a basic immersive training program is provided in Table 7.7. This dissertation demonstrates that it is essential to provide an immersive context that is closer to a realistic technological and social context. Immersive training allows surgical training in a social context with a high amount of information delivered by medical IT that is more congruent with cognitively demanding OR. Realism and real output of information is important to improve the immersion of the training environment (Dede, 2009).

The basic immersive training program developed throughout this dissertation could be implemented in surgical training as depicted in Figure 7.1a and Figure 7.1b. It is based on the basic notion of immersive training that the technological and social context of training should be congruent with the context in the OR. It aims to foster transfer from VR simulation training to clinical performance in the OR (Jakimowicz and Fingerhoot 2009; Moulton, Dubrowski, MacRae, Graham, Grober, and Reznick, 2006; Seymour, 2008). This is highly required as the amount of information delivered by IT and social context impose high mental demands that may inhibit surgical performance and stress (see also Berguer, Smith, and Chung, 2001; Stefanidis et al., 2007).

Table 7.7. Components of a basic immersive simulation training program

Item	**Description**
Technology	
Surgical simulator with primary and secondary laparoscope monitor	The primary laparoscope monitor depicts the image of the camera embedded in the laparoscope. The secondary laparoscope monitor delivers the exact same information as the primary laparoscope monitor. It is a duplicate monitor.
Procedural checklist	Checklist for step-by-step performance of the simulated surgical procedure. This involves both steps that have to be taken before (e.g., selection of correct instruments) and during (e.g., cut tissue) the simulated procedure.
Vital signs monitor	Monitor providing information on the health condition of the simulated patient. The vital signs are: heart rate, blood pressure, blood pressure (arterial), consciousness, saturation (concentration of oxygen in the blood) and body temperature.
Auditory pulse-oxy signal	Auditory pulse signal varying in speed and pitch. The speed of the pulse represents the heart rate of the simulated patient. The pitch of the signal represents the saturation level of the patient.
Personal computer with web access	Internet computer available to the co-actor performing the role of the anaesthesiologist-assistant in training. The co-actor was left free to (not) use the computer.
Pager	Personal telecommunication device. The pager "beeps" when it receives a call.
Streaming radio	Streaming radio signal delivered through a laptop computer.
Facilities and personnel	
Co-actor	Performing the role of the anaesthesiologist-assistant in training.
Sound-proof and temperature controlled room	Sound-proof to block other sources of information. Temperature controlled to allow objective assessment of facial temperature in case the thermal imaging camera is used.

The social context depicted in Figures 7.1ab (e.g., laparoscope navigator, anesthesiologist in training) can be used merely to increase reality of the social context that is encoded in LTM. It can also easily be extended to embrace aspects of both technical-, cognitive-, and team training (see Helmreich, 2000) and physiological measures such as thermal imaging. It is part of a second stage of validation that focuses on the manipulation of both technological and social context to train surgical residents in teams of three using merely simulation in a real OR. However this was not the focus of this dissertation as it requires additional team theory. It does illustrate the *potential* of the basic immersive training program developed throughout this dissertation.

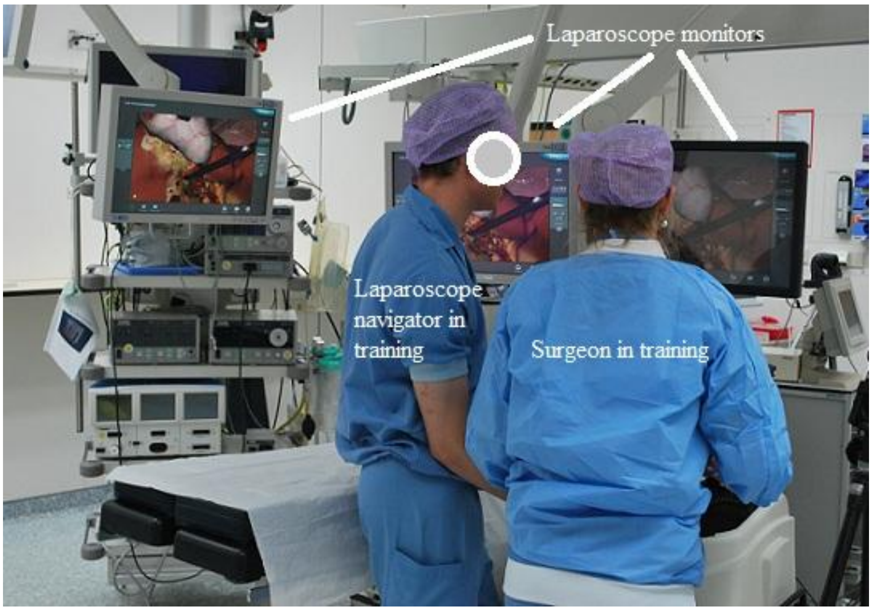


Figure 7.1a. Applications of immersive simulation training (role of surgeon and surgeon-assistant performing as laparoscope navigator)

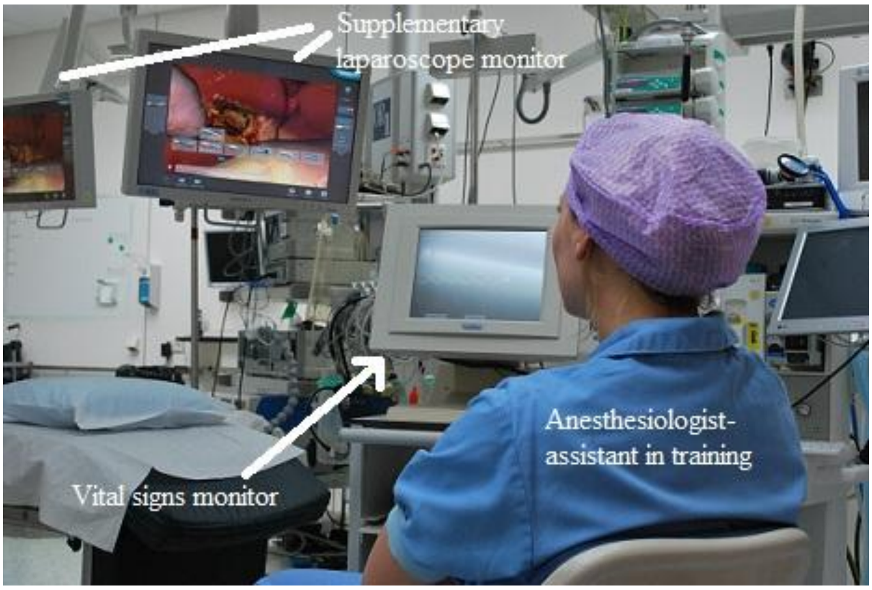


Figure 7.1b. Applications of immersive simulation training (role of anesthesiologist in training)

This dissertation demonstrated using subjects with no prior encoded cognitive schemata on simulation training that immersive training in a realistic context with high amounts of information delivered by technology in a social setting can increase training effectiveness. Further research is required to identify if more experienced subjects are equally susceptible to immersive training. On the one hand they may already be conditioned in a realistic setting due to their experience in clinical practice. On the other hand they might also benefit from immersive training because they are used to realistic settings (Wilkerson, Avstreih, Gruppen, Beier, and Woolliscroft, 2008)

Elements of serious gaming could potentially further improve the training approach. Serious gaming has successfully been deployed in other domains such as the military, aviation and car driving (Koonce and Bramble, 1998; Binsubaih, Maddock, and Romano, 2006). Verdaasdonk, Dankelman, Schijven, Lange, Wentink, and Stassen (2009) define serious gaming in a surgical context as “a broad spectrum of computer-based simulations for training or education in a single or multi-user environment [that] are intended to provide an engaging, self-reinforcing context motivating and educating its users” (p. 233). Potential participants of surgical simulation training can be further motivated to participate by introducing competitive elements of serious gaming. Verdaasdonk et al. (2009) for example demonstrated that sharing training scores online and rewarding the best trainee increased the surgical trainees’ motivation to participate in VR training.

7.2.2 Proactive management of patient safety in the Operating Room

Medical staff

The IGZ (2007) reported that patient safety risks are not sufficiently recognized by physicians. The results of this dissertation indicate that the medical staff should be aware of the effect of overload and patient safety in the OR. Chapter 3 showed the impact of several realistic sources of overload on the cognitive (surgical performance) and emotional manifestations (stress) of overload in the surgical trainee. Social sources of overload such as case-irrelevant communication are often present in the OR. Also technological sources such as laparoscope images that poorly represent the operative field are not uncommon, especially in the absence of sufficient preclinical training of laparoscope navigation (Sevdalis, Healey, and Vincent, 2006; Moorthy, Munz, Undre, and Darzi, 2004; Mahawar, 2003; Zheng et al., 2003). The medical staff should be aware of these effects and also spread awareness among colleagues.

Experience of overload by the surgical team is also not limited to surgeons. A vast amount of literature is devoted to IT-related overload experienced by anesthesiologists and anesthesiologist assistants (Daniels and Ansermino, 2009). Interestingly the cognitive demand that is put on these members of the surgical team at a certain point in time is fluctuating considerably across different roles. That is, while a surgeon may experience a peak in cognitive load, the anesthesiologist assistant might experience relative load and vice versa (Wadhera, Henrickson Parker, Burkhart, Greason, Neal, Levenick, Wiegmann, and Sundt, 2010). The team member experiencing low load should be aware not to impose additional load on colleagues experiencing high load through for example case-irrelevant communication as presented in Chapter 3.

