FAKULTÄT FÜR INFORMATIK

TECHNISCHE UNIVERSITÄT MÜNCHEN

Bachelor's Thesis in Informatics

Design and Evaluation of a Vascular Simulator for Medical Education

Liesa Weigert

FAKULTÄT FÜR INFORMATIK

TECHNISCHE UNIVERSITÄT MÜNCHEN

Bachelor's Thesis in Informatics

Design and Evaluation of a Vascular Simulator for Medical Education

Design und Evaluation eines Vaskulären Simulators für Medizinischen Ausbildung

Author: Liesa Weigert
Supervisor: Prof. Dr. Nassir Navab
Advisor: Philipp Stefan
Submission Date: TODO: Submission date

I assure the single handed composition of this bachelor's thesis in informatics only supported by declared resources.

Munich, TODO: Submission date Liesa Weigert

Acknowledgments

I would like to thank Dr. Reza Ghotbi, head of vascular surgery at Helios Kliniken, for dedicating his time and expertise to this project.

Abstract

Contents

1 Introduction

Surgical procedures are traditionally taught through apprenticeship model in which the trainee's education is guided by a practicing surgeon proficient in his field. The mentee learns procedures by initially observing them and discussing diagnosis, procedure and possible complications with his or her mentor. Thereupon they move on to assisting the performing surgeon and gradually advance to taking over parts of the surgery themselves under supervision. Only after satisfactorily passing these steps do the resident surgeons move on to performing the operation themselves. However this model has some significant drawbacks.

1.1 Disadvantages of the Apprenticeship Model

The education through a mentor-mentee relationship is exceedingly time consuming and therefore occupies a massive amount of work hours for both the expert surgeon and the trainee. However, as the European Working Time Directive (EWTH) is ensures to reduce working hours throughout Europe, this time might not be sufficiently available in the future[Pan+05]. In fact, the reductions have let to a considerable decrease in hours that can be spent on practicing for surgeons in training[Joh+11]. Consequently the question arises, whether the quality of training will suffer from this development. Furthermore the current teaching process is often criticized for not being standardized. The proficiency level trainees can achieve is strongly dependant on the quality of interaction with their mentor and the availability of cases in their hospital. Nevertheless, although the apprenticeship model has been scrutinized as being inefficient and unpredictable, there is little regulation on the assessment of performance. To ensure an adequate surgical training, the uniformity of training and the evaluation of post-training skills has to be equalized and controlled[Joh+12][Bis+10].
Another predicament of this training method is the inevitable increase of risk of patient harm or discomfort, as the junior surgeon has to perform the procedure on a real patient ab initio. Although there is a general consensus in the area of skill acquisition that proficiency can not be achieved exclusively by visual observation of a task, there are little to no options of practicing the procedure outside of actual surgery. The lack of other opportunities to train jeopardizes patient safety and creates a stressful and possibly detrimental work environment[Joh+11] [Pan+05].

Some of these deficiencies can be compensated through the integration of simulation devices into medical education.

1.2 Medical Simulation

The origin of simulation in complex work environments with high safety standards lies in aviation. Similar to the surgical field, pilots are required to handle a variety of complications and intricate operational sequences while minimizing the risk potential. However, simulation technology is widely accepted and adopted in aviation and therefore represents an essential part of the teaching process, whereas the medical field hasn't fully incorporated these devices yet[PW12]. Therefore simulators in aviation feature a more life-like surrounding as well as an abundance of typical and exceptional scenarios, which still have to be cultivated in medicine [Nie13]. Like aviation, medicine can benefit from exploiting the advantages of simulators.
For instance, simulators offer the opportunity to create training modules that cover a variety of different procedures, cases and even complications. This way, the trainees can learn from a predefined assortment instead of the random cases dependent on the patients in their hospital. The versatile offer allows students to try several approaches, learn from their mistakes without harming a patient and to experience uncommon cases in a low-stress and predetermined environment. Through focused training sessions, direct feedback and progress tracking the learning progress can be made more effective and predictable.This benefits the trainees and allows to assess their improvement in a standardized manner[Eas05][Lak05].

