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To Feedback or not to Feedback – the Value of Haptics in Virtual Reality Surgical Training

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ABSTRACT

*As surgical procedures become more complex; require higher levels of precision and surgical skill; as patient safety is taking in an increasingly important place and ethical awareness, practicality and cost, rule out more and more training on cadavers or animal models; Virtual Reality (VR) surgical training comes progressively into the picture. Compared to training by apprenticeship, on animals or on cadavers, VR is convenient and versatile. However, it is not always the preferred [MFT*05] or best choice of training. The fidelity of the virtual reality environment plays here a determining role. Apart from visual, especially haptic feedback is perceived of key importance. Some studies question the benefit of haptics indicating that people receiving no haptic feedback during training outperformed participants that did receive haptic feedback [Mon10]. It was suggested that the quality of presented feedback formed the main reason for this result. This work provides a view of the current state of virtual reality surgical training systems and the role haptics plays herein. It also sketches directions for further research in this area.*

Categories and Subject Descriptors (according to ACM CCS): Software and its engineering~Virtual worlds training simulations

1. Introduction

Virtual Reality (VR) surgical training systems are coming increasingly into the picture as an appealing way to upgrade modern surgical training programs. VR training is ethical, practical and allows pupils to train repetitively in a stress-free environment where fear for making mistakes does not hinder the learning process [Gra08]. The goal of current simulation-based training is to create pre-trained novices. This term describes individuals who may have little or no experience with performing the actual procedure, but who are trained to the point where many of the required fundamental skills have already been mastered [GR07]. Further goals are to help experts maintain their skills – a consistent link between period of nonuse of a skill and skill decay has been demonstrated [GR07] – and to help surgeons to prepare and rehearse specific even exotic procedures. E.g. a VR exercise could be set up and tailored to a certain intervention on a specific patient by loading pre-operatively acquired patient-specific data into the simulation environment. Since VR training enables objective skill assessment, such system could be used for credentialing or selecting the best candidate for the job amongst available surgeons [GR07]. The quality of the available VR is obviously determining for it meeting above goals. In this article we aim to give an overview of the current state of VR surgical simulation and give directions for future work.

2. Requirements

Many of the advantages provided by VR surgical training only start making sense if the fidelity of the VR training environment is sufficiently realistic. An ultimate simulator would "suspend the trainee's disbelief" [SCS01]. For surgical training following list of requirements to obtain a high-fidelity training environment can be compiled. The simulator should:

- allow repetition of procedures;
- contain a training program based on task deconstruction and skill analysis [GR07];
- show close correspondence to the targeted task;
- allow accurate and objective assessment;
- behave anatomically correct;
- show a high level of interactivity;

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- foresee a high-resolution congruent visuo-haptic representation of anatomy and interaction [TPH*10];
- and as such demonstrate good transfer of training (TOT) to the real case.

Ideally such environment would further:

- foresee a broad pallet of procedures, including exotic cases;
- be affordable;
- allow training for decision making
- and assist in training collaborative tasks.

Some of abovementioned properties are contradictory. An appropriate, domain-specific, trade-off is therefore to be made [ADP*06]. For example, when training basic skills to novices, ultrarealistic looks were found not to be essential. Randomized double-blinded studies have been conducted between standard trained and simulator trained groups where even for low fidelity simulators latter groups have been shown to significantly outperform the former ones in terms of intraoperative laparoscopic skills [GR07] [GKB*04]. In general, as the risk of the targeted procedure increases so does the importance on the fidelity of the simulator. E.g. for laparoscopic cholecystectomy procedures the risk for life-threatening or life-altering complications is low, whereas in high-risk carotid angioplasty the risk of stroke or death at 30 days after the procedure is in the order of 5%. For such delicate procedures there is little room for training on the job and the use of low-fidelity simulators is to be discouraged [GR07]. The bottom-line is thus that simulators should meet exactly that set of requirements necessary for doing the job they are meant for. The terms alignment, validity and reliability are frequently used in literature to indicate in how far VR training environments meet this goal.

3. Evaluation of Simulators

Alignment refers to the requirement that the trained procedure should correspond to the actual procedure that one wants to learn and execute [CSA*05]. In order to learn or assess a skill for a particular intervention, training or evaluating should be done on an as similar as possible scenario in the VR environment.

The term validity is defined as the extent to which an assessment or training instrument measures what it was designed to measure or train [CSA*05], a valid VR simulator should approximate the characteristics of the environment in which the task eventually will be performed closely [CSA*05] [ASJ*07]. Different aspects of validity can be distinguished, summarized by Carter et al.[CSA*05] as: face validity that gauges the degree of resemblance between the system under study and the real activity; content validity examines the level to which the system covers the subject matter of the real activity; the degree to which the assessment can discriminate between different abilities or experience levels is called construct or contrast validity; more powerful evidence is gained through concurrent or predictive validity, in which performance of the assessment is compared with outcomes from established assessment methods. Finally, Transfer of Training is used to indicate whether the skill transfers to the operating room.

