Acquiring minimally invasive surgical skills

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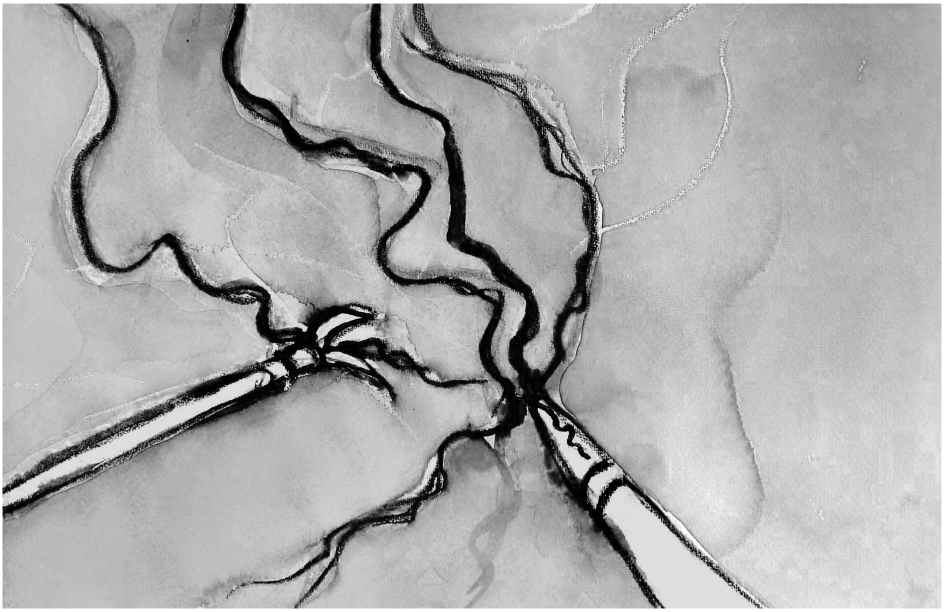
CHAPTER 3

VIRTUAL REALITY IN LAPAROSCOPIC SKILLS TRAINING: IS HAPTIC FEEDBACK REPLACEABLE?



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INTRODUCTION

Surgeons traditionally rely on vision and touch to obtain information about the operation field. In minimally invasive surgery (MIS), like laparoscopy, these senses can only provide indirect information. Regarding vision, the operation field has to be interpreted from a two-dimensional projection of the endoscopic view.[Westebring-van der Putten EP et al., 2008] Regarding touch, the gloved surgeon's hand is in indirect contact with the tissue through laparoscopic instruments. The latter results in limited haptic (kinaesthetic and tactile) feedback.[Bholat et al., 1999] However, correct perception of the operation field is essential to guarantee efficient and safe tissue manipulation. Consequently, laparoscopic surgeons have to be capable of correctly interpreting indirect visual and haptic feedback.

The development of training facilities outside the operating room (OR) has taken a great leap. One of the explanations is that the apprenticeship model turned out to be insufficient for acquiring MIS skills.[Aggarwal et al., 2004] For training on inanimate models, numerous simulators have been introduced and validated.[Stefanidis et al., 2009b] Roughly, these simulators are divided into physical box trainers and computer-aided virtual reality (VR) trainers.[Dunkin et al., 2007] In box trainers, real laparoscopic instruments are used. A consequence of training with real laparoscopic instruments is that realistic haptic feedback is provided in box trainers. None of the VR trainers provides natural haptic feedback. Therefore, these devices are mainly focused on training hand eye-coordination.[Schijven et al., 2003]

Haptic feedback is considered necessary for tissue handling in laparoscopy. It is used to regulate force application, and thereby, avoid tissue damage.[Strom et al., 2006] Furthermore, it provides information on tissue texture, shape and consistency. Despite its clinical significance, little is known about the exact role of haptic feedback during simulator training. Only a few studies revealed its importance in the early training phase of skills acquisition.[Botden et al., 2008; Strom et al., 2006] Obviously, with respect to haptic feedback, box training models are superior to VR systems.

In response, attempts have been made to compensate the lack of haptic feedback in VR trainers by adding electromechanically transmitted information.[Westebring-van der Putten EP et al., 2008] This allows the trainee to "feel" an illusion of contact in the grip of the instrument. However, current technology is not yet able to provide it in a highly realistic manner.[Basdogan et al., 2004; Schijven & Jakimowicz, 2003; Westebring-van der Putten EP et al., 2008] Others tried to compensate for the lack of haptic feedback by using software that simulates real-time instrument tissue interactions based on instrument movements and imaginary physical properties of the objects in the virtual environment.[Basdogan et al., 2007] It is unknown whether tissue handling skills can be acquired using a VR trainer model equipped with this software. Therefore, the aim of this study is to determine whether (and to which extent) additional kinematic interaction in VR trainers can replace haptic feedback during laparoscopic skills training, by comparing the effect of box and VR training with different levels of kinematic interaction.