Hospital management: strategy and IT investments

Perhaps most importantly the hospital management should define a comprehensive safety strategy embedding ECO, among other safety issues. It should embed and enable subordinate means such as training and investment in medical IT. Unfortunately more than half of the hospitals do not have a clear policy with respect to minimally invasive surgery and related risks and investments in training and technology (IGZ, 2007, p. 50). Embedding IT-innovations in the strategic mission of a hospital is desirable to maintain a focus on the patient (i.e., increase patient safety) rather than simply introducing new tools (Spanjers, 2012).

This dissertation demonstrated that information delivered by medical IT can impose high cognitive demands that may result into overload. Overload with information delivered by medical IT should be considered in investment decisions when bringing even more IT into the OR. For example, Chapters 3 and 5 demonstrated that cognitive schemata have to be updated constantly to adapt to new IT. The OR staff may benefit from **standardization** of the medical IT that they use in different OR rooms and procedures. Standardization reduces the frequency of updating cognitive schemata that are inherent to the cognitive resources available for processing information delivered by these ITs. Standardization of IT in different ORs also standardizes the context of information delivered by IT. This could amplify the effect of context-dependent learning and retrieval demonstrated in Chapter 3 and 5. Consistent with this view, an anesthesiologist-assistant mentioned:

> *"In every OR we have the same, very advanced anesthesia IT. This is expensive but ensures standardization [...] in the emergency-OR this IT is probably not necessary but you know exactly how it works once you have to use it as it's all the same"* [Anesthesiologist-assistant during neuro-surgery]

Management should also consider IT-related overload during investment in new IT for the OR. Important preconditions such as facilitation of (time available for) training and fit within the existing technological infrastructure should be considered. The same IT can be a cause or a cure of IT-related depending on how well such preconditions are met.

For example, **technologies supporting the workflow** such as checklist technology and patient data management systems can function as cognitive aids reducing ECO. Intraoperative checklist technology that was used in Chapter 3 and 5 (see also appendix A, Figure A.2) aims to “chunk” the surgical process into meaningful steps. It is a cognitive aid that can facilitate maintaining stable performance levels in situations of high cognitive load and stress (Harrison, Manser, Howard, and Gaba, 2006). Congruently Buzink, Van Lier, de

Hingh, and Jakimowicz (2010) demonstrated that a procedural checklist reduces risk sensitive events and raises general safety awareness among the OR staff.

Another supporting technology that is under constant national and global attention is the integrated Patient Health Record (PHR) system. It is an electronic record of medical data of an individual patient. Recent versions allow automation of several administrative processes that are performed concurrently with the surgical tasks in the OR. Anesthesiologists for example have to record the types and doses of drugs administered to the patient. Perfusionists have to keep constant record of blood gas values and other parameters. Automated record systems could be used to “offload” parts of that administrative process from these individuals to an automated IT:

> *"The biggest change is going to be the patient data management system. It is very much less cumbersome [compared to paper based] and particularly when the surgical process consumes a lot of attention, you don't have to pay attention to the secondary process [updating patient records]"* [Perfusionist]

However careful implementation of such new ITs in the OR is required along with appropriate training to prevent ECO. In fact, inability to adapt to such IT may saddle the user with simply even more IT delivering more information. Also, decreasing overload does not mean that cognitive load should be reduced as much as possible. This may lead to episodes of underload. Underload manifests in boredom and loss of concentration (Parasuraman and Purohit, 2000, p. 77). It may decrease sustained attention or vigilance of the surgeon. Vigilance is “the ability to maintain attention and alertness over the course of a laparoscopic operation" (Zheng, Tien, Atkins, Swindells, Tanin, Meneghetti, Qayumi, and Panton, 2011, p. 673). Strong dependence on IT through for example automation may lead to episodes of vigilance decrement and therefore decreased situation awareness, surgical performance and patient safety (Woods, Cook, and Billings, 1995). Automation of for example patient record keeping and parts of operations by using surgical robots is an increasing trend in the OR. These technological developments may impact the surgeons’ situation awareness and therefore require attention (Stefanidis, Wang, Korndorffer Jr., Dunne, and Scott, 2010).

IT design: aligning medical IT design to Short-Term- and Long-Term Memory

This dissertation demonstrates that information delivered by medical IT can induce a state of ECO. Designers should incorporate overload into their design strategy to reduce ECO delivered by medical IT. They should design medical IT against overload by aligning the design with the cognitive architecture of the user. According to Cognitive Load Theory (CLT: Sweller, 1998; see Chapter 2) attention should be paid to the Short-Term Memory (STM) that has a limited capacity to process information of various modalities (e.g., visual, auditory).

Remember that processing information presented in different modalities draws from cognitive resources that are only partially overlapping. This dissertation also demonstrated that the personal mental organization of Long-Term Memory (LTM) is equally important to understand and counter overload. This is in line with the Emotional-Cognitive Overload Model (ECOM: Rutkowski and Saunders, 2011). Designers should explore and exploit the role of chunking, cognitive schemata and pertinence in their design.

Cognitive Load Theory design principles

Designing against overload by aligning the design with the architecture of human memory fits within the stream of cognitive and instructional design. Sweller and colleagues developed multiple design guidelines based on Cognitive Load Theory (CLT). These guidelines primarily aimed at decreasing extraneous cognitive load during learning. That is, cognitive load imposed by design that does not contribute to the construction of cognitive schemata during learning (Sweller, 1988). An overview of the guidelines, proposed as effects, is provided in Sweller (2003). Below, applications of two of those effects are discussed as ways to improve design of medical IT. These are the split attention effect and the redundancy effect

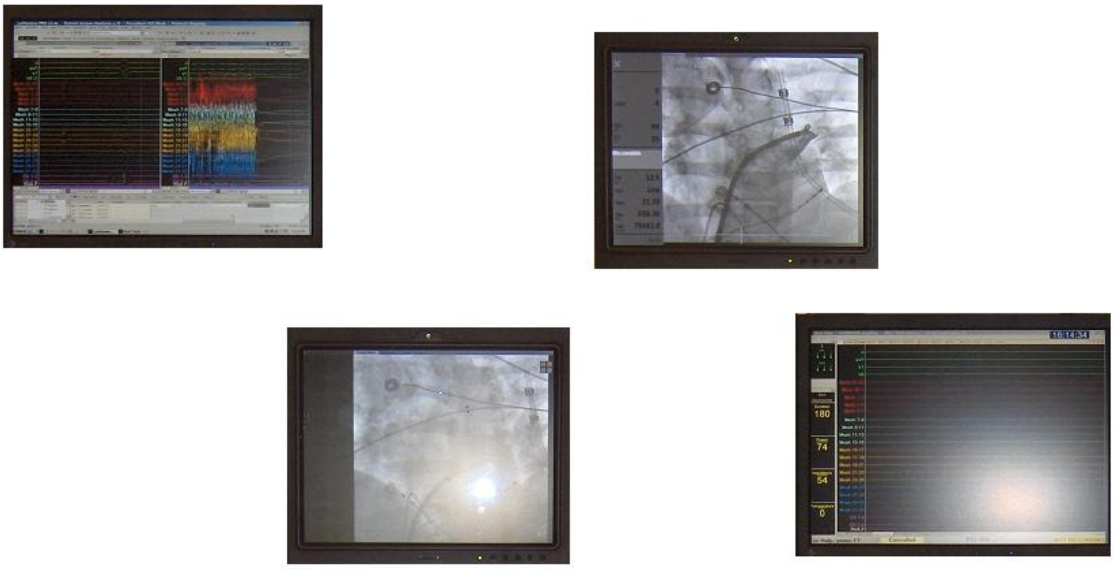


Figure 7.2a. Monitors for cardiac intervention spatially separated
(from left to right: electrocardiograph (ECG) live view, X-ray freezed view, X-ray live view; ECG freezed view)

The **split-attention effect** occurs when individuals have to process and mentally integrate visual information that is related but spatially separated. A cardiologist for example uses multiple screens presenting complementary information to perform minimally invasive cardiac interventions (see section 3.1). If these screens are spatially separated a higher load is put on the visuospatial sketchpad to hold and process the information (see Figure 7.2a). Figure 7.2b presents a design that reduces the spatial separation and groups the screens two-by-two based on the information that has to be processed concurrently.

Figure 7.2b. Monitors for cardiac intervention spatially integrated
(upper row from left to right: electrocardiograph (ECG) live view and freezed view; lower row from left to right: X-ray live view and freezed view)

The latter design reduces the time that is required to hold and process information that was previously spatially separated.

The **redundancy effect** prescribes that when the same information is presented more than once, cognitive load is higher and performance is lower than when the information is presented only once. This holds at least for experienced individuals (Kalyuga, Chandler, and Sweller, 1999). According to CLT the duplicate information has to be processed in the same limited capacity system, thereby drawing from the same attentional resources. The OR is filled with duplicate information such as primary and supplementary laparoscope monitors required for surgeons, nursing staff, and anesthesiologist assistants or on the job training of surgical residents. Other examples include multiple vital sign monitors presenting on top both visual and acoustic redundant information. Duplicate monitors are indeed sometimes required but should at least be carefully directed towards the information receiver to control the flow of information. Also caution should be taken when using duplicate acoustic information as it is often exposed to the entire surgical team including a number of unaddressed recipients.

Design based on Long-Term Memory

Based on ECOM (Rutkowski and Saunders, 2011), it can be argued that design should focus not only on temporary storage of information. This dissertation repeatedly demonstrated the role of LTM in explaining IT-related overload. For example, consider the following quote from an anesthesiologist who was interviewed about overload with information delivered by medical IT (see also Rutkowski and Saunders, 2010). The anesthesiologist monitors the patient vital sign information delivered by IT in two modalities: visual and auditory. The auditory information is a pulse signal representing heart rate (pulse speed) and saturation level (pulse pitch). He noted:

> *"When they just released a new version of the anesthetics machine I was frightened at the beginning because they changed the pitch of the pulse. To me it sounded like the patient was not doing well but instead he was stable"* [Anesthesiologist during cardiac surgery]

The meaning of the new pitch was not aligned to the meaning encoded in the cognitive schemata of the anesthesiologist. He had to update his cognitive schemata to adapt to the updated version of the anesthetics machine. This puts a higher load on the anesthesiologist. Maintaining the same pulse pitch would have made it unnecessary for the anesthesiologist to update his cognitive schemata, thereby decreasing ECO.

