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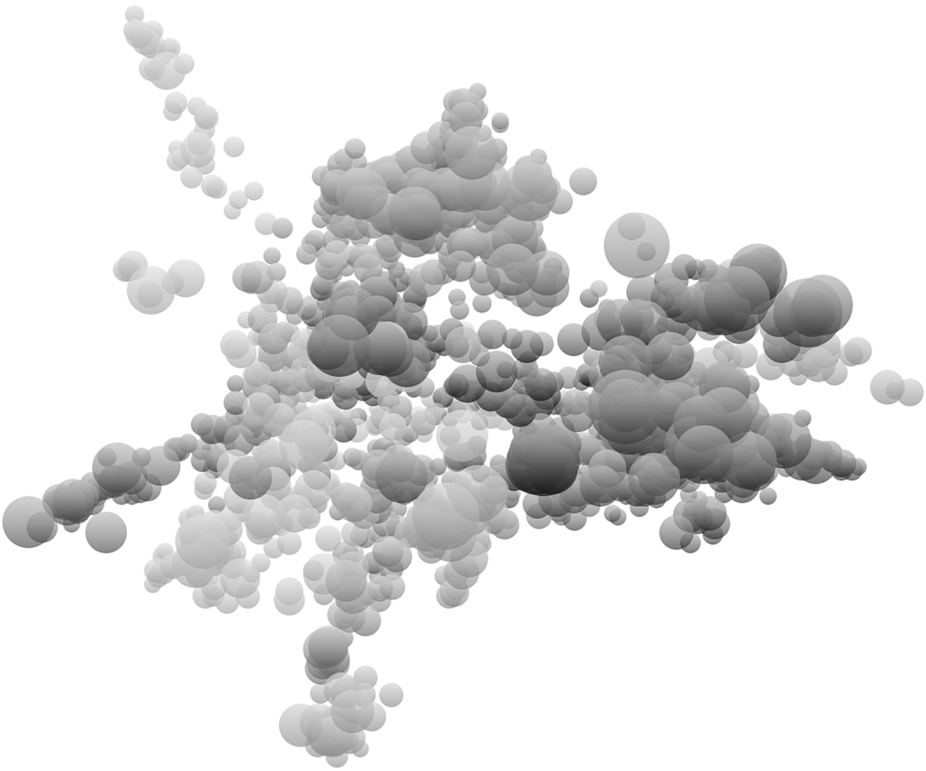
**Title**: Towards safety in minimally invasive surgery : patient safety, tissue handling and training aspects
**Issue Date**: 2014-12-17

# CHAPTER 9

# INFLUENCE OF VISUAL FORCE FEEDBACK ON TISSUE HANDLING IN MINIMALLY INVASIVE SURGERY



# ABSTRACT

## Background

Force feedback might improve surgical performance during minimally invasive surgery. This study sought to determine whether training with force feedback shortened the tissue-handling learning curve, and examined the influence of real-time visual feedback compared with postprocessing feedback.

## Methods

Medical students without experience of minimally invasive surgery were randomized into three groups: real-time force feedback, postprocessing force feedback and no force feedback (control). All performed eight suturing tasks consecutively, of which the first and eighth were the premeasurement and postmeasurement tasks respectively (no feedback). Depending on randomization, either form of feedback was given during the second to seventh task. Time, mean force non-zero and maximum force were measured with a force sensor. Results of the groups were compared with one-way ANOVA, and intragroup improvement using a paired-samples t test.

## Results

A total of 72 students took part. Both intervention groups used significantly lower interaction forces than the control group during the knot-tying phase of the postmeasurement task and improved their interaction forces significantly during the knot-tying phase. The form of feedback did not influence its effectiveness.

## Conclusion

The tissue-handling skills of medical students improved significantly when they were given force feedback of their performance. This effect was seen mainly during the knot-tying phase of the suturing task.

# INTRODUCTION

Basic surgical skills should preferably be developed in a non-clinical setting[1–3]. Complex surgical tasks performed in laparoscopic procedures place higher demands on the motor skills of the surgeon and require extensive training. Objective assessment of basic laparoscopic skills in the laboratory setting has been shown to be possible in box and virtual reality trainers. In box trainers motion-tracking systems provide information about economy of movement[4] and force-sensing systems about tissue-handling skills[5]. In general, this information is analysed and interpreted after completing a task (postprocessing), providing objective assessment (for example at examination) and individualization of the training programme. Individual trainees gain insight into which basic laparoscopic skills are still lacking so that an individual training programme can specifically focus on these areas.