1.3 Proposed Project

While simulation is beneficial for the education and assessment of all surgical procedures, minimally invasive procedures, such as interventional radiology or cardiology are particularly well fitted to be simulated, because the performance in these operations is eminently influenced by the surgeon's skill to interpret a two-dimensional image, e.g. fluoroscopy or ultrasound.[Joh+12][Gre+14] These procedures can be modeled through a combination of 2D visual representation and haptic feedback, unlike open surgery, which is more challenging due to its 3D work environment[PW12]. Moreover, many movements in these processes are hard to entirely comprehend, as they are only perceptible through the imaging and the outside manipulation of the instruments by the surgeon. However, the main clue to reenact the movements, the haptic feedback, is only accessible to the trainee in practice. To minimize the potential harm for patients, simulation can offer the experience of these tactile responses without risking harm on

real-life patients[Joh+11].
Endovascular surgery is particularly well fit to be simulated, as it is a potentially life-saving procedure that is mainly led by angiography and fluoroscopy. Furthermore the objective of this project was to simulate these procedures without the use of actual radiation, as this also poses a threat to the performing surgeon. If the operations, such as percutaneous transluminal angioplasties, can be practiced beforehand both the surgeon and the patient can profit from the gain in efficiency as it may lead to a decrease in radiation dose.
We will discuss the design and the validation of such a simulator in the following.

2 Related Work

Through the high risk potential in the medical field the requirements for simulators are particularly high. To assure that the simulation can actually benefit or even partly replace the traditional surgical education and skill assessment every part of the development and testing process has to be thoroughly documented and analysed. Therefore there are several fields of research to consider when aspiring to create a simulation device which adheres to the current standards. We will discuss some of these concepts specifically in the following.

2.1 Cognitive Task Analysis

The challenge to consider, especially in medicine, is teaching intricate and lengthy procedures as a sequence of steps while acknowledging the underlying thought process. While different approaches and instruments can be memorized and taught verbally, the actual performance of the procedure, including the cognitive processes, is more challenging to transfer. This "procedural knowledge how" is acquired through extensive practice. According to Lanzer et al. the transfer of this knowledge is currently highly dependent on the quality of interaction between the student and his or her mentor.[Nie13] This dependency can be neutralised by accessing the underlying cognitive processes and implementing the relationship of tactile cues and appropriate behavior into the workflow of a simulator[Can+13].

2.1.1 Method

CTA describes a collection of techniques designed to elicit knowledge from experts. It is typically divided into a knowledge elicitation and an analysis and representation phase. While the progress in the second phase is dependant on the preceding work, there are several methods of knowledge extraction to consider in the first stage[Cra+12][Can+13]. Commonly used approaches include semi-structured or structured interviews. These can be accompanied by data elicitation from literature to collect substantial domain knowledge of the procedure in question. Special emphasis has to be put on the integrity of steps featuring exhausting descriptive data[Cra+12]. Important details include required information, tactile clues and possible mistakes or complications. To identify

the risks in particular one can also have the experts describe past critical incidents and the skills and patterns they used to salvage the situation[Can+13].
Some researchers also recommend the identification of automated steps. These actions often require little cognitive involvement for experienced surgeons and are often overlooked in traditional education [Tji+12].
This kind of data acquisition can be supplemented by observing and videotaping the procedure[Joh+11].

2.1.2 Think-Aloud

Another approach often used to elicit data is the Think-Aloud technique, which has been specifically developed to access information on cognitive processes while performing a task. This method requires participants to verbalize their thought process whilst executing an assignment [Jas09].
The underlying research suggests a division of memory functions into working, short-term and long-term memory. Assuming that the working memory can be directly verbalized, the Think-Aloud technique yields a direct depiction of the behavioural and mental processes with minimal distortion[Jas09][LS10].
Due to the immediate description of steps the identification of automated components of the procedure can be facilitated. As literature suggests that many experts cannot fully explain how they perform psychomotor tasks in a traditional way this method can be used as an instrument to access this knowledge[Low+11].
The Think-Aloud method has been widely used in the development of simulators, as it retrieves extensive data from a comparatively small number of participants. The experts usually perform the task either in their usual work-environment or with the use of simulators. These sessions are controlled, but only minimally influenced by a present researcher. The general consensus is that the observer should not intervene in the procedure other than to benefit an ideal outcome of the study[LS10].
The data is ordinarily video- or audiotaped and subsequently transcribed and analysed by the researcher.

