Rasmussen's model of human behavior in laparoscopy training

Article *in* Surgical Endoscopy · September 2003

DOI: 10.1007/s00464-002-9140-z · Source: PubMed

5 authors, including:

Mark Wentink
multiSIM
50 PUBLICATIONS **599** CITATIONS

Laurents Stassen
Maastricht University
216 PUBLICATIONS **7,482** CITATIONS

Ian PJ Alwayn
Nova Scotia Health Authority
108 PUBLICATIONS **3,200** CITATIONS

Ruud Hosman
AMS Consult
74 PUBLICATIONS **1,086** CITATIONS

有效和高效的训练技巧，规则和知识的腹腔镜

Effective and efficient training of skills, rules and knowledge in laparoscopy

Mark Wentink[1], L.P.S. Stassen[2], I. Alwayn[2], R.J.A.W. Hosman[1,3], H.G. Stassen[1]

[1] Delft University of Technology, Faculty OCP, Section Man-Machine Systems, Delft, The Netherlands.

[2] Reinier de Graaf Group Delft and Voorburg, Dept. of Surgery, Delft, The Netherlands.

[3] Aerospace Man-Machine Systems Consulting, Delft, The Netherlands.

Abstract

微创手术 设想 手术

Aims. Virtual reality (VR) simulators for minimally invasive surgery (MIS) envision the next generation surgical training. Compared to aviation, where training has been standardised and simulators have proven their benefits, in MIS the objectives, needs and means of training have not been standardised yet. The aim of the study presented is to introduce Rasmussen's model of human behaviour as a practical framework for the definition of the training objectives, needs and means in MIS.

Methods. Rasmussen distinguishes three levels of human behaviour: skill-, rule- and knowledge-based behaviour. Future 腹腔镜 objectives in VR laparoscopy training should address all three levels of behaviour. Furthermore, the training needs of a laparoscopic novice can be established by identifying the specific skill-, rule- and knowledge-based behaviour that is required for safe laparoscopy.

Results. Most commercially available simulators for laparoscopy aim at training skill-based behaviour. Especially the training of knowledge-based behaviour during 并发症 complications in surgery will enhance safety levels. However, the cost and complexity of a training means increase exponentially when the training objectives proceed from the training of skill-based behaviour to the training of complex knowledge-based behaviour

Conclusion. In aviation, human behaviour models have been used successfully to integrate the training of skill-, rule- and knowledge-based behaviour in a Full Flight Simulator. Understanding surgeon behaviour is one of the first steps towards a future Full-scale Laparoscopy Simulator.

Introduction

To shorten the learning curve of laparoscopic surgeons, many training methods have been developed in the last 15 years. Simple box trainers have evolved to the first generation Virtual Reality (VR) simulators for laparoscopy [3,5,6,9,10,14,15,16,20,24,28]. The second generation simulators that was introduced only recently is capable of simulating complex surgical steps. Some of them have now entered the commercial market, like Virtual Patient [23,29] and Lap-Sim*One* [27].

Lately, the surgical societies have recognized the potential benefits of VR simulation in surgical education and certification [21]. Economic considerations and the constant drive to improve safety levels in surgery demand for training of laparoscopic residents outside the Operation Theatre (OT). Furthermore, simulators could replace the use of laboratory animals for training. Many governments have already severely restricted the use of animals, or they will do so in the near future.

Pilot training in aviation demonstrates the potential effectiveness and efficiency of simulator training. Not only have safety levels reached a very high level, they can also be certified and accredited due to the standardization of simulator training in aviation. To point out that many lessons can be learned from pilot training, den Boer [1] postulates:

Given their education curriculum, a surgeon would rather be the first passenger of a pilot than a pilot the first patient of a surgeon.

In aviation, human behaviour models have been implemented successfully to develop and to evaluate new training methods [13]. Human behaviour models are useful to specify the training objectives, needs and means of a certain training method. A clear definition of the training objectives, needs and means facilitates the classification, evaluation and ideally even the certification of training simulators according to the behaviour that is educated and consequently transferred to the OT.