The loss of haptic feedback in minimally invasive surgery, owing to resistance inside the trocars and the use of long laparoscopic instruments, hinders the estimation of applied forces in instrument–tissue interaction[6,7]. A force-sensing system has been developed that gives real-time feedback about the applied interaction force[5,8]. The real-time visualization of applied forces during training seems to facilitate the acquisition of tissue-handling skills for complex laparoscopic tasks[8], but the influence of real-time force feedback on the learning curves of trainees has not been established. Previous studies[7,9] indicated that there was no strong learning curve present in force parameter outcomes when no attention was drawn to the tissue manipulation force. The aim of this study was to determine whether training with real-time visual force feedback or postprocessing force feedback influenced the tissue-handling learning curve.

# METHODS

Trainees were first to sixth year medical students with no previous laparoscopic experience. Students with extensive suturing experience were excluded. To show an improvement of 25 per cent in use of forces, the sample size for this study was calculated to be 24 trainees in each group based on the results of a pilot study[8].

Because novices have to adjust to all of the challenges that minimally invasive surgery poses, such as loss of depth perception and spatial orientation owing to two-dimensional vision[10–12], perceived inversion of movement from the handle to the working end of the instrument (fulcrum effect)[13–15], limited motion freedom because of the use of long rigid instruments[12,15] and loss of haptic feedback due to resistance inside the trocars[6], it was speculated that they would have the greatest advantage of training on tissue handling

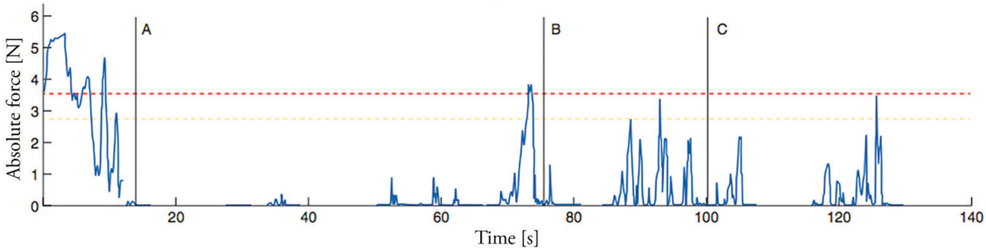


Figure 1. Post processing feedback. The yellow line represents the 75% allowable force limit (2.5 N) and the red line represents the maximal allowable force limit (3.5 N).

after they had had a chance to adjust to the other factors. All participants, therefore, received pretrial training consisting of six suture tasks. No force-related feedback was provided during these pretraining sessions,.

Each participant completed a questionnaire about their personal characteristics (age, sex, dominant hand, year of study), previous experience (games and musical instruments), self-rated dexterity and interest in surgical specialization, measured on a 7-point Likert scale. After the training, they were asked to rate their dexterity and interest in surgical specialization again, and to rate the exercise on level of difficulty and the degree of frustration experienced during the exercise, all on a 7-point Likert scale.