Disregarding the type of assessment method, the reliability of the method is of importance as it tells us how consistent and thus trustworthy the results are. Test–retest reproducibility and internal consistency are often used for estimating the reliability [CSA*05].

4. VR simulation environments and their validity

A large number of VR surgical training systems have been developed so far. Table 1 provides a non-exhaustive list of commercially available training systems spanning different surgical specialities. The largest number of systems has been developed to train laparoscopic skills or to train interventional radiology procedures, but, also in other domains the popularity of VR trainers is increasing. A multitude of training systems that were developed in research centres – each at varying level of realism – are not commercialised (yet) and not listed here.

Arthroscopy	
InsightArthroVR	GMV Healthcare
Arthro Mentor	Simbionix
SIMENDO	DeltaTech
GI Tract, Bronchoscope, Endoscopy	
EndoVR	CAE Healthcare
Bronch Mentor	Simbionix
EndoSim	Surgical Science Ltd
GI Mentor	Simbionix
Dental simulator	
Simodont	MOOG
DentSIM	DENX
Voxel-Man Dental	Voxel-Man
Endourology	
URO Mentor	Simbionix
ENT	
Voxel-Man / Temposurg	Voxel-Man
Interventional Radiology	
CathlabVR	CAE Healthcare
VIST Lab	Mentice AB
VIST C-system	Mentice AB
Xitact CHP	MENTICE AB
Angio Mentor	Simbionix
Compass/Simantha	Simsuite
CathSim	Immersion
Hysteroscopy	
VirtaMed HystSim	Simbionix & VirtaMed
Laparoscopy	
LapVR	CAE Healthcare
proMIS	CAE Healthcare
LapVR	Immersion
Virtual Tracking Interface	Immersion
Laparoscopic Surgical Workstation	Immersion
MIST / MIST-VR	Mentice AB
LAP Mentor / Express	Simbionix
LapSim	Surgical Science Ltd
VEST-one	Select IT / Karlsruhe
Reachitn LT	Reachin Lap.Trainer
SIMENDO	DeltaTech
SurgicalSim	METI, SimSurgery SEP platform)
Ophthalmology	
EyeSi	VRMagic
Eye Surgery Simulator	MOOG

Pelvic interventions	
Pelvic Mentor	Simbionix
Percutaneous Renal Access	
PERC Mentor	Simbionix
Robotic Surgery	
DV TrainerTM	Mimic Technologies
Xron	Altair Robotics Lab
RoSSTM	Simulated Surgical Systems
SEP RobotTM	SimSurgery
da Vinci Skills SimulatorTM	Intuitive Surgical, Inc.
Spinal cord stimulation	
Neurostimulation	Simsuite
TURP	
VirtaMed TURPSim	Simbionix & VirtaMed
US Procedures	
MedaPhor	ScanTrainer
VIDEMIX	CAE Healthcare
U/S Mentor	Simbionix

Table 1: *Non-exhaustive list of commercial VR surgical trainers, listed per surgical domain*

The validity (face, construct, predictive, TOT) of quite a few of these trainers has been demonstrated for basic skill training such as in laparoscopy, interventional radiology, colonoscopy [CSA*05] [CDL*06] [MSK*06] [ASJ*07] [KG09] [TS10] amongst others, however for procedural skills (i.e. entire procedure training) only a few types of validity have been confirmed for a few of these systems. For the LapMentor® face validity was proven earlier [ASJ*07] Van Bruwaene et al. investigated additionally construct validity and TOT for learning procedural skills [VBr13]. Concerning the former Van Bruwaene et al. could only construct validity for the entire procedure (cholecystectomy), but not for individual sub-tasks. Furthermore TOT could not be demonstrated, whereas it could be proven for training on a cadaver. The lack of realism of haptic feedback and anatomic detail were reported by the participants as plausible explanations for failure to transfer the targeted procedural skills [VBr13].

5. VR simulation versus box trainer

In fact many participants with experience in box trainers preferred the latter training method. To evaluate the cost/benefit of VR surgical training programs the effectiveness and appreciation of trainees working with VR simulators has been compared to the cheaper box trainers (aka video trainer). Figure 1 depicts the two configurations. From the figure it can be seen that for both systems the layout is quite similar and corresponds to the real procedure. Where in the case of a VR trainer the user looks at a screen depicting a virtual reality environment, in the box trainer images are real camera images. Box trainers can in principle only be used for some basic skill trainers. They also require the attendance of a third party who monitors and judges the performance. For a VR training system obviously skills assessment is done automatically.