This paper especially wishes to review Rasmussen's model of human behaviour [18] as a framework for the definition of the training objectives, needs and means of a training method. Furthermore, education in laparoscopy in the Netherlands is discussed to indicate the training needs of surgical residents that are addressed by the current training curriculum. In analogy, the training of pilots in aviation is discussed as an example of the use of VR simulation as an effective and efficient extension of training means. The paper ends with a discussion on the capabilities and limitations of VR laparoscopy simulators with regard to the training of skill-, rule- and knowledge-based behaviour.

Human behaviour model

Figure 1 shows Rasmussen's model of human behaviour. Three different levels of behaviour are distinguished: skill-, rule- and knowledge-based behaviour.

Skill-based behaviour

Skill-based behaviour represents human behaviour that takes place without conscious control. Task execution is highly automated at this level of behaviour and is based on fast selection of motor programs which control the appropriate muscles. An example of an everyday skill is walking. In general, many human activities can be considered as a sequence of skilled acts.
Many tasks in surgery can be considered as a sequence of skilled acts. For example, an experienced surgeon performs a suture task smoothly, without conscious control over his movements. In the case of experienced surgeons, suturing in MIS can also be considered as skill-based behaviour. However, due to the indirect access to the tissue it is a much more complicated skill (reduced depth perception and difficult hand-eye coordination). Therefore, acquiring the desired skill-based behaviour necessary to suture during MIS, takes a relatively long time.
Rasmussen defines the sensory information that is perceived during skill-based behaviour as continuous signals (Figure 1). Visually perceived movement information from the instrument tip on the monitor is an example of a continuous signal.

Rule-based behaviour

At the next level of human behaviour, rule-based behaviour is applied. During rule-based behaviour task execution is controlled by stored rules or procedures. These may have been derived empirically from previous occasions or communicated from other persons' expertise as instructions or as a cookbook recipe. Appropriate rules are selected according to their 'success' in previous experiences. For example, many procedural steps in MIS require rule-based behaviour.
At the rule-based level, the information is typically perceived as discrete signs (Figure 1). A sign serves to activate or to trigger a stored rule.

Knowledge-based behaviour

In unfamiliar situations, faced with a task for which no know-how or rules are available from previous encounters, human behaviour must move to a higher level. At this level behaviour is knowledge-based. During knowledge-based behaviour the goal is explicitly formulated, based on an analysis of the overall aim. Different plans are developed, and their effects mentally tested against the goal. Finally a plan is cognitively selected.
Serious complications that occasionally occur during surgery require a great deal of knowledge-based behaviour of the surgeon. He or she has to analyse the complication and the aim of the surgical procedure in order to develop strategies to counter the complication. Then he or she has to select the *best* strategy and consequently undertake the appropriate actions.
At the knowledge-based level, information is perceived as symbols. Symbols refer to *chunks* of conceptual information, which are the basis for reasoning and planning. Pathological symptoms are a good example of symbols in medical practice.

Training skills, rules and knowledge

Analogous to the three kinds of behaviour described by Rasmussen, three phases of learning can be distinguished during the training of a new task [7]: the cognitive phase,