7.3 Theoretical contribution

This dissertation combines both rigor and relevance by studying overload delivered by medical IT. This has been a delicate issue in the field of Management and Information Systems (Applegate, 1999, Benbasat and Zmud, 1999). The theoretical contribution of this dissertation is mainly to overload research in the field of IS, surgery, and surgical training using an interdisciplinary approach.

Contributions to the IS literature

This dissertation mainly contributes to the overload literature in the field of IS. Although overload has received considerable attention in the field of IS, theory-driven understanding has previously mostly been lacking. Overload has usually been studied with too little theoretical foundation based on human information processing. IS focuses mainly on technological countermeasures (for a review see Eppler and Mengis, 2004; Rutkowski and Saunders, 2011).

ECOM was recently introduced by Rutkowski and Saunders (2011) as the very first overload theory in the field of IS. The conceptualization of overload in this study is based on ECOM (Rutkowski and Saunders, 2011). The results have important theoretical implications.

This dissertation demonstrates why and when a high amount of information can be less overloading than a low amount of information. This is inconsistent with the typical conceptualization of overload in the field of IS being an excessive amount of information (see e.g., Chervany and Dickson, 1974; Cook, 1993; Denning, 1982; Farhoomand and Drury, 2003; Nelson, 1994; and for an exhaustive list Eppler and Mengis, 2004).

Based on ECOM, this dissertation underlines (1) that individuals are unequally overloaded when facing the same amount of information delivered by IT. (2) This appears to be due to personal mental organization of LTM and most importantly to the role of personal mental dispositions and congruence of cognitive schemata. The concluding study of this dissertation demonstrated the external validity of overload with information delivered by IT. The study is based on theory driven SEM analysis of a large sample of n=1868 respondents. Thereby it contributes to a more theory-driven understanding of IT-related overload beyond the walls of the hospital.

Additionally, thermal imaging technology extends the set of psychophysiological measures of IT constructs proposed by Dimoka, Banker, Benbasat, Davis, Dennis, Gefen, Gupta, Ischebeck, Kenning, Pavlou, Müller-Putz, Riedl, vom Brocke, and Weber (2011). Thereby it is a methodological contribution to the field of Neuro-IS. It is a response to a call for improving instrument quality and IS theory rigor (Straub, Boudreau and Gefen, 2004). Psychophysiological measures such as thermal imaging should be complementary to excising measures including self-reported measures and brain imaging tools. Multiple sources of measurement allow triangulation and might shed light on different dimensions of the construct of interest. They also counterbalance part of each other’s methodological weaknesses and reduce the impact of common method variance. Further research on the specificity and sensitivity of thermal imaging is recommended using Multi-Trait-Multi-Method analysis.

Finally, this dissertation coincides with several other research streams in the IS literature. Particularly it shares the notion that individuals are unequal when dealing with information delivered by IT with Contingency Theory and Task Technology Fit Theory (Goodhue and Thompson, 1995). Presumably a misfit between user and technology may lead to a state of ECO, which is a potential direction for further research. Also it shares the recognition of emotional reactions towards new IT with the work on technostress (Tarafdar, Tu, Ragu-Nathan, and Gagu-Nathan, 2007). Studying the impact of IT-related overload on surgical performance and stress also fit within work on post-adoption (Ahuja and Thatcher, 2005).

Contributions to the surgical literature

This dissertation contributes to at least three lines of research in the field of surgery. The first stream of research includes studies identifying overload as an important cognitive issue in surgery (Berguer, Smith, and Chung, 2001; Carswell, Clarke, and Seales, 2005; Tollner, Riley, Matthews, and Shockley, 2005; Zheng, Cassera, Martinec, Spaun, and Swanstrom, 2010). In general the surgical literature takes a very practical position and focuses mainly on the impact of new medical technologies on mental workload and performance of the surgeon. This dissertation introduces a more theory-driven understanding of overload in the OR.

The second stream of research covers “VR to OR” studies discussing the transfer of surgical skills from Virtual Reality simulation training to clinical performance in the OR (Moulton, Dubrowski, MacRae, Graham, Grober, and Reznick, 2006; Seymour, 2008 Stefanidis, Korndorffer Jr, Markley, Sierra, Heniford, and Scott, 2007). Particularly the results of this dissertation suggest that transfer from VR to OR could be smoothed using immersive training. Immersive training aims to create congruence between the cognitive schemata of the trainee and the OR context by providing simulation training in a realistic context. This dissertation demonstrates that subjects undergoing immersive training experience lower levels of ECO and stress when being confronted with information delivered by medical IT. Lower levels of ECO are also associated in Chapter 5 with higher levels of performance.

These efforts coincide with a third stream of research covering efforts aimed at embedding simulators in more comprehensively designed training curricula with appropriate technical and cognitive training outcome measures (Jakimowicz and Cuschieri, 2005; Carswell et al., 2005). Immersive training demonstrates potential as a more comprehensive training program. Also the self-reported and physiological thermal imaging measures demonstrate potential for assessment of IT-related overload as a cognitive training outcome.

Few studies have integrated these efforts, with the notable exception of at least the study by Stefanidis et al. (2007). Their study focused on training under realistic conditions as a possible means to smoothen the transfer from training to clinical practice with special attention for workload. However, the benefit of realistic training could not be demonstrated in their study. This is possibly due to the fact that final assessment in their study was not performed in the most realistic setting that the participants were trained in.

7.4 Limitations and future research

Probably the limitation that pops up first in the reader’s mind is the use of subjects with no prior cognitive schemata in Chapters 3.3 to 5. First it must be noted that this limitation is also the major strength of this dissertation. It allowed the unbiased comparison of several simulation training settings in the absence of prior encoded cognitive schemata that could interfere with the experimental manipulations. The participants were equally absorbed with technology and equally interested in learning new technology. In other words, they were equal on important personal mental dispositions and predictors of ECO. The contribution of this dissertation is believed to be relevant because it started from scratch to design a theory-driven training program. As a drawback however, one additional round of validation is required before deploying immersive training into healthcare curricula. A suggestion for this final validation was proposed in the previous section on design of surgical simulation training programs. It was not included in this dissertation as it requires team theory.

This leads to the second limitation. The scope of this dissertation was restricted to the individual level of analysis of IT-related overload. Further research could focus on team level applications using ECOM supplemented with team theory. In general, research on IT-related overload in the OR is pivotal. It has gained attention throughout the past decade as identified in the literature review. Further research is required. Without proper research and management, the OR will be flooded with screens that put an ever-increasing load on the surgeon and other members of the surgical team (Bitterman, 2006). Several future directions of research are identified:

- Configuration of training methods. Research on the configuration as well as the costs and effectiveness of “on the job” training and various forms of simulation training (e.g., conventional training, immersive training) is required. This would allow design of an improved training curriculum combining both technical and non-technical (e.g., cognitive) aspects of surgery.

- Expand to different specialisms. The focus of this dissertation was restricted to laparoscopic surgery. Expansion to other surgical specialisms such as intervention cardiology, interventional radiology and neuro-surgery is recommended. These specialisms are highly dependent on IT (see also Table 3.1).

- Research effort from design science is required to decrease IT-related overload delivered by the interface and information delivered by medical technologies. Such research should not only focus on an IT in isolation, but also on the interaction of various technologies. Also research is required assess whether IT in the OR is optimally used and how this can be improved.

A third limitation and direction for further research addresses the thermal imaging technology. This dissertation was among the first to explore the potential of thermal imaging as a tool measuring physiological responses to mental load during on surgical training devices. Thermal imaging has large potential, as outlined above. However, more research is required to further identify its specificity and sensitivity. Multi-Trait Multi-Method (MTMM) analysis is specifically recommended. MTMM allows determining discriminant and convergent validity of constructs measured using multiple measurement tools (e.g., psychophysiological, brain imaging, self-report) against related constructs. It could also be used to reach consensus on the region of interest (e.g., frontal head, periorbital area) and unit of analysis (e.g., maximum value, average value, standard deviation). MTMM could potentially be used to identify response biases in further research. However this requires multiple measurement tools to measure the same dimension of each construct.

Finally, the focus of this dissertation was on the healthcare domain. It notably demonstrated external validity beyond surgical training. In particular, Chapter 6 showed the concerns about IT-related overload with video conferencing technology of potential patients with their physicians. Theory-driven research on IT-related overload in other domains is encouraged. Overload has been identified as an important issue across a wide variety of business domains within and outside the field of Information Systems (IS). The results of this dissertation, applications of ECOM, and possibly even the theoretical foundations of immersive training can possibly be used to study and resolve IT-related overload in managerial decision making (Farhoomand and Drury, 2002; Sparrow, 1999), accounting and financial decision making (Rose, Roberts, and Rose, 2004) such as bankruptcy prediction (Hwang and Lin, 1999), marketing and consumer behavior (Malhotra, 1984; Jacoby, 1984), e-learning (Mayer and Moreno, 2003), computer-mediated communication (Hiltz and Turoff, 1985) such as public online spaces (Jones, Ravid, and Rafaeli, 2004) and electronic meetings (Grise and Gallupe, 1999/2000), humanitarian emergency response information systems (Muhren, 2011), police officers using tablets (Allen and Shoard, 2005), car driving (Orr and Duffy, 2007), aviation and air traffic control (O’Reilly, 1980; Seamster, Redding, Cannon, Ryder, and Purcell, 1993), aerospace (Bock, Weigelt, and Bloomberg, 2010) and nuclear power operations (Woods, Patterson, and Roth, 2002).