Gurusamy et al. summarized the results of the studies conducted prior to 2009 on this subject [GAP*09]. They concluded that VR can supplement standard laparoscopic surgical training and that it is at least as effective as video trainer training. Gurusamy showed that the virtual reality trained group was more accurate than a video trainer trained group [GAP*09]. Nevertheless, virtual training was still perceived to display inferior realism compared to video trainers.

Also in other studies participants indicated to prefer exercises with box trainers citing realism of images and haptic feedback as the main reasons for their preference [HSF*02] [POA*10].

Figure 1: *[left] typical box trainer versus [right] virtual reality trainer (LAP MentorTM, Symbionix)*

6. Role of Haptics in Medical Training

The explanation that the lack or limited quality of haptic feedback in VR motivated participants to prefer box trainer or cadaver experiments over virtual reality training, suggests that high-quality haptics plays an important role in surgical training.

However, as pointed out by Coles et al. this expectation is not confirmed by a recent study by Van Der Meijden et al. who indicated that there is no firm and solid consensus on the value of haptic feedback for laparoscopic simulators [VdMS09]. This is also the finding in a (limited) study by Thompson et al.[TLD*11]. Van Der Meijden further indicated that randomized and controlled trials that add haptics to VR are needed to establish the true value of such costly equipment in MIS training. Coles pointed out that there is not a single complete evaluation of transfer of skills, e.g. with a control group using no simulator, one with a simulator and one with a simulator with haptic feedback done at this point.

Some recent work by Panait et al. suggests that additional expenses of currently available haptic-enhanced laparoscopic simulator for surgical residency programs may be justified for advanced skill development in surgical trainees [PAB*09]. Panait et al. conclude this from their finding that people with haptic feedback outperformed people without haptic feedback in FLS-like tasks in a VR training environment, where the FLS exam was already associated in earlier work to improve resident performance in the operating room.

Even if, despite these mixed signals, the importance of haptic feedback would be confirmed by such study, it still seems necessary to further improve or at least align the provided quality/type of haptic feedback. Here, a remark made by Coles et al. comes into mind, namely that the right amount of haptic feedback is needed at the right time. In fact providing too high fidelity of force/torque feedback

can be as much as a problem as providing too little haptic feedback [CMJ11]. For example in the case of laparoscopic surgery, instruments enter the body through tight introducers. The friction forces that develop while sliding instruments in and out through these introducers will mask the interaction forces at the instrument tip to large extent. Providing clear interaction forces in the training environment could therefore negatively affect the training experience as in the real scenario the user would not possess have access over this quality of information.

Another explanation raised e.g. in an interview to Medscape Surgery Magazine [Mon10] is that "Because haptics is so sensitive, it may be that the haptics technology is just not developed enough at this stage, not exactly correct enough to effectively impact surgical training".

7. Conclusions and future work

Simulation training is found essential and mandatory in current surgical residency (75% of JR and 67% of SR) [BOS06]. While simulators have shown good validity to train basic surgical skills, further analyses are needed to show Transfer of Training for complete procedural skills. The lack of high quality haptic feedback could be a partial reason why validity has not been demonstrated on a procedural level up till now.

In several studies participants named the limited fidelity of the haptic feedback as one of the main reasons to prefer other training methods such as training on box models or cadavers over VR based training. It is not unimaginable that participants experienced the haptic feedback from the VR not sufficiently good and thus not useful to learn from it. Also at this point – as far as the authors are aware of – no solid study has been performed to confirm the validity of haptic feedback in surgical simulation based training.

When investigating the question on the use and transferability of haptic-enabled training methods great care should be taken that the provided haptic feedback is indeed of excellent quality and appropriate for the procedure at hand. This remark naturally follows from the existing concerns about the quality of some current trainers and of the need to correctly align the provided haptic feedback in VR with the feedback that is present during the real surgical intervention.

Haptic feedback for future simulators could be improved in several ways. From hardware point of view, novel actuators, materials and designs could lead to new devices that are lighter, stiffer, and stronger and that show improved transparency. More realistic tissue models should be used to derive more natural responses and interactions with tissue and structures [FVS08]. Increases in computation power and parallelisation would allow computing moresophisticated models showing higher biofidelity, while keeping collision detection algorithms and response computations in pace. Also physiological phenomena such as flow, heartbeat etcetera would need to be accounted for.

In a study by Boyd et al. residents indicated the need to extend VR training towards open surgery (67% JR and 60% SR) as well [BOS06]. In open surgery palpation is a very common and important medical examination used for example to detect the location of arteries that need to be accessed for catheterization procedures. In current commercial endovascular simulators palpation is typically not included [CJG*09]. Apart from improving or adjusting the quality of the kinaesthetic feedback component, there will be a need to provide and improve the tactile component of the haptic feedback system.

Lastly, it can be expected that as the confidence in the validity of these training environments rises, futher attention will go to elaborate virtual reality training programs and validate the skill assessment instrumentation and use this e.g. for selection and credentialing of candidate surgeons.

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