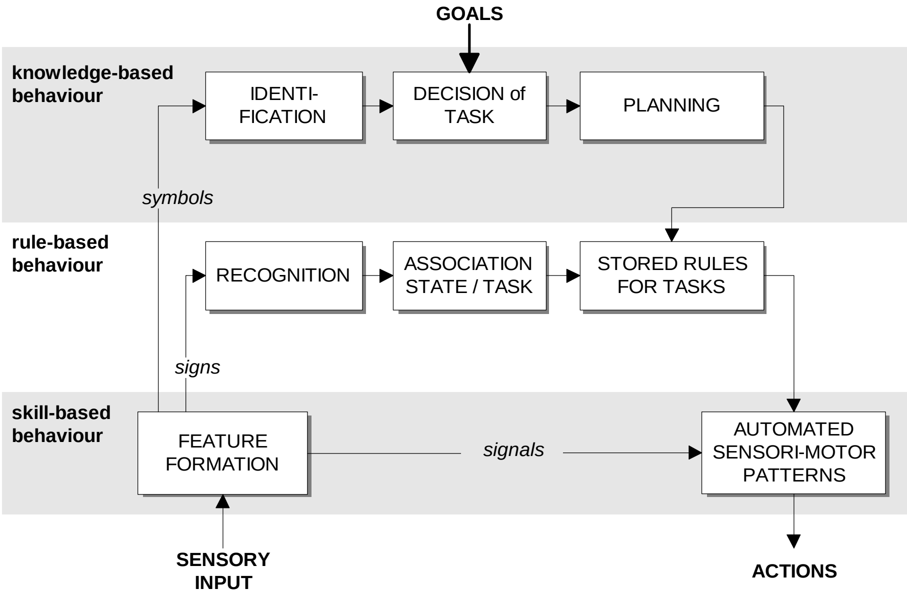

Fig. 1. *Human behaviour model of Rasmussen [18] with three levels of human behaviour: skill-, rule-, and knowledge-based behaviour.*

the associative phase and the autonomous phase. These three phases of learning correspond to the knowledge-, rule- and skill-based level, respectively. A trainee will pass the different phases of learning, beginning in the cognitive phase. Whether the autonomous phase is ever reached depends on the difficulty of the task and the effectiveness of the training method.

Stassen [22] uses Rasmussen's model to describe the surgeon's behaviour from the viewpoint of the systems engineering methodology. In his paper, a lot of practical examples of the application of Rasmussen's model to the surgeon's task can be found.

培训的最终目标是什么?应该培训什么?我们如何训练它?

Training objectives, needs and means

To facilitate the design and evaluation of a new training method it is of foremost importance to establish the training objectives, needs and means [25], since they provide an answer to the questions: *What is the end-goal of the training? What should be trained?* and *How can we train it?* The objectives represent the level of competence that is expected of the trainee after he or she has completed the training. Training needs are the difference between the initial level of competence of the trainees and the required level of competence after successful completion of the training (defined in the objectives). Ultimately, demands for effectivity and efficiency on the one hand, and the state-of-the-art in technology on the other hand, determine the tools and methods for training, i.e.: the training means.
Effective training ensures that all training objectives are met. *Efficient training* ensures that the training means are cost effective and that the training time determined by the training needs is minimized. Since safety and patient outcome are the most important criteria in surgery, training effectivity should be of primary importance.

Figure 2 shows how the training objectives, needs and means can be defined by applying Rasmussen's framework of human behaviour. The objectives determine the level of professional skill-, rule- and knowledge-based behaviour that is strove after by a certain training method. The needs represent the kind and amount of skill-, rule- and knowledge-based behaviour that should be trained to meet the objectives. The means are determined by the tools and methods that should be developed in order to fulfil the training needs.
The complexity and the costs of the means of training are greatly determined by the training objectives that have been set. Fulfilling all training needs of laparoscopic residents with only one training method will require a highly complex and very expensive trainer in which all three levels of behaviour can be trained. Such a trainer is not available yet. The complexity and the cost of a training means are relatively low if the training objectives comprise skill-based behaviour only, since this can be trained with simple models like Pelvi trainers. On the one hand, the cost and complexity of a training means increases exponentially when the training objectives advance from the training of skill-based behaviour to the training of knowledge-based behaviour. On the other hand, the overall effectivity of training increases as well when higher levels of behaviour, such as knowledge-based behaviour, are incorporated in the training.

Training in laparoscopy

A closer look at the training program of laparoscopic residents in the Netherlands provides an indication of the training needs that are addressed and the training means that are available today.
Similar to conventional surgery, the laparoscopic surgeon must effectively combine the three levels of behaviour. Instrument handling and dissection techniques require skill-based behaviour, whereas the recognition of surgical anatomy requires a great deal of rule-based behaviour. Complications, like uncontrollable bleeding or the encountering of aberrant anatomy require problem solving on a knowledge-based level of the surgeon.
Obviously, additional training of skill-based behaviour in laparoscopic surgery is highly desired as it combines unusual hand-eye coordination with the use of complex instruments. In the Netherlands, surgical residents are trained in laparoscopic surgery during a facultative two-day introduction course. Basic skill-based behaviour like instrument tissue handling and minimally invasive suturing