MATERIALS AND METHODS

This study was conducted at the skills laboratory of the Leiden University Medical Centre (LUMC) in the Netherlands from 2008 to 2009. The SIMENDO® VR trainer (Delltatech, Rotterdam, The Netherlands) was used for VR training setups. A physical box trainer (LUMC, Leiden) was used for the box trainer setups.

Study population

Novices (i.e. medical students in the preclinical phase of their studies) were recruited to the study by means of advertisement in the medical library of the LUMC. They participated on a voluntary basis. After enrolment, they completed a questionnaire providing demographic information (i.e. gender, hand dominancy, self-perceived dexterity, prior laparoscopic or simulator experience, and experience in computer gaming).

Study design

As a pre-test, all participants performed a validated[Kolkman et al., 2008] rubber band task in a box trainer. To fulfil this task, the rubber band first had to be put outside all 16 nails on the wooden board. Then, it had to be zigzagged around the nails, starting in the upper left corner. This task was chosen to simulate tissue handling during laparoscopic surgery, because it requires hand eye coordination as well as a proper application of forces.

After pre-testing, novices were randomly assigned to one of four training setups and a control group that received no training (Figure 1). In all training setups, which will be described in detail in the next section, participants performed an exercise to pile up three cylinders. Duration of the training was 20 minutes, the control group waited during that period. The duration of 20 minutes had been based on a pilot study in which we found that most of the short-term training effect was achieved within 20 minutes regarding piling up cylinders correctly in box and VR setups. The rubber band task was performed again as a post-test after training or waiting. The flowchart of the study is presented in figure 1.

Intervention – the training setups

In the *VR-I* setup, the cylinder task of the basic curriculum of SIMENDO® (SimSoft Basic 1.0 package) was used. Such a setup allows psychomotor skills training in a conventional VR environment. The curriculum has been validated and has shown to improve OR performance.[Verdaasdonk et al., 2007a] In the *VR-II* setup, the cylinder task of the new Simsoft Advanced 2.0 package of the SIMENDO® was used. The kinematic behaviour of the objects in the VR environment has been changed by adding object movements based on instrument's velocity and the physical properties of the objects (e.g. weight). Consequently, VR-II has a different kinematic instrument-object interaction based on calculated forces that are virtually applied. With these kinematic properties, it is, for example, determined whether a tower of cylinders will fall over when the table they are placed on tilts due to the virtual forces applied with a virtual laparoscopic grasper. The *Box-I* and the *Box-II* setups have been designed to be an equivalent of the VR-I setup and the VR-II setups, respectively. The only difference between these setups was that the table, on which the cylinders were placed, was fixed in Box-I, whereas in Box-II the

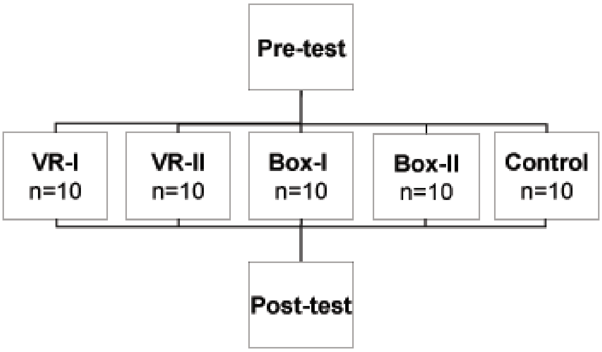

Figure 1. Study design. VR-I: set-up in conventional VR environment, VR-II: set-up with kinematic object interaction application, Box-I: box trainer equivalent of VR-I, Box-II: box trainer equivalent of VR-II. Control: no training. Participants were equally distributed to the five groups using randomization using the website www.randomization.com.

legs of the table were replaced by springs in order to allow the table to tilt. The endoscopic view of the four training setup is shown in figure 2.

The image of a fixed 0° scope was presented on the monitor in all training setups. Participants used two laparoscopic graspers, one in the right and one in the left hand. The dimensions of grasper of laparoscopic instrument, the cylinders, and the square table (on which cylinders were placed) were identical in each training setup. Consequently, the training varied with respect to the absence or presence of haptic feedback (i.e. the VR, and the box