2.2 Simulator Assessment

To assure that a simulator is sufficiently realistic and therefore suitable to fulfill the proposed task, it has to be thoroughly tested and performance and inaccuracies have to be documented. As one of the main goals of simulator development in medicine is to create a standardized assessment process of a surgeon's skill level this subject is most commonly used in research to validate a simulator. Moreover, to show effectiveness as a teaching tool is significantly more time consuming and susceptible to exterior influences. Therefore research generally aims to show that the developed simulation tool is reliably able to distinguish the participants' skill levels. For this purpose several participants with a background in the specific field are asked to perform a number of tasks on the simulator and evaluated by analysis of their performance regarding the pre defined metrics. Afterwards the dependency of scores and actual skill level is assessed to determine whether the simulator is a sufficient assessment tool. This process is commonly referred to as validation.

2.2.1 Validity

Understanding the concepts and goals behind validation is a crucial part of creating a sensible and conclusive assessment. Without validation, the simulator's scores meaningless. Therefore research dictates certain characteristics to consider during the validation process. Validity itself is defined as

> "the degree to which evidence and theory support the interpretations of test scores entailed by the proposed uses of tests"[Rat+08].

This means, it describes the how dependable test scores concerning a specific intended goal truly are.
Although it seems most instinctive to validate an instrument, such as a simulator, as a whole through a predefined standardized method, the actual process is more fluid. Firstly, it is not the simulator itself which gets validated but its propriety to assess a certain value, such as the surgeon's psychomotor or cognitive skills concerning a specific task. This abstract concept represents the hypothesis the validation is based on. Analogous to other fields of science, this hypothesis is tested and the accumulated evidence is then used to either support or refute the underlying theory. Therefore validity is not a dichotomy, but a series of tests and evidence leading to revision and refinement of the hypothesis [CB06] [Dow03].

Sources of Evidence

List of Figures

List of Tables

Bibliography

[Bis+10] J. Bismuth, M. A. Donovan, M. K. O'Malley, H. F. El Sayed, J. J. Naoum, E. K. Peden, M. G. Davies, and A. B. Lumsden. "Incorporating simulation in vascular surgery education." In: *Journal of Vascular Surgery* 52.4 (Oct. 2010), pp. 1072–1080. ISSN: 1097-6809. DOI: 10.1016/j.jvs.2010.05.093.

[Can+13] J. Cannon-Bowers, C. Bowers, R. Stout, K. Ricci, and A. Hildabrand. "Using cognitive task analysis to develop simulation-based training for medical tasks." In: *Military Medicine* 178.10 (Oct. 2013), pp. 15–21. ISSN: 1930-613X. DOI: 10.7205/MILMED-D-13-00211.

[CB06] D. A. Cook and T. J. Beckman. "Current Concepts in Validity and Reliability for Psychometric Instruments: Theory and Application." In: *The American Journal of Medicine* 119.2 (Feb. 2006), 166.e7–166.e16. ISSN: 0002-9343. DOI: 10.1016/j.amjmed.2005.10.036.

[Cra+12] C. Craig, M. I. Klein, J. Griswold, K. Gaitonde, T. McGill, and A. Halldorsson. "Using cognitive task analysis to identify critical decisions in the laparoscopic environment." In: *Human Factors* 54.6 (Dec. 2012), pp. 1025–1039. ISSN: 0018-7208.

[Dow03] S. M. Downing. "Validity: on the meaningful interpretation of assessment data." In: *Medical Education* 37.9 (Sept. 1, 2003), pp. 830–837. ISSN: 1365-2923. DOI: 10.1046/j.1365-2923.2003.01594.x.

[Eas05] M. P. Eason. "Simulation devices in cardiothoracic and vascular anesthesia." In: *Seminars in Cardiothoracic and Vascular Anesthesia* 9.4 (Dec. 2005), pp. 309–323. ISSN: 1089-2532.

[Gre+14] S. M. Green, A. J. Klein, S. Pancholy, S. V. Rao, D. Steinberg, R. Lipner, J. Marshall, and J. C. Messenger. "The current state of medical simulation in interventional cardiology: a clinical document from the Society for Cardiovascular Angiography and Intervention's (SCAI) Simulation Committee." In: *Catheterization and Cardiovascular Interventions: Official Journal of the Society for Cardiac Angiography & Interventions* 83.1 (Jan. 1, 2014), pp. 37–46. ISSN: 1522-726X. DOI: 10.1002/ccd.25048.