7.5 Conclusion

Concluding, this dissertation demonstrates the importance of the personal mental organization of Long-Term Memory (LTM) when analyzing IT-related overload of participants of surgical simulation training. This dissertation demonstrates that congruence of the information stimulus with the cognitive schemata encoded in LTM can be improved using immersive training. Immersive simulation training in a realistic technological and social context prepares participants better for the cognitively demanding Operating Room (OR). Compared to conventional simulation training, immersive simulation training is beneficial in terms of Emotional-Cognitive Overload (ECO) and stress of the participant. Also it increases parts of surgical performance indirectly through its effect on ECO. Hence, immersive training has potential to improve patient safety in the OR. Further research is required to further validate the immersive simulation training program on surgical residents.

On a theoretical level, this dissertation demonstrates based on the Emotional-Cognitive Overload Model (ECOM: Rutkowski and Saunders, 2011) that a high amount of information can be less overloading than a low amount of information. This is inconsistent with the typical conceptualization of overload in the field of IS being an excessive amount of information (see e.g., Chervany and Dickson, 1974; Cook, 1993; Denning, 1982; Farhoomand and Drury, 2003; Nelson, 1994; and for an exhaustive list Eppler and Mengis, 2004). The potential of thermal imaging technology demonstrated in this dissertation provides ground for further research on physiological measures of mental load, ECO and related constructs.

Appendix A. Illustration of simulators, tasks and other medical IT used per chapter

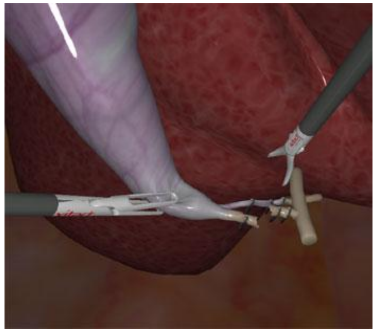
This appendix provides an overview of the simulation technologies used in this dissertation in Table A.1. An overview of the simulation tasks performed on these simulation technologies is provided in Table A.2. An overview of the information delivered by IT in the experimental studies is provided in Table A.3 with illustrations in Figures A.1-A.3.

Table A.1. Overview of simulation platforms used per Chapter (abbreviated as "Ch" in the tables)

	Simulation platform	**Information delivered by Information Technology (IT)**	**Illustration**	**Ch 3.2**	**Ch 3.3**	**Ch 4**	**Ch 5**
p1	*Virtual Reality (VR) simulator* The VR simulator used in this dissertation is the Xitact Laparoscopic Cholecystectomy (LC) 3.0 simulator. It has physical instruments with virtual tools (graspers, clip appliers, cutter, and laparoscope with camera) and virtual tasks (see T1 in Table A.2).	**Yes**: the surgical tasks are performed based on a monitor depicting the image of the camera embedded in the laparoscope.		x			
p2	*Augmented Reality (AR) simulator* The AR simulator used in this study is the Haptica Promis I simulator. It allows performing	**Yes**: the surgical tasks are performed based on a monitor depicting the image of the camera embedded in the laparoscope.			x	x	x

	basic surgical tasks that are required during laparoscopic surgery. It has physical instruments (graspers, clip appliers, cutter, and laparoscope with camera) and physical tasks (see T2abc in Table A.2).						
p3	*Open box trainer* It has physical instruments (graspers, clip appliers, cutter, and laparoscope with camera) and physical tasks (see T2abc in Table A.2).	**No**: the open box trainer provides the surgeon a direct view on the operating area without the mediation of a laparoscope and monitor.			x	x	x

Table A.2. Overview of simulated surgical tasks used per chapter

	Surgical tasks	**Illustration**	**Ch 3.2**	**Ch 3.3**	**Ch 4**	**Ch 5**
T1	*Simulated laparoscopic gallbladder removal* This task is a virtual simulation of a laparoscopic gallbladder removal. The medical term is Laparoscopic Cholecystectomy (Lap Chol).		x			
T2a	*Aiming and translocating task* This task is a simulated basic surgical task. The trainee picks up a ball from a pot and transfers it to a different pot in a pre-defined order. This task aims to train single hand dexterity required during laparoscopic surgery.			x	x	x

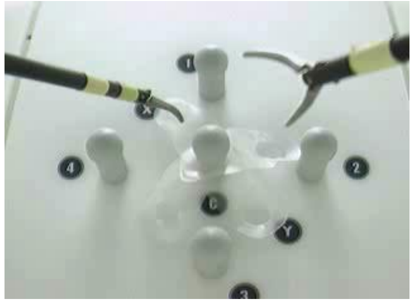
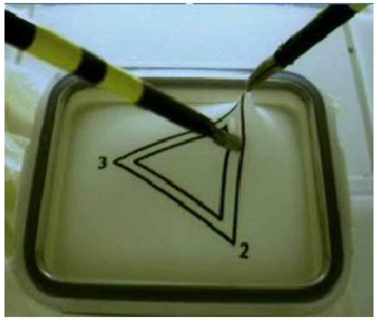
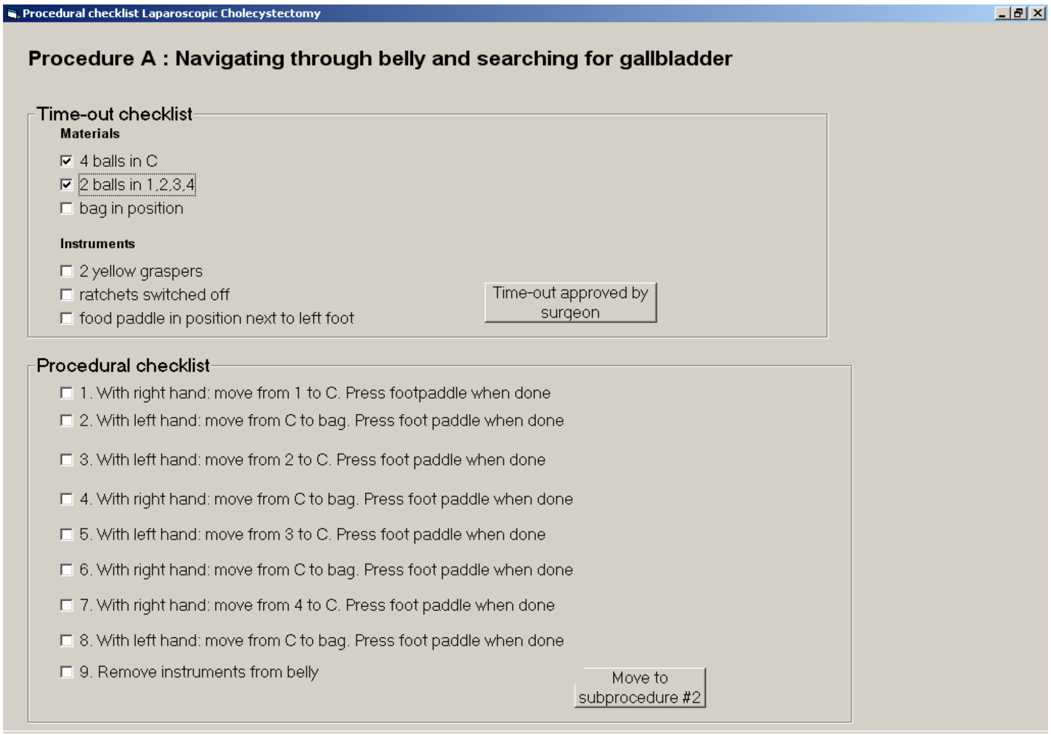
	Surgical tasks	**Illustration**	**Ch 3.2**	**Ch 3.3**	**Ch 4**	**Ch 5**
T2b	*Stretching task* This task is a simulated basic surgical task. The trainee picks up a band, stretches it, and puts it around a pillar in a pre-defined order. This task aims to train bi-manual dexterity required during laparoscopic surgery.			x	x	x
T2c	*Cutting task* This task is a simulated basic surgical task. The trainee picks up the simulated tissue, and cuts it in a pre-defined order and shape. This task aims to train bi-manual dexterity and dissection required during laparoscopic surgery.			x	x	x

Table A.3. Overview of information delivered by IT per chapter

IT delivering information:	**Modality of information**	**Description of information**	**Illustration**	**Ch 3.2**	**Ch 3.3**	**Ch 4**	**Ch 5**
Primary laparoscope monitor	Visual	The primary laparoscope monitor depicts the image of the camera embedded in the laparoscope. This monitor delivers information to the surgeon in training.	Figure A.1	x	x	x	x
Supplementary laparoscope monitor	Visual	Monitor delivering the exact same information as the primary laparoscope monitor. It is a duplicate monitor.	Figure A.1		x	x	x
Procedural checklist [computer based]* * the paper based procedural checklist contains the exact same information in the same font and size	Visual	Checklist for step-by-step performance of the simulated surgical procedure. This involves both steps that have to be taken before (e.g., selection of correct instruments) and during (e.g., cut tissue at point 1) the simulated procedure.	Figure A.2		x	x	x
Vital signs monitor	Visual	Monitor providing information on the health condition of the simulated patient. The vital signs are: heart rate, blood pressure, blood pressure (arterial), consciousness, saturation (concentration of oxygen in the blood) and body temperature. All participants were instructed that heart rate and saturation were sufficient for determination of the patient health in the studies. Therefore it could be	Figure A.3		x	x	x

		assessed equally well with the auditory pulse-oxy signal.						
Personal computer with web access	Visual	Internet computer available to the co-actor performing the role of the anaesthesiologist-assistant in training. The co-actor was left free to (not) use the computer.						x
Auditory pulse-oxy signal	Auditory	Auditory pulse signal varying in speed and pitch. The speed of the pulse represents the heart rate of the simulated patient. The pitch of the signal represents the saturation level of the patient.	-		x	x	x
Pager	Auditory	Personal telecommunication device. The pager “beeps” when it receives a call.	-		x	x	x
Streaming radio	Auditory	Streaming radio signal delivered through a laptop computer.	-	x	x	x	x