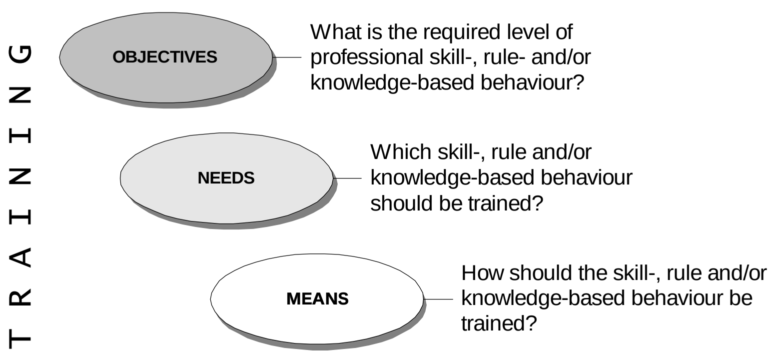

Fig. 2. *Definition of training objectives, needs and means*

are trained. Additionally, rule-based behaviour is trained through lectures, text books and video instructions. Only after the resident has successfully completed this course, he or she will receive training in the OT. It is here, that in addition to skill- and rule-based behaviour, most knowledge-based behaviour necessary to deal with complications and emergencies is acquired.
Technological innovations like Virtual Reality (VR) will change the way laparoscopic surgery is trained. As Satava stated [21], current accomplishments in surgical simulation envision the dawning of the next-generation surgical eduction. In this respect, aviation provides excellent examples of the effectiveness and efficiency of VR simulators as a means of training. Many lessons can be learned from pilot training.

Simulator training in aviation

In contrast to surgery, the training needs in aviation have explicitly been defined by regulatory authorities (Federal Aviation Administration) and the training means are certified accordingly [26]. The training objectives, needs and means in pilot training have been investigated in-depth [13]. Half a century of extensive research has resulted in many training tools, from simple Flight Training Devices (FTDs) to the highly effective Full Flight Simulator (FFS).

After the introduction of virtual reality training methods in the 1990's, the training of surgeons has often been compared to the training of pilots. The training of laparoscopic residents can best be compared to *type conversion training* of pilots. During type conversion training, young pilots that have finished flight training at the academies and have recently joined an airliner are trained to fly a particular type of aircraft. The general objective of type conversion training is to teach the trainee how to safely control, to navigate and to manage a particular operational aircraft. Since the trainees have already acquired much of the skill-based behaviour required to fly a multi-engine aircraft, the training needs mainly consist of acquiring additional rule- and knowledge-based behaviour. The trainees have to learn the new checklist, the specific procedures (e.g. take-off and landing) and they have to get familiar with all the aircraft systems (e.g. electronics, hydraulics). Furthermore, they have to train all sorts of emergency scenarios that may occur during actual flight. Training of this knowledge-based behaviour is very important since it significantly improves flight safety. The FFS provides an excellent training tool to accomplish all the specified training needs. The high level of realism of the current generation FFSs enables the integration of skill-, rule- and even knowledge-based behaviour training in one training device. FFSs have even made possible *Zero Flight Time Training*, during which type conversion training takes place completely outside a real aircraft.
In surgery, the ultimate challenge of the next generation laparoscopy simulators is to achieve the same level of effectiveness and efficiency as the FFS in pilot training.