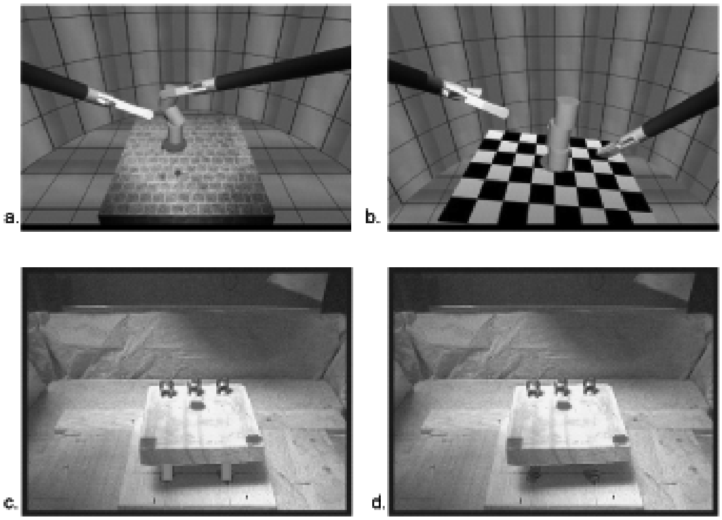

Figure 2. Four training setups. (a) VR-I: set-up in conventional VR environment, (b) VR-II: set-up with kinematic object interaction application, (c) Box-I: box trainer equivalent of VR-I, (d) Box-II: box trainer equivalent of VR-II.

trainers, resp.), and the absence or presence of the newly developed kinematic instrument-object interaction (i.e. the -I, and the -II setups, resp.). By this study design, the influence of these simulator features on the performance of participants could be compared.

Outcome Measures

The movements of the tip of the instruments were recorded during the pre- and post-test with the TrEndo tracking device, developed at Delft University of Technology[Chmarra et al., 2006], and motion-analysis parameters were established. The motion-analysis parameters were:

- Time: defined as the total time taken to perform the task (s)
- Total path length: defined as the average length of the curve described by the tip of the right and the left instrument while performing the task (m)
- Motion in depth: defined as the total distance travelled by right and left instrument along its axis (m)

Time expresses the speed with which the exercise has successfully been performed. Path length is a measure for the economy of movements. The motion in depth is influenced by the depth perception of the trainee, in which problems with perceiving depth is likely to result in a longer motion in depth. Outcome measures were the differences between the parameters at the pre- and the post-test.

Statistical analysis

The recorded pre- and post-test results were collected, and analysed with the Statistical Package for Social Sciences (SPSS, version 16.0, Chicago, IL). The median and range of the outcome measures were given in case the data were not normally distributed. The relative improvement in parameters was calculated for the individual participant, and was expressed in percentage of the pre-test score. Additionally, the mean improvement within each group was determined. The Wilcoxon signed-rank test was used to establish the difference between pre- and post-test results. A p-value less than .05 was considered statistically significant.

RESULTS

In total 50 novices were enrolled in the study, and completed the entire study protocol. All denied prior laparoscopic or simulator experience. The five groups did not differ significantly with respect to gender, percentage of right-handed persons, self-perceived dexterity, and history of computer gaming.

The median scores and ranges of the pre- and post-test results are presented (Table 1). No statistically significant differences were present between the five groups regarding the pre-test results.

The observed improvement varied among groups. The control group did not show a significant improvement at post-testing with respect to time, path length and motion in depth. Regarding the four training modalities, all groups significantly improved in time to completion of the rubber band task. Regarding both economy of movement parameters, path length as well as motion in depth improved significantly in both box trainer groups. The VR-II trained group also improved significantly with regard to both these parameters, but the VR-I trained group did not.

Table 1. Time and economy of movement parameters.

	Pre-test median	(range)	Post-test median	(range)	Improvement p-value
VR1 (n=10)					
Time [s]	257	(240 - 345)	158	(117-277)	<.005
Path Length [m]	7.4	(4.8 - 22.3)	5.1	(4.0 – 17.2)	N.S.
Motion in Depth [m]	2.3	(1.1 - 4.1)	1.8	(1.2 – 4.6)	N.S.
VR2 (n=10)					
Time [s]	204	(152 - 413)	173	(130-311)	<.005
Path Length [m]	7.5	(3.5 – 14.8)	5.2	(3.3 – 10.9)	<.05
Motion in Depth [m]	2.2	(1.3 – 4.3)	1.8	(1.2 – 3.0)	<.05
Box 1 (n=10)					
Time [s]	245	(160-490)	156	(133-250)	<.005
Path Length [m]	8.1	(5.7 – 13.1)	4.9	(3.6 – 6.9)	<.005
Motion in Depth [m]	2.4.	(1.3 – 4.1)	1.7	(1.3 – 2.6)	<.01
Box 2 (n=10)					
Time [s]	245	(189-399)	157	(130-233)	<.005
Path Length [m]	6.8	(5.4 – 9.4)	4.8	(3.9 – 10.1)	<.05
Motion in Depth [m]	2.1	(1.6 – 3.1)	1.5	(1.0 – 2.5)	<.05
Control (n=10)					
Time [s]	255	(97-499)	195	(115-432)	N.S.
Path Length [m]	5.7	(3.0 – 1.5)	5.0	(3.4 – 15.6)	N.S.
Motion in Depth [m]	1.9	(1.2 – 3.8)	1.6	(0.9 – 4.1)	N.S.