Figure A.1. Information delivered by primary and supplementary laparoscope monitor



Procedure A : Navigating through belly and searching for gallbladder

Time-out checklist

Materials

☑ 4 balls in C
☑ 2 balls in 1,2,3,4
☐ bag in position

Instruments

☐ 2 yellow graspers
☐ ratchets switched off
☐ food paddle in position next to left foot

Procedural checklist

☐ 1. With right hand: move from 1 to C. Press footpaddle when done
☐ 2. With left hand: move from C to bag. Press foot paddle when done
☐ 3. With left hand: move from 2 to C. Press foot paddle when done
☐ 4. With right hand: move from C to bag. Press foot paddle when done
☐ 5. With left hand: move from 3 to C. Press foot paddle when done
☐ 6. With right hand: move from C to bag. Press foot paddle when done
☐ 7. With right hand: move from 4 to C. Press foot paddle when done
☐ 8. With left hand: move from C to bag. Press foot paddle when done
☐ 9. Remove instruments from belly

Figure A.2. Computer based procedural checklist

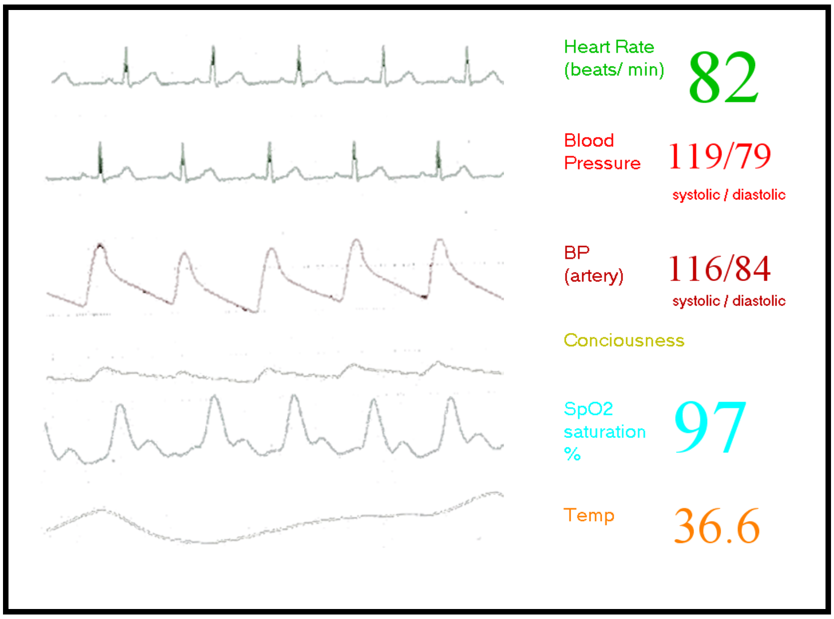


Figure A.3. Vital signs monitor
From top to bottom: heart rate, blood pressure, blood pressure (arterial), consciousness, saturation, body temperature.

Appendix B. Review of the surgical overload literature: coding per article

Table B.1. Coding per article

Article (Author(s), Journal, Year of publication)	**Context**	**Definition of overload (or related terminologies)**	**Causes: Individual, Team, Role, Information, Information Technology (IT), Organization, Task, Time**	**IP model and storage**	**Study design: Experimental (within, between subjects, or mixed), clinical trial, post-hoc analysis, qualitative study, literature review**	**Sample**	**Data collected in Patient (P) or Simulation setting (S: animal, virtual or augmented model)**	**Overload measured? self-reported, physiological, primary/ secondary/ dual task performance**	**Symptoms and other dependent measures**
1 Rogers, Heath, Uy, Suresh, and Kaber (Applied Ergonomics, 2012)	Laparoscopic surgery	**Cognitive workload:** not defined	**IT:** Visual display location	None	Experimental within subject Latin Square Design	24 novices with no experience in performing any type of surgery	S	**Self-reported**: NASA-TLX	Performance, monitor preference, monitor usage
2 Klein, Warm, Riley, Matthews, Doarn, Donovan, and Gaitonde (J of Endourology, in press)	Laparoscopic surgery	**Mental workload, workload**: not defined	**IT:** Laparoscopic vs. Robotic Da Vinci	Effort with distress and strain coping in compensatory control (Frankenhaeuser, 1986; Hockey, 1997)	Experimental within subject design	15 novice first year medical students	S	**Self-reported**: Multiple Resource Questionnaire (MRQ: Boles, Bursk, Phillips, and Perdelwitz, 2007)	Stress, performance
3 Andersen, Klein, Gögenur, and Rosenberg (Surg Laparosc Endosc Percutan Tech, 2012)	Laparoscopic surgery	**Mental strain**: not defined	**Individual:** Experience, pre-operative sleep quality	None	Post-hoc analysis	8 experienced surgeons (senior staff) vs. 8 inexperienced surgical residents	P	**Self-reported:** 5 single item measures (time-pressure, effort, performance, frustration, satisfaction)	Physical strain, post-operative sleep quality
4 Tomasko, Pauli, Kunselman, and Haluck (American Journal of Surgery, 2012)	Endoscopy	**Cognitive workload, mental workload**: "workload has been described as a hypothetical construct that represents the cost incurred by the human operator to achieve a particular level of performance" (p. 38)	**Individual:** sleep in between learning and testing (sleep vs. sleep-deprived)	None	Experimental between subject design	15 vs. 16 medical students included after achieving expert performance in pre-test	S	**Self-reported:** NASA-TLX, **Dual task performance**	Sleepiness, performance (of familiar task and new task)
5 Zheng, Rieder, Cassera, Martinec, Lee, Panton, Park, and Swanström (Surg Endosc, forthcoming) * * Counts is 2011 article because published online ahead of print	Endoscopy: Natural Orifice Transluminal EndoScopic (NOTES) procedures	**Mental workload:** obliquely referred to as inverse of spared mental resources (p. 2)	**IT:** Laparoscopic vs. NOTES platform	None	Study 1+2: experimental within subject design	Study 1: 9 surgeons with varied backgrounds in surgical training Study 2: 5 experienced surgeons and. 5 novice surgeons in training	S	**Secondary task performance:** study 1+2 **Self-reported:** NASA-TLX (study 1)	Primary surgical task performance in study 1
6 Deka, Kahol, Smith, and Ferrara (American Journal of Surgery, 2011)	Laparoscopic surgery	**Cognitive load**: obliquely referred to as multi-tasking	**Task:** Psychomotor (load at constant level) vs. psychomotor + cognitive skills training(load varied)	Theory of embodied cognition (Cowart, 2004)	Experimental between subject design	7 vs. 7 surgical residents	S	Not measured	Learning curve and performance

Article (Author(s), Journal, Year of publication)	**Context**	**Definition of overload (or related terminologies)**	**Causes: Individual, Team, Role, Information, Information Technology (IT), Organization, Task, Time**	**IP model and storage**	**Study design: Experimental (within, between subjects, or mixed), clinical trial, post-hoc analysis, qualitative study, literature review**	**Sample**	**Data collected in Patient (P) or Simulation setting (S: animal, virtual or augmented model)**	**Overload measured? self-reported, physiological, primary/ secondary/ dual task performance**	**Symptoms and other dependent measures**
7 Youssef, Lee, Godinez, Sutton, Klein, George, Seagull, and Park (Surg Endosc, 2011)	Laparoscopic surgery	**Mental workload:** not defined	**IT:** positioning towards IT: side-standing vs. between-standing; **Role, IT, task:** one-handed (surgeon does his own camera navigation) vs. two-handed (assistant does camera navigation)	None	Experimental within subject design	8 subjects including residents, fellows, and attending surgeons	S	**Self-reported:** NASA-TLX	Physical ergonomics, performance
8 McCaskie, Kenny, and Deshmukh (Med J Aust, 2011)	Surgery	**Cognitive and emotional load:** not defined	Not applicable	None	Literature based plea to leverage knowledge from motor development theory, musical acquisition, neuroscience and performance psychology for surgical training and performance under high cognitive load and pressure	Not applicable	Not applicable	Not applicable	Performance, arousal, and anxiety
9 Zheng, Tien, Atkins, Swindells, Tanin, Meneghetti, Qayumi, and Panton (American J of Surgery, 2011)	Laparoscopic surgery	**Mental workload**: not defined **Vigilance**: "the ability to maintain attention and alertness over the course of a laparoscopic operation" (p. 673)	**Individual:** Novice vs. expert **Information:** Stable vs. unstable patient information on simulated anesthetic monitor	None	Experimental mixed subject design: novice vs. expert (between subject) and stable vs. unstable (within subject)	13 experienced vs. 10 novice surgeons	S	**Self-reported:** NASA-TLX **Physiological**: vigilance using eye tracking	Performance
10 Rieder, Martinec, Cassera, Goers, Dunst, and Swanstrom (J Am Coll Surg, 2011)	Laparoscopic surgery (single-site)	**Workload, mental workload, mental demand:** not defined	**IT:** Standard laparoscopic surgery vs. Single port crossed articulated instruments vs. Single port true-left and true-right manipulation	None	Experimental within subject design	14 subjects with varied backgrounds (attending, fellow surgeons, surgical resident, pre-med students)	S	**Self-reported:** NASA-TLX	Performance