Towards effective and efficient simulator training in laparoscopy

Defining the training objectives, needs and means

During the initial phase of the development of a VR simulator for training, the training objectives that are aimed at should be defined. An explicit formulation of the training objectives facilitates the development and certification of a simulator since it determines what the simulator should be capable of. Often the feasible training objectives of simulator training are constrained by the technology that is available or by commercial and marketing considerations. For example, pilots spend many hours training on low cost FTDs. The training objectives of these basic trainers are on a much lower level than that of the FFS. FTDs aim at training a specific kind of behaviour (usually rule-based behaviour) that is only a small part of the required level of competence. As a training means, FTDs are usually more efficient than a FFS in training a specific aspect of professional behaviour.
The laparoscopy simulators that have been developed during the past decade can all be considered as Laparoscopy Training Devices (LTDs, equivalent to FTDs). Most of these simulators specifically aim at training skill-based behaviour, like endoscopic manipulation and endoscopic camera navigation. However, performing safe laparoscopy also requires a professional level of rule-and knowledge-based behaviour from the surgeon, ideally these should also be trained outside the OT. Technological innovations (i.e.: increasing computing power, detailed anatomical models, soft tissue modelling, etc.) will most likely enable the integration of all levels of behaviour in one training simulator for laparoscopy. In near future, this might result in a Full-scale Laparoscopy Simulator (FLS), comparable to the FFS in pilot training. Perhaps a FLS even introduces *Zero Operating Time Training* as the ultimate training objective.

Training skill-, rule- and knowledge based behaviour

To provide guidelines for the design of laparoscopy simulators and to enable the certification of those simulators, the medical society should establish detailed objectives of training. The general objective of training in laparoscopy is to teach the resident surgeon how to operate minimally invasively through small incisions in the abdomen while maintaining a high level of safety. Recently, a number of expert groups [4,8,9,19] have begun to investigate what level of professional behaviour is required to perform save laparoscopy. In addition, they are establishing the training needs of laparoscopic residents by determining what should be trained to accomplish the training objective. The question which aspects of skill-, rule- and knowledge-based behaviour should be trained is addressed. Currently, there is no such standard available. Once the training objectives and needs are established, the simulator society will have clear guidelines as to what their training devices should be capable of.

One of the most obvious training needs of laparoscopic residents is the training of manual skills. The manual skills required during MIS are rather different compared to conventional surgery [2,12]. Training of skill-based behaviour is feasible with basic trainers like a Pelvi-trainer. The VR basic skill trainers that are commercially available usually simulate a generic abdomen and endoscopic instruments on a computer monitor. Basic tasks, like *pick and place* tasks, are implemented to train endoscopic manipulation. To facilitate the training of skill-based behaviour the simulated environment, e.g. the organs, does not have to be highly realistic. For example, the MIST VR trainer simulates basic manipulation tasks in a highly simplified environment similar to the Pelvi-trainer box. Several studies [5,10,14] have reported that training on the MIST VR facilitated the learning of skill-based behaviour. The level of realism that is required to accomplish the skill-based training needs of a trainee are still a matter of dispute. Do you need a VR simulator for this purpose, or does a Pelvi-trainer suffice? In both cases the level of realism must be high enough to assure correct interaction between the trainee and the endoscopic environment on the level of skill-based behaviour (i.e.: the signals should be veridical, Figure 1). Hamilton [11] found that both training on a Pelvi trainer and the MIST VR trainer improved endoscopic task performance. To their own surprise they also found that the trainees who trained on the MIST VR improved more.

A huge advantage of VR simulators over simple Pelvi-trainers is the capability to standardize the training and to register the trainee's progress. Furthermore, the training capabilities of laparoscopy simulators can easily be extended to the rule-based level of behaviour since textbook theory, instructions and training videos are easily integrated in the software [17]. A lot of textbook material and training videos that provide rule-based behaviour training have been made available on the Internet.

Although laparoscopy simulators are now capable of training skill- and rule-based behaviour, they are not yet used widely spread to facilitate training outside the OT. One of the reasons might be that they are still limited as a training device compared to hands-on training in the OT, since the training of knowledge-based behaviour on a simulator still poses a huge challenge. To train knowledge-based behaviour, a laparoscopy simulator should be capable of accurately imitating the surgical environment encountered during laparoscopic surgery. This is true particular during training of knowledge-based behaviour, since then a rich variety of information from the environment is used for cognitive reasoning and planning. The integration of knowledge-based behaviour training on a simulator would enhance safety levels in laparoscopy, since then every possible surgical complication could be simulated and trained beforehand. In analogy, a pilot practices the required procedures during an engine failure hundreds of times in the simulator. Although an engine failure is a serious complication, the pilot is very well trained to deal with it and can solve the problem efficiently on a rule-based level. Had the pilot not been trained so well, then the same complication would require extensive problem solving on a knowledge-based level. Training can effectively transform time consuming knowledge-based problem solving to faster and more efficient problem solving on a rule based level.