Improvement is calculated using the Wilcoxon signed-rank test on the difference post-test and pre-test. VR-I: set-up in conventional VR environment, VR-II: set-up with kinematic object interaction application, Box-I: box trainer equivalent of VR-I, Box-II: box trainer equivalent of VR-II. Control: no training

DISCUSSION

Box training leads to a significant improvement in speed and in economy of movement during an exercise in which both force application and hand eye coordination are required. Conventional VR training results in improvement in terms of speed alone. However, a VR setup supplied with additional kinematic instrument-object interaction has an enhanced training capacity which is shown by the significant improvement in economy of movements of the trainees.

Prior studies have already compared the learning potential of box trainers and VR trainers.[Chmarra et al., 2008; Hamilton et al., 2002; Jordan et al., 2000; Kothari et al., 2002; Madan et al., 2007; Munz et al., 2004; Pearson et al., 2002; Torkington et al., 2001b] Most of these studies did not reveal significant differences in outcome measures.[Kothari et al., 2002; Madan & Frantzides, 2007; Munz et al., 2004; Pearson et al., 2002; Torkington et al., 2001b] Two studies showed an advantage for the VR trainer,[Hamilton et al., 2002; Jordan et al., 2000] and one showed an advantage for the box trainer.[Chmarra et al., 2008] An important limitation of the majority of these studies is that the tasks were not equivalent in the compared trainers. As the training conditions were unequal, the implication of these studies' results is limited. However, in the study of Chmarra et al., novices performed three equivalent exercises in both a VR trainer and a box trainer using a cross-over design.[Chmarra et al., 2008] They found that VR trained novices perform worse in a box trainer than the non-trained group who started with box training for the one exercise in which force transmission was required. For the exercises that mainly require hand eye coordination the group that had been trained on VR outperformed the non-trained group. These results indicated the effect of the need of realistic feedback to train tissue handling.

The novelty of our study is that not only equivalent exercises were used for all training setups, but also a pre- and post-test that differed from the trained task. Regarding the latter, individual progression can be taken as the result of the training setup, combined with a fixed effect of having performed the pre-test. Moreover, by choosing a force requiring task, we intended to simulate tissue handling during laparoscopy instead of only hand-eye coordination. However, the results of the box training groups might have been positively influenced by the fact that pre- and post-test are performed in a box trainer. By choosing equivalent exercises in this study, it was intended to have the presence of haptic feedback and kinematic instrument-object interaction as the only varying features.

Large ranges in pre-test scores with skewed distribution were observed. This can be explained by a variance in innate ability. Due to this distribution, it was only possible to draw conclusions about whether each training setup led to a significant improvement. Unfortunately, no quantitative comparison between the training systems could be made. Though not statistically proven, natural haptic feedback seems superior to a VR trainer with the newly developed interaction, as indicated by the larger percentage of improvement in economy of movement parameters in both box trainer setups when compared to the VR-II setup (median: 36 vs. 26% in path length, and 30 vs. 12% in motion in depth for both box trainers groups and VR-II, resp.).

Continued training is required to achieve real competence in basic laparoscopic skills. However, it is found that much progress is generally made during the early phase of the process to acquire psychomotor skills.[Larsen et al., 2006] Therefore, despite the short duration of the training, a significant progression in psychomotor skills could be observed. An additional advantage of a short duration of the training is that the experiment could be held in one session without fatigue of a participant influencing the results.

Haptic feedback is considered to be essential for tissue handling. Next to providing information on tissue texture, shape and consistency, it can be used to regulate force application and to avoid tissue damage.[Strom et al., 2006] In laparoscopy, the balance between a firm grip on the tissue and not causing any damage even is harder to acquire.[Westebring-van der Putten EP et al., 2008] From this theoretical point of view, training using a model with haptic feedback should be considered superior in order to acquire proper force application. On the other hand, new technologies like robotic surgery are introduced in the clinical field. Probably, training models without haptic feedback will provide surgeons with good psychomotor skills to become proficient in this technique.

The transferability of skills acquired on simulators to the real OR setting remains the key concern, though the hardest to objectify. This transferability to laparoscopic surgery was proven for box trainers[Scott et al., 2000] as well as for VR trainers[Grantcharov et al., 2004; Seymour et al., 2002], using global rating scales and expert opinions. Based on our study on simulator features and on theoretical considerations, we judge a box trainer system with a natural instrument-tissue interface to be superior to VR training systems for acquiring tissue handling skills in laparoscopic surgery. Furthermore, box trainer are cheaper and easy accessible, which makes them likely to be actually used for laparoscopic skills training.[Sharma et al., 2009] However, if a VR training system is selected to train these skills, a system with kinematic instrument-object interaction can be a promising surrogate for haptic feedback to train tissue handling.