[Jas09] M. W. M. Jaspers. "A comparison of usability methods for testing interactive health technologies: methodological aspects and empirical evidence." In: *International Journal of Medical Informatics* 78.5 (May 2009), pp. 340–353. ISSN: 1872-8243. DOI: 10.1016/j.ijmedinf.2008.10.002.

[Joh+11] S. J. Johnson, S. M. Guediri, C. Kilkenny, and P. J. Clough. "Development and validation of a virtual reality simulator: human factors input to interventional radiology training." In: *Human Factors* 53.6 (Dec. 2011), pp. 612–625. ISSN: 0018-7208.

[Joh+12] S. J. Johnson, C. M. Hunt, H. M. Woolnough, M. Crawshaw, C. Kilkenny, D. A. Gould, A. England, A. Sinha, and P. F. Villard. "Virtual reality, ultrasound-guided liver biopsy simulator: development and performance discrimination." In: *The British Journal of Radiology* 85.1013 (May 2012), pp. 555–561. ISSN: 1748-880X. DOI: 10.1259/bjr/47436030.

[Lak05] C. L. Lake. "Simulation in cardiothoracic and vascular anesthesia education: tool or toy?" In: *Seminars in Cardiothoracic and Vascular Anesthesia* 9.4 (Dec. 2005), pp. 265–273. ISSN: 1089-2532.

[Low+11] N. Low-Beer, T. Kinnison, S. Baillie, F. Bello, R. Kneebone, and J. Higham. "Hidden practice revealed: using task analysis and novel simulator design to evaluate the teaching of digital rectal examination." In: *American Journal of Surgery* 201.1 (Jan. 2011), pp. 46–53. ISSN: 1879-1883. DOI: 10.1016/j.amjsurg.2010.09.004.

[LS10] H. Lundgrén-Laine and S. Salanterä. "Think-aloud technique and protocol analysis in clinical decision-making research." In: *Qualitative Health Research* 20.4 (Apr. 2010), pp. 565–575. ISSN: 1049-7323. DOI: 10.1177/1049732309354278.

[Nie13] P. L. Niels Taatgen. "Procedural Knowledge in Percutaneous Coronary Interventions." In: *Journal of Clinical & Experimental Cardiology* (2013). ISSN: 21559880. DOI: 10.4172/2155-9880.S6-005.

[Pan+05] V. A. Pandey, S. A. Black, A. M. Lazaris, J. R. Allenberg, H. H. Eckstein, G. W. Hagmüller, J. Largiader, J. H. N. Wolfe, and European Vascular Workshop, Pontresina. "Do workshops improved the technical skill of vascular surgical trainees?" In: *European Journal of Vascular and Endovascular Surgery: The Official Journal of the European Society for Vascular Surgery* 30.4 (Oct. 2005), pp. 441–447. ISSN: 1078-5884.

[PW12] V. A. Pandey and J. H. N. Wolfe. "Expanding the use of simulation in open vascular surgical training." In: *Journal of Vascular Surgery* 56.3 (Sept. 2012), pp. 847–852. ISSN: 1097-6809. DOI: 10.1016/j.jvs.2012.04.015.

[Rat+08] N. Ratanawongsa, P. A. Thomas, S. S. Marinopoulos, T. Dorman, L. M. Wilson, B. H. Ashar, J. L. Magaziner, R. G. Miller, G. P. Prokopowicz, R. Qayyum, and E. B. Bass. "The reported validity and reliability of methods for evaluating continuing medical education: a systematic review." In: *Academic Medicine: Journal of the Association of American Medical Colleges* 83.3 (Mar. 2008), pp. 274–283. ISSN: 1040-2446. DOI: 10.1097/ACM.0b013e3181637925.

[Tji+12] I. M. Tjiam, B. M. A. Schout, A. J. M. Hendrikx, A. J. J. M. Scherpbier, J. A. Witjes, and J. J. G. van Merriënboer. "Designing simulator-based training: an approach integrating cognitive task analysis and four-component instructional design." In: *Medical Teacher* 34.10 (2012), e698–707. ISSN: 1466-187X. DOI: 10.3109/0142159X.2012.687480.