At this stage, technology has reached the required state-of-the-art to realise a FLS, however, a lot of important parameters concerning organ properties (like elasticity, colour, etc.) and soft tissue dynamics are simply still missing. Currently, a lot of effort is put into the identification of these properties [23].

Capabilities and limitations

In Figure 3 an attempt has been made to categorize some of the training means available today according to the training needs that they can accomplish. A future FLS accomplishes the training of skill-, rule-, and knowledge-based behaviour. All the other training devices in Figure 3 can be classified as LTDs. A categorization as sketched in Figure 3 provides guidelines for the development as well as the evaluation of a training method. For example, a simulator that was developed to train basic skills, should only be evaluated with respect to transfer of skill-based behaviour, whereas a full scale simulator should be evaluated on all three kinds of behaviour.

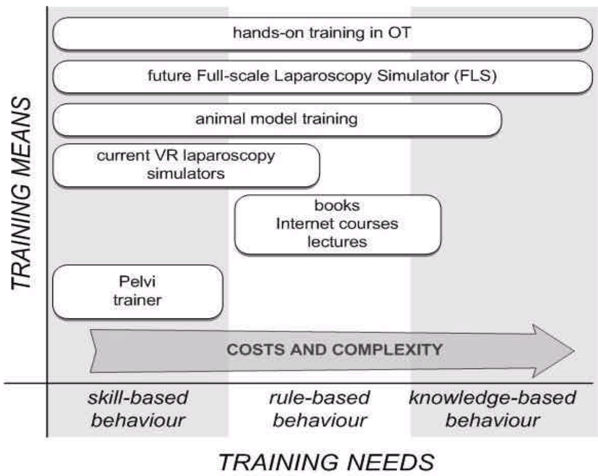

Fig. 3. *Categorization of different training methods for laparoscopy according to the kind of behaviour that is trained. The costs and complexity go up when the objectives include higher levels of behaviour.*

Conclusions

In this paper it was pointed out that it is of foremost importance to establish the training objectives, needs and means, since they provide an answer to the questions: *What is the end-goal of the training? What should be trained?* and *How can we train it?* To establish the objectives, needs and means of training, in-depth knowledge of human behaviour and performance is required. In this paper the human

behaviour model developed by Rasmussen was introduced, and the convenient categorization of human behaviour into skill-, rule- and knowledge-based behaviour was demonstrated. Rasmussen's model provides a practical framework for the definition of the training objectives, needs and means in MIS, and the evaluation thereof.
The training of skill-, rule- and knowledge based behaviour requires different training modalities. Skill-based behaviour does not require highly sophisticated means of training, a simple Pelvi trainer already facilitates skill-based behaviour training. To train knowledge-based behaviour, a high fidelity laparoscopy simulator that accurately imitates the surgical environment encountered during MIS is demanded. In general the effectivity of training increases when higher levels of behaviour can be incorporated in the training objectives, however, the efficiency of training does not necessarily increase as well since the training of knowledge-based behaviour requires very expensive VR training simulators.

In aviation the Full-Flight Simulator provides a highly effective and efficient means of training professional behaviour. In laparoscopy training, the next generation VR simulators are committed to reach the same level of effectiveness and efficiency in a future Full-scale Laparoscopy Simulator.