Article (Author(s), Journal, Year of publication)	**Context**	**Definition of overload (or related terminologies)**	**Causes: Individual, Team, Role, Information, Information Technology (IT), Organization, Task, Time**	**IP model and storage**	**Study design: Experimental (within, between subjects, or mixed), clinical trial, post-hoc analysis, qualitative study, literature review**	**Sample**	**Data collected in Patient (P) or Simulation setting (S: animal, virtual or augmented model)**	**Overload measured? Self-reported, physiological, primary/ secondary/ dual task performance**	**Symptoms and other dependent measures**
11 Yurko, Scerbo, Prabhu, Acker, and Stefanidis (2010)	Laparoscopic surgery	**Workload:** not defined **Mental workload:** "can be thought of as reflecting the amount of attention an operator can direct to a task at any given moment" (p. 267) or "the difference between task demands and available attentional resources" (p. 267)	**Team + IT + Task:** "unrealistic" FLS simulation model solo setting without anesthesia monitor vs. "realistic" porcine OR setting with multiple team members and anesthesia monitor	None	Experimental within subject design (aggregated data from two previous experiments by authors)	28 novice medical- and pre-medical students	S	**Self-reported:** NASA-TLX	Performance
12 Wadhera, Henrickson Parker, Burkhart, Greason, Neal, Levenick, Wiegmann, and Sundt (J Thoracic and Cardiovascular Surgery, 2010)	Cardiovascular surgery	**Mental workload, cognitive workload, workload**: not defined	**Information + team: s**tructured communication protocol absent vs. present	None	Clinical trial	18 vs. 16 cases	P	**Self-reported:** NASA-TLX	Communication breakdowns during high cognitive workload events
13 Reiley, Plaku, and Hager (Proceedings of the IEEE Eng Med Biol Soc, 2010)	Robotic surgery	**Cognitive workload:** not defined	Not applicable	None	Design: modeling and machine learning	5 cases for learning, 5 cases for testing	S	Not measured	Not applicable
14 Cheung, Wedlake, Moore, Pautler, and Peters (MICCAI, 2010)	Laparoscopic surgery	**Cognitive workload:** not defined	**IT + information:** Independent presentation of video and ultrasound information vs. integrated presentation of information in 2D vs. integrated in 3D	None	n=1 Experimental within subject design with 6 repetition of all 3 conditions in randomized order	1 surgeon	S	Not measured	Performance
15 Zheng, Cassera, Martinec, Spaun, and Swanström (Surg Endosc, 2010)	Laparoscopic surgery	**Mental workload:** "is a finite resource and is increased while learning new tasks and performing complex tasks" (p. 45)	**Individual: n**ovice vs. experts	Human Information Processing Model (HIP: Norman and Bobrow, 1975), Multiple Resource Theory (MRT: Wickens, 1984) and Automaticity theory in motor learning (Marteniuk, 1976)	Experimental between subject design	12 junior residents (novices) vs. 9 senior residents, fellows and attending surgeons (experts)	S	**Secondary task performance**	Primary task performance

Article (Author(s), Journal, Year of publication)	**Context**	**Definition of overload (or related terminologies)**	**Causes: Individual, Team, Role, Information, Information Technology (IT), Organization, Task, Time**	**IP model and storage**	**Study design: Experimental (within, between subjects, or mixed), clinical trial, post-hoc analysis, qualitative study, literature review**	**Sample**	**Data collected in Patient (P) or Simulation setting (S: animal, virtual or augmented model)**	**Overload measured? Self-reported, physiological, primary/ secondary/ dual task performance**	**Symptoms and other dependent measures**
16 Song, Tokuda, Nakayama, Sato, and Hattori (Interactive CardioVascular and Thoracic Surgery, 2009)	Cardiac surgery	**Mental strain, anxiety:** not defined	**Role: r**ole of attending-consultant surgeon: primary surgeon vs. surgeon supervising a resident	None	Clinical trial or post-hoc analysis (unclear if roles were manipulated for the purpose of the study)	1 attending surgeon performing in two conditions: 30 cases role of primary surgeon vs. 20 cases role of assisting a residents (role of resident performed by 2 individuals throughout study)	P	**Physiological:** heart-rate variability using intraoperative holter based electrocardiogram	Performance
17 Schuetz, Gockel, Beardi, Hakman, Dunschede, Moenk, Heinrichs, and Junginger (Surg Endosc, 2008)	Laparoscopic surgery	**Mental strain, stress, mental load:** not defined	Four different stressors: **Information and time (2x):** anesthesiologist information provided inducing time pressure to terminate the procedure **Team:** presence of superior **Task:** mathematical secondary task	Drawing from literature on autonomic nervous system	Experimental within subject design	18 surgeons with varied experience ranging from ten to over one hundred performed laparoscopic operations	S	Not measured	Stress reaction, performance
18 Hsu, Man, Gizicki, Feldman, and Fried (Surg Endosc, 2008)	Laparoscopic surgery	**Cognitive distraction, dual-tasking,:** not defined	**Individual:** Experienced vs. novice; **Task and information:** single task vs. dual task (additional distracting mathematical task) performance	Automaticity theory (Schneider, and Shiffrin, 1977) Top down and bottom up theories of attention (Pashler, Johnston, Ruthruff, 2001) Psychological refractory period (PRP; Van Selst, Ruthruff, and Johnston, 1999) Bottleneck Theory (Welford, 1967)	Experimental mixed subject design (experience: between subjects; single vs. dual task within subjects)	31 novice medical postgraduate year 1-2 students vs. 9 experienced fellows/attendants/ post-graduate year 4-5	S	**Dual task performance**	None

Article (Author(s), Journal, Year of publication)	Context	Definition of overload (or related terminologies)	Causes: Individual, Team, Role, Information, Information Technology (IT), Organization, Task, Time	IP model and storage	Study design: Experimental (within, between subjects, or mixed), clinical trial, post-hoc analysis, qualitative study, literature review	Sample	Data collected in Patient (P) or Simulation setting (S: animal, virtual or augmented model)	Overload measured? Self-reported, physiological, primary/ secondary/ dual task performance	Symptoms and other dependent measures
19 Lerotic and Yang (Computer Aided Surgery, 2007) 20 Lerotic and Yang (MICCAI, 2006) duplicate of 19	Endoscopic surgery	**Cognitive load, visual load:** not defined	**Information and IT:** low vs. high resolution	None	Design: Creation of high resolution image from multiple low resolution images	Low resolution images recorded from 1 video sequence in phantom study, and 2 secondary data video sequences in in-vivo OR setting	S + P	Not measured	Not measured
21 Cao, Zhou, Jones, and Schwaitzberg (J Gastrointest Surg, 2007)	Minimally Invasive Surgery	**Cognitive load**: obliquely referred to as allocation of attentional or cognitive resources	**Individual:** experienced vs. novice (5 groups) **Task:** cognitive load imposed by arithmetic task absent (low load) vs. present; (high load) **Information:** haptic information absent vs. present	None	Experimental mixed subject design	30 (equally divided over 5 groups) surgical residents and attending surgeons	S	**Dual task performance**	None
22 Hedman, Klingberg, Enochsson, Kjellin, and Felländer (Surg Endosc, 2007)	Laparoscopic surgery	**Mental strain, burden on working memory**: not defined but explicitly referred to limited capacity WM	**Individual:** Visual and verbal working memory span, visual-spatial ability	Working Memory (Baddeley, 2002; Smith and Jonides, 1996), chunking (no reference), theory of deliberate practice (Ericsson, Krampe, and Tesch-Römer , 1993)	Experimental within subject design	28 medical students with no experience with simulation	S	**Self-reported:** mental strain by Borg (1998)	Performance, subjective experience of flow
23 Mankuyan, Waseda, Inaki, Torres Bermudez, Gacek, Rudinski, and Buess (Surg Endosc, 2007)	Laparoscopic surgery	**Mental stress, mental fatigue:** not defined	**IT:** straight vs. curved graspers; central vs. excentral trocar position	None	n=1 Experimental within subject design (study 1) and n=1 clinical trial	1 experienced surgeon performing 30 simulated resections (study 1) and 5 clinical resections with curved excentral vs. 1 straight excentral position (study 2)	S (study 1) and P (study 2)	**Self-reported:** mental fatigue as part of the SAGES questionnaire on ergonomic problems associated with laparoscopic surgery (no reference provided)	Physical ergonomics
24 Goodell, Cao, and Schwaitzberg (J Laparoendoscopic and Advanced Surgical Techniques, 2006)	Laparoscopic surgery	**Cognitive distraction:** not defined	**Task and information:** secondary arithmetic task absent vs. present	Multiple Resource Model in Information Processing (Baddeley, 1996)	Experimental within subject design	13 surgical residents and medical students	S	**Primary task performance**	None