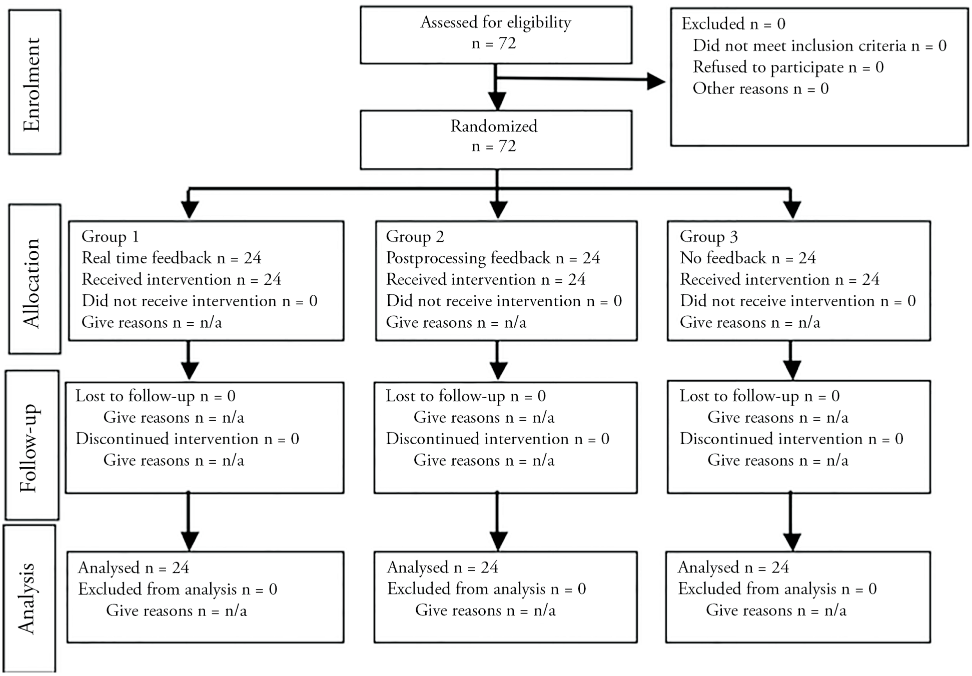


Figure 2. Diagram of randomization.

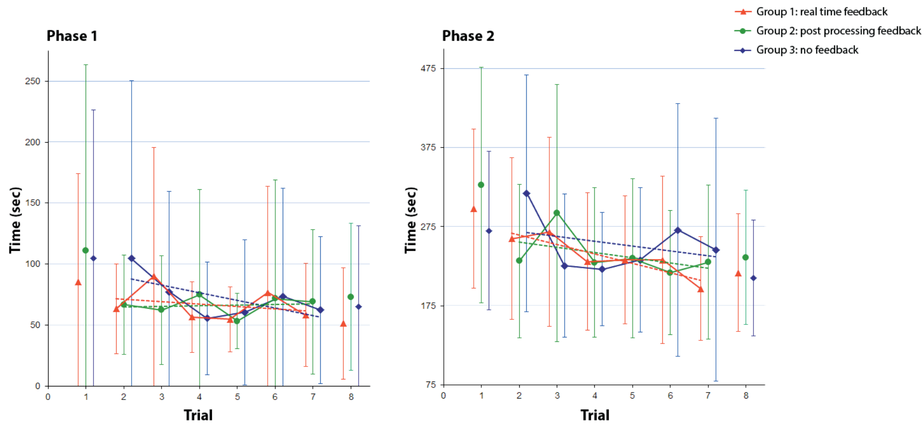



Figure 3. Learning curve for time: a phase 1 and b phase 2. The dotted lines are linear trend lines fitted to the mean data points of training trials 2–7

A similar experimental set-up was used as described in the pilot study[8]. This included a force sensor to measure time and force in laparoscopic box trainers ranging from 0 to 10 N in three dimensions, with an accuracy of 0.1 N and a measurement frequency of 60 Hz. A webcam was used to capture images of the work space of the instruments[8]. A box trainer illuminated to simulate laparoscopic surgery was equipped with two trocars and two needle drivers (Ethicon E705R 5 mm; Johnson & Johnson, Norderstedt, Germany). Artificial tissue (Professional Skin Pad, Mk 2; Limbs & Things, Bristol, UK) was mounted on top of the force platform. All forces exerted by straight laparoscopic instruments on the artificial tissue were measured.

A user interface built in MATLAB displayed the camera image inside a separate screen while data were recorded from the force platform at a rate of 30 Hz. Data were saved in arbitrary units together with a time vector. Because the relationship between the force sensor output and the applied forces in newtons is known after calibration, the output was computed in newtons[5].

Participants were asked to perform a suturing task consisting of two phases: needle-driving and knot-tying. In the first phase, they had to drive a needle (PremiCron® 3/0 braided coated suture with a half-circle round-bodied needle and taper point 26 mm long; B. Braun, Oss, The Netherlands) through the artificial tissue mounted on the force platform, inserting and exiting the needle at predetermined positions (indicated with 2 lines) over a distance of 8 mm. The trainee was then asked to move the left needle driver behind the thread while holding the needle in the right needle driver. The thread was spiralled around the left needle driver twice. With the left needle driver the short end of the thread had to be grasped and pulled over the artificial tissue. Next, the thread was spiralled once around the right needle driver and pulled into a knot. The last action was repeated at the left needle driver, constructing a three-loop knot.