References

1. den Boer KT (2001) Surgical task performance; assessment using time-action analysis. PhD-thesis, Delft University of Technology, Delft, The Netherlands
2. Breedveld P, Wentink M (2001) Eye-hand coordination in laparoscopy: an overview of experiments and supporting aids. Min Invas Ther & Allied Technol 10: 155-62.
3. Bro-Nielsen M (1997) Simulation techniques for minimally invasive surgery. Min Invas Ther & Allied Technol 6: 106-10
4. Cuschieri A, Francis NK, Crosby BJ, Phil M, Hanna GB (2001) What do master surgeons think of surgical competence and revalidation? Am J Surg 182: 110-16
5. Derossis AM, Bothwell J, Sigman HH, Fried GM (1998) The effect of practice on performance in a laparoscopic simulator. Surg Endosc 12: 1117-20
6. Derossis AM, Fried GM, Abrahamowicz M, *et al.* (1998) Development of a model for training and evaluation of laparoscopic skills. Am J Surg 175(6): 482-7
7. Fitts PM, Posner MI (1968) Human performance. Belmont, CA: Brooks/Cole Publishing Company
8. Francis NK, Hanna GB, Cresswell AB, Carter FJ, Cuschieri A (2001) The performance of master surgeons on standard aptitude testing. Am J Surg 182: 30-3
9. Gallagher AG, Richie K, McClure N, McGuigan J (2001) Objective psychomotor skills assessment of experienced, junior and novice laparoscopists with virtual reality. World J Surg 25: 1478-1483
10. Grantcharov TP, Rosenberg J, Pahle E, Funch-Jensen P (2001) Virtual reality computer simulation; an objective method for the evaluation of laparoscopic surgical skills. Surg Endosc 15: 242-44
11. Hamilton EC, Scott DJ, Fleming JB, *et al.* (2001) Comparison of video trainer and virtual reality training systems on acquisition of laparoscopic skills. Surg Endosc online publication
12. Holden JG, Flach JM, Donchin Y (1999) Perceptual-motor coordination in an endoscopic surgery simulation. Surg Endosc 13: 127-32
13. Hosman R (1999) Are criteria for motion cueing and time delays possible? AIAA Modeling and Simulation Technologies Conference, Portland, OR, USA, AIAA-99-4028
14. Jordan JA, Gallagher AG, McGuigan J, McClure N (2001) Virtual reality training leads to faster adaptation of novel psychomotor restrictions encountered by laparoscopic surgeons. Surg Endosc online publication
15. Noar MD (1991) Endoscopy simulation: A brave new world. Endoscopy 23: 147-9
16. Ota D, Loftin B, Saito T, Lea R, Keller J (1995) Virtual reality in surgical education. Comput Biol Med 25(2): 127-37
17. Park A, Schwartz RW, Witzke DB, *et al.* (2001) A pilot study of new approaches to teaching anatomy and pathology; the laparoscopic view for medical students. Surg Endosc 15: 245-50
18. Rasmussen J (1983) Skills, rules, and knowledge; signals, signs and symbols, and other distinctions in human performance models. IEEE Transactions on Systems, Man, and Cybernetics 13(3): 257-66
19. Society of American Gastrointestinal Endoscopic Surgeons (SAGES) (1998) Integrating advanced laparoscopy into surgical residency training. Surg Endosc 12: 374-6
20. Satava RM (1993) Virtual reality surgical simulator: the first steps. Surg Endosc 7: 203-05
21. Satava RM (2001) Accomplishments and challenges of surgical simulation; dawning of the next-generation surgical education. Surg Endosc 15: 232-41
22. Stassen HG, Dankelman J, Grimbergen KA, Meijer DW (1998) Man-machine aspects of minimally invasive surgery. IFAC-MMS Conference, Kyoto, Japan: 7-18
23. Szekely G, Brechbuehler CH, Dual J, *et al.* (2000) Virtual reality-based simulation of endoscopic surgery. Presence 9(3): 310-33

24. Tendick F, Downes M, Goktekin T, *et al*. (2000) A virtual environment testbed for training laparoscopic surgical skills. Presence 9(3): 236-55
25. Teunissen PAM, The future of simulation and training.

Internet Pages

26. Federal Aviation Administration, Federal Aviation Regulations: www.faa.gov
27. Select IT VEST Systems AG, Lap-SimOne: www.select-it.de
28. Surgical-Science, LapSim: www.surgical-science.com
29. XiTact LS500, Virtual Patient: www.xitact.com