Article (Author(s), Journal, Year of publication)	**Context**	**Definition of overload (or related terminologies)**	**Causes: Individual, Team, Role, Information, Information Technology (IT), Organization, Task, Time**	**IP model and storage**	**Study design: Experimental (within, between subjects, or mixed), clinical trial, post-hoc analysis, qualitative study, literature review**	**Sample**	**Data collected in Patient (P) or Simulation setting (S: animal, virtual or augmented model)**	**Overload measured? self-report, physiological, primary/ secondary/ dual task performance**	**Symptoms and other dependent measures**
25 Strauss, Koulechov, Röttger, Bahner, Trantakis, Hofer, Korb, Burgert, Meixensberger, Manzey, Diets, and Lüth (The Laryngoscope, 2006)	Ear, Nose, Throat (ENT) surgery	**Cognitive load, workload:** not defined	**IT:** navigation system vs. current standard system	None	Clinical trial	4 novice surgeons (performing a total of 48 procedures) vs. 3 experienced surgeons (performing a total of 54 procedures)	S	**Self-reported:** workload scale based on the efficiency categories of a medical engineering system (p. 565)	Surgical system properties and ergonomic system properties
26 Lee, Rafiq, Merrell, Acherman, and Dennerlein (Surg Endosc, 2005)	Endoscopy	**Mental stress:** not defined	**IT:** manual vs. telerobotic endoscopic surgery	None	Experimental within subject design	13 participants (medical students, junior medical residents and surgical residents) with no experience as primary surgeon in endoscopic surgery	S	**Self-reported:** using single-item measure	Job strain and physical strain, intuitiveness of technology, performance
27 Carswell, Clarke, and Seales (Surgical Innovation, 2005)	Laparoscopic surgery	**Mental workload, cognitive workload:** "the mental workload for a given task is the ratio of mental resources required to the total resources available, on a moment-to-moment basis. Put another way, mental workload is inversely related to spare capacity when performing the task of interest" (p.80)	**IT:** introduction of new technologies in the OR and for training	Multiple Resource Theory (MRT: Wickens, 1986)	Literature based plea on various measurement instruments of mental workload during surgery and surgical training	Not applicable	Not applicable	Overload measurement instruments proposed: **Self-reported:** NASA-TLX, Subjective Workload Analysis Technique (SWAT: Reid and Nygren, 1988) Workload Profile (WP: Tsang and Velazquez, 1996), subjective estimation of time (Zakay and Shub, 1998) **Dual task performance** **Physiological measures:** heart rate variability, pupilometry, eye blink rate, brain imaging using Electroencephalograms (EEGs) and evoked potentials (EPs)	Not applicable
28 Lingard, Espin, Whyte, Regehr, Baker, Reznick, Bohnen, Orser, Doran, and Grober (Qual Saf Health Care, 2004)	Surgery	**Cognitive load:** not defined	**Team:** communication failures	Systems and error theory (Reason, 1990)	Ethnographic/ observational research: systematic identification of communication failures that theoretically may contribute to overload	48 surgical procedures involving 94 team members from anesthesia, surgery, and nursing	P	Not measured	Communication failures

Article (Author(s), Journal, Year of publication)	**Context**	**Definition of overload (or related terminologies)**	**Causes: Individual, Team, Role, Information, Information Technology (IT), Organization, Task, Time**	**IP model and storage**	**Study design: Experimental (within, between subjects, or mixed), clinical trial, post-hoc analysis, qualitative study, literature review**	**Sample**	**Data collected in Patient (P) or Simulation setting (S: animal, virtual or augmented model)**	**Overload measured? Self-reported, physiological, primary/ secondary/ dual task performance**	**Symptoms and other dependent measures**
29 Demirtas, Tulmac, Yavuzer, Yalcin, Ayhan, Latifoglu, and Atabay (Plast Reconstr Surg, 2004)	Rhino surgery	**Mental strain, mental burden, mental load:** not defined	**Task:** office work vs. surgery **Role:** primary surgeon vs. first assistant	Early evidence linking cardiac arrhythmia to mental work(load) (Kalsbeek and Ettema, 1963)	Post-hoc analysis of holter data	5 primary surgeons performing a total of 38 operations vs. 7 junior residents performing role of assistant in a total of 52 operations	P	Not measured	Stress
30 Zheng, Janmohamed, and MacKenzie (Surg Endosc, 2003)	Endoscopic surgery	**Mental load:** not defined	**Task:** Study 1: simple (reach and touch object) vs. Study 2: difficult (reach, grasp, transport object) task **IT:** display location: projected on vertical monitor (requires high sensori-motor integration) vs. superimposed over training box (requires low sensor-motor integration) **Information:** number of target locations + aligned vs. misaligned (requires mental rotation)	Hick-Hyman law (Hick, 1952)	Experimental within subject design (both studies)	Study 1: 8 students Study 2: 8 students	S	Not measured	Performance
31 Reddy, Pratt, McDonald, and Shabot (AMIA, 2003)	Surgery (ic)	**Information overload:** too many notifications	**IT:** alphanumeric pager bringing clinical information notifications **Information:** number of notifications sent to user + lack of context	None	Qualitative: semi-structured interviews and observations during three months	10 physicians (surgical residents, fellows, attending) and n=? IT staff	Not applicable	**Self-reported:** in semi-structured interview	Perception of alert pager

Article (Author(s), Journal, Year of publication)	**Context**	**Definition of overload (or related terminologies)**	**Causes: Individual, Team, Role, Information, Information Technology (IT), Organization, Task, Time**	**IP model and storage**	**Study design: Experimental (within, between subjects, or mixed), clinical trial, post-hoc analysis, qualitative study, literature review**	**Sample**	**Data collected in Patient (P) or Simulation setting (S: animal, virtual or augmented model)**	**Overload measured? Self-reported, physiological, primary/ secondary/ dual task performance**	**Symptoms and other dependent measures**
32 Berguer, Smith, and Chung (2001) 33 Smith, Chung, and Berguer (Medicine Meets Virtual Reality, 2000) is duplicate of 32 without analysis of experience	Laparoscopic surgery	**Mental workload, mental effort:** not defined	**IT:** laparoscopic surgery vs. open surgery **Individual:** experience high (more than five years) vs. medium (less than five years)	Drawing from literature on autonomic nervous system	Experimental within subject design	28 surgeons	S	Mental workload operationalized using: **Self-reported: m**ental stress, concentration **Physiological:** skin conductance (mental stress) and eye blink (concentration), and in study of Smith, Chung and Berguer, 2000: electroencephalogram (results not interpreted in original study due to spillover effects of other physiological measures)	Performance
34 Böhm, Rötting, Schwenk, Grebe and Mansmann (Arch Surg, 2001)	Laparoscopic surgery	**Mental strain:** "while stress comprises all factors influencing an individual, strain is defined as the physical and psychological effects of stress on an individual. Because individuals may cope differently with identical situations…we have decided to assess strain as an indicator of the individual response to stress" (p. 306)	**IT:** laparoscopic vs. open surgery **Individual:** experienced vs. less experienced **Role:** primary surgeon vs. assistant of primary surgeon	Drawing from literature on autonomic nervous system	Post-hoc analysis	2 surgeons (one experienced and one less experienced). Each performing 5 open and 5 laparoscopic procedures as a primary surgeon, while other participant performs role of assistant	P	**Physiological:** heart-rate-variability	None
35 Rovetta, Bejczy, and Sala (Medicine Meets Virtual Reality, 1997)	Robotic surgery	**Mental workload, visual workload:** not defined	**IT:** surgical robot	None	n=1 test performed once in simulated and once in human patient setting	2 x 1 surgeon with no experience with robotic surgery	S and P	Unknown if and how mental/visual workload was measured	Ease of use of robotic technology, attitude towards robotic surgery, performance
36 Berguer, Loeb, and Smith (Medicine Meets Virtual Reality, 1997)	Laparoscopic surgery	**Mental workload**: not defined	**IT + information:** data display numeric vs. analog vs. integrated; angle of laparoscopic graspers **Individual:** experts vs. novices post hoc analysis	None	Experimental within subject design	Study 1: 6 medical design students Study 2: 7 medical design students	S	**Physiological**: electromyogram and heart rate variability proposed as measures but results not reported	Performance

Article (Author(s), Journal, Year of publication)	Context	Definition of overload (or related terminologies)	Causes: Individual, Team, Role, Information, Information Technology (IT), Organization, Task, Time	IP model and storage	Study design: Experimental (within, between subjects, or mixed), clinical trial, post-hoc analysis, qualitative study, literature review	Sample	Data collected in Patient (P) or Simulation setting (S: animal, virtual or augmented model)	Overload measured? Self-reported, physiological, primary/ secondary/ dual task performance	Symptoms and other dependent measures
37 Czyzewska, Kiczka, Czarnecki, and Pokinko (Eur J Appl Physiol, 1983)	Open surgery	**Mental load:** not defined	**Task**: mental load during four different stages of operation	Early evidence linking cardiac arrhythmia to mental work(load) (Kalsbeek and Ettema, 1963)	Post-hoc analysis	7 surgeons performing 12 surgeries	P	**Physiological**: various heart-rate related measures	Emotion