A video of a knot-tying task was shown twice to participants before the pretrial training and before the trial training. During the pretrial training, they also received explanation of the knot-tying task using a schematic figure. In the pretrial training session students executed a series of six knot-tying tasks. Between a minimum of 1 week and a maximum of 2 months, each trainee received subsequent training in which a series of eight suturing tasks were performed consecutively. Trainees received no feedback during the premeasurement (1st trial) and postmeasurement (8th trial) tasks.

Participants were randomized into three groups. Group 1 received real-time force feedback, whereby an arrow was displayed inside the camera image. The arrow represented the magnitude and direction of the force, and increased in size as greater force was applied. At first the arrow was green (representing allowable force). With an increase to 75 per cent of the allowable force it turned yellow (2.5 N), and when the maximum allowable interaction force was exceeded (3.5 N) it turned red to indicate tissue damage. Trainees received explanation on the interpretation of the arrow as described above before and during the trial.

Group 2 received postprocessing feedback. After performing each single knot-tying task, the trainee received feedback in the form of a graph in which task performance was shown. A yellow line represented the 75 per cent of the allowable force limit (2.5 N), and a red line the maximum allowable force limit (3.5 N) (Fig. 1). Individual results were discussed and the trainee was shown when exerted forces were too high during the training. The trainee was reminded to prevent excessive force during the entire task. Group 3 (control) received no feedback on the applied interaction forces.

The mean time to complete the two separate phases was recorded. Two force parameters were used to describe the results: mean force non-zero and maximum force applied. The mean force non-zero was defined as the force averaged across all time points of the task during which force was exerted so that the resulting measure was based only on the times when interaction with the tissue took place (interaction force more than 0.01 N). Maximum force was the highest force applied during that phase.

## Statistical Analyses

Results are reported as mean(s.d.). Statistical analyses were performed using Chi square test and one-way ANOVA for the demographic data, and one-way ANOVA plus Bonferroni post hoc tests for comparisons between the three groups in each phase. Differences between premeasurement (trial 1) and postmeasurement (trial 8) tasks, representing the improvement in a specific parameter, were tested using the paired-samples t test for each group in each phase. $P < 0.050$ was considered statistically significant. Data were analysed by SPSS® version 16.0 (IBM, Armonk, New York, USA).

**Table 1. Trainee characteristics**

| | **Real-time feedback (group 1, n = 24)** | **Postprocessing feedback (group 2, n = 24)** | **No feedback (group 1, n = 24)** | **P†** |
|---|---|---|---|---|
| Age (years) | 21.3(2.4) | 21.3(2.2) | 20.7(1.8) | 0.536 |
| Sex ratio (M : F) | 6 : 18 | 10 : 14 | 11 : 13 | 0.288 †† |
| Mean year of study | 3.42(1.06) | 3.29(1.46) | 3.17(1.40) | 0.807 |
| Time between pretrial training and trial (months) | | | | |
| 1–2 | 11 | 10 | 10 | |
| < 1 | 13 | 14 | 14 | |
| Interest in a surgical specialization* | | | | |
| Before training | 4.63(1.06) | 5.21(1.22) | 4.71(1.12) | 0.176 |
| After training | 4.63(1.10) | 5.26(1.01) | 5.00(1.03) | 0.148 |
| Overall skill* | | | | |
| Before training | 4.50(0.83) | 4.42(1.25) | 4.54(0.83) | 0.906 |
| After training | 4.21(0.98) | 4.43(1.08) | 4.09(1.00) | 0.504 |
| Computer skills* | 3.75(1.19) | 4.12(1.51) | 3.96(1.52) | 0.657 |
| Difficulty of the training* | 5.00(0.83) | 5.30(1.02) | 5.00(0.91) | 0.435 |
| Frustration after the training* | 4.25(1.51) | 4.61(1.56) | 3.61(1.41) | 0.078 |

Values are mean(s.d.), unless indicated otherwise. *Scored on 7-point Likert scale. † One-way ANOVA †† Chi square test.