Appendix C. The Modal Model and the Working Memory Model

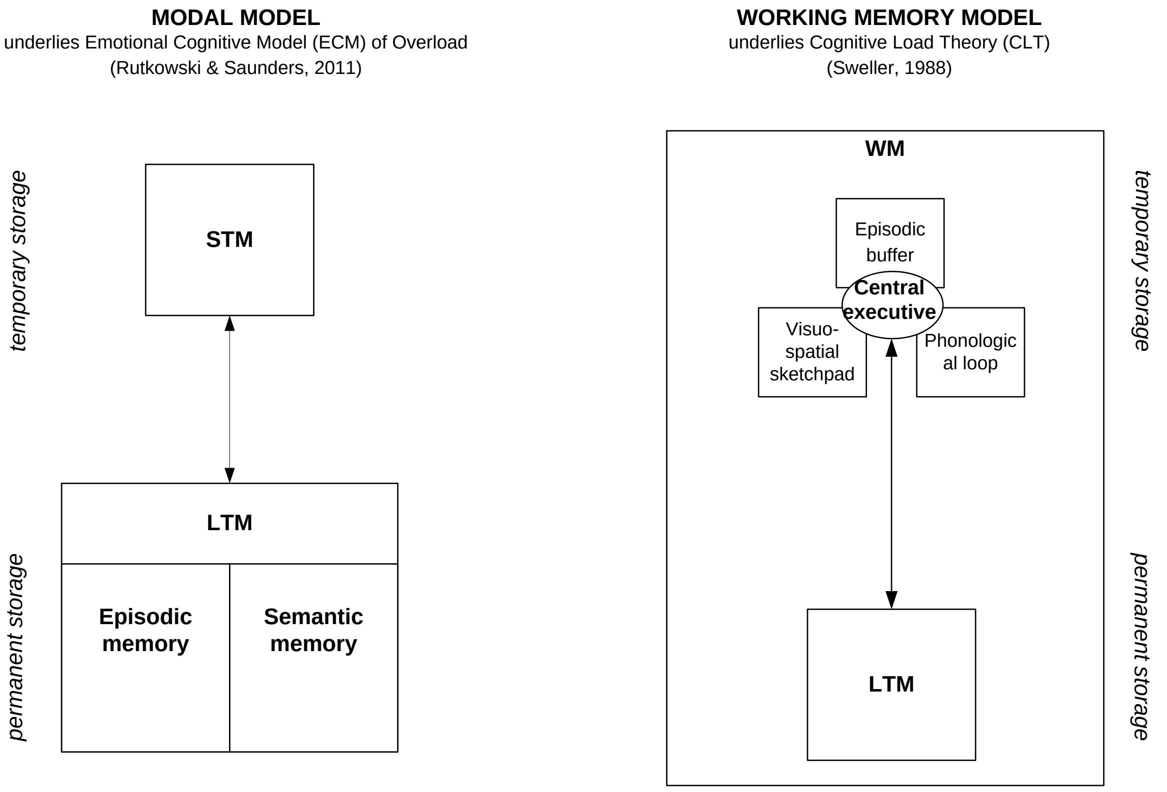


Figure C.1. Comparison of models underlying Emotional-Cognitive Overload Model (ECOM: Rutkowski and Saunders, 2011) and Cognitive Load Theory (CLT: Sweller, 1988)

Appendix D. Measurement scales

	Variable	Type of variable	Items	Scale	Included in Chapter	Cronbach Alpha
1	**Need For Cognition (NFC)** (Cacioppo and Petty, 1982)	Independent	I like to solve complex problems I need things explained only once I can handle a lot of information I am quick to understand things	7-point Likert scale (strongly disagree to strongly agree)	3.2, 3.3, 6	Alpha from ch3.2 = .84 ch6 = .91
2	**Anxiety** (adapted from NEO-PI-R scale by Costa and McGrae, 1992)	Independent	I worry about things I fear the worst I get stressed out easily I get caught up in my problems	7-point Likert scale (strongly disagree to strongly agree)	6	Alpha from ch6 = .85
3	**Encoded experience of Emotional-Cognitive Overload with IT in Long-Term Memory (encodedECO)** (adapted from Rutkowski and Saunders, 2010)	Independent (in Chapter 3,5) Dependent (in Chapter 6)	*Cognitive dimension (encodedC)* I cannot handle the number of requests I receive to use new IT I cannot cope with the number of requests I receive to use new IT I have problem keeping up to date with the number of requests I receive to use new IT I overwhelmed by the mental effort I have to make to deal with the number of requests I receive to use new IT I have no issue dealing with the request I receive to use new IT *Emotional dimension (encodedE)* I am pretty annoyed by the intrusion of the number of request to use new IT in my everyday life I am pretty upset by the number of requests I receive to use new IT I am satisfied by the number of requests I receive to use new IT [item excluded in analysis due to strong negative contribution to cronbach]	7-point Likert scale (strongly disagree to strongly agree)	3.3, 5, 6	Alpha from ch3.3=.93 ch5=.72 ch6 = .92 Alpha from ch3.2=.63 ch5=.85 ch6=.91
4	**Prior experience with simulation technology and gaming**	Independent	Virtual worlds (e.g., Second Life) Video gaming (e.g., Online gaming, Computer games) Wii	5-point Likert scale from never to always	3.3, 5	---

			Flight simulator Driving simulator Surgical simulator Surgical box trainer			
5	**Social relationship with the co-actor**	Independent (3x single item measures)	I consider [name of co-actor] as a close friend I consider [name of co-actor] as a fellow student I do most of my assignments at the university with [name of co-actor]	7-point Likert scale (strongly disagree to strongly agree)	5	---
6a	**Cognitive Absorption (CA) with IT** (adapted from Agarwal and Karahanna, 2000)	Independent	*Focus immersion* When using IT I am able to block out most other distractions When using IT I am immersed in the task I am performing When using IT I am absorbed in what I am doing When using IT my attention gets diverted very easily *Temporal dissociation* Time appears to go very quickly when I am using IT I spend more time on IT than I usually intend Time flies when I am using IT Most time, when I get on IT, I end up spending more time than I plan Sometimes I lose track of time when I am using IT Time happens to be very slow when I am using IT	7-point Likert scale (strongly disagree to strongly agree)	3.3, 5	Alpha from ch3.3 =.78 ch5 =.76 Alpha from ch3.3 =.71 ch5 =.76
6b	**Cognitive Absorption (CA) with IT** (specifically the surgical simulator) (adapted from Agarwal and Karahanna, 2000)	Dependent	*Focus immersion* When using the simulator I am able to block out most other distractions When using the simulator I am immersed in the task I am performing When using the simulator I am absorbed in what I am doing When using the simulator my attention gets diverted very easily *Temporal dissociation* Time appears to go very quickly when I am using the simulator I spend more time on the simulator than I usually intend Time flies when I am using the simulator. Most time, when I get on the simulator, I end up spending more time than I plan	7-point Likert scale (strongly disagree to strongly agree)	3.2	Alpha from ch3.2 = .89 Alpha from ch3.2 = .88

			Sometimes I loose track of time when I am using the simulator Time happens to be very slow when I am using the simulator			
7a	**Emotional-Cognitive Overload (ECO) with information delivered by the laparoscope monitor** (adapted from Rutkowski and Saunders, 2010)	Dependent	The amount of information that I received via the simulator screen prevented me from doing as well as I would like The amount of information that I received via the simulator screen interfered with how well I got things done. The amount of information that I received via the simulator screen led me to make mistakes The amount of information that I received via the simulator screen confused me	7-point Likert scale (strongly disagree to strongly agree)	3.3, 5	Alpha from ch3.3=.83 ch5=.81
7b	**Perceived ECO with information delivered by the Video Conferencing (VC) technology** (adapted from Rutkowski and Saunders, 2010)	Dependent	You are concerned that the amount of information received using the video contact tool will prevent you from assimilating the useful/meaningful information You are concerned that the amount of information received using the video contact tool will lead you to make mistakes in your financial and medical book records You are concerned that the amount of information received using the video contact tool could lead you to make wrong decisions You are concerned that the amount of information received using the video contact will confuse you during the conversation	7-point Likert scale (strongly disagree to strongly agree)	6	Alpha from ch6 = .91
8	**Facial temperature** (physiological response to mental load)	Dependent	Thermal imaging camera		4,5	---
9	**Surgical performance** (objective performance measured by the simulator)	Dependent	a) Time b) Economy of movement (AR simulator only) c) Smoothness of movement (AR simulator only) d) Task error (VR simulator only) e) Task score (VR simulator only) f) Task completion (VR simulator only)		3,4,5	---
10	**Overall stress** (adapted from from Cohen et al,1983)	Dependent	When performing the laparoscopic task …I was unable to control the important things that were necessary to complete the task …I felt nervous and “stressed” …I dealt successfully with irritating hassles brought by IT	7-point Likert scale (strongly disagree to strongly agree)	3.2, 3.3, 4, 5	Alpha from literature = .84

			…I was ineffectively coping with important things brought by IT (e.g., changes in heart rate) …I felt that I could not cope with all the things I had to do …I was able to control irritations …I felt I was on top of things			
11a	**Stress towards the assistant handling the laparoscope** (adapted from Cohen et al, 1983, Monroe and Kelly, 1995)	Dependent	When performing the laparoscopic task I felt frustrated by the attitude of the assistant I felt irritated by the way the assistant acted when performing the laparoscopic task When performing the laparoscopic task I felt stressed by the way the assistant performed I would have performed better with another assistant	7-point Likert scale (strongly disagree to strongly agree)	3.2	Alpha from ch3.2 =.83
11b	**Stress towards the co-actor performing the role of the anesthesiologist in training** (adapted from Cohen et al, 1983, Monroe and Kelly, 1995)	Dependent	When performing the laparoscopic task I felt frustrated by the attitude of the anesthesiologist in training I felt distracted by the anesthesiologist in training I felt irritated by the way the anesthesiologist in training acted when performing the laparoscopic task When performing the laparoscopic task I felt stressed by the way the anesthesiologist in training performed I would have performed better with a different anesthesiologist in training	7-point Likert scale (strongly disagree to strongly agree)	5	Alpha from ch5 = .90
12	**Stress towards the noise** (adapted from Cohen et al, 1983, Monroe and Kelly, 1995)	Dependent	When performing the laparoscopic task I felt frustrated by the noise around me I felt irritated by the noise when performing the laparoscopic task I felt extremely displeased by the noise when performing the laparoscopic task When performing the laparoscopic task I felt stressed by the noise in the room	7-point Likert scale (strongly disagree to strongly agree)	3.2	Alpha from ch3.2 =.97
13	**Time required to detect changes in heart rate**	Dependent	Measured using timer		3.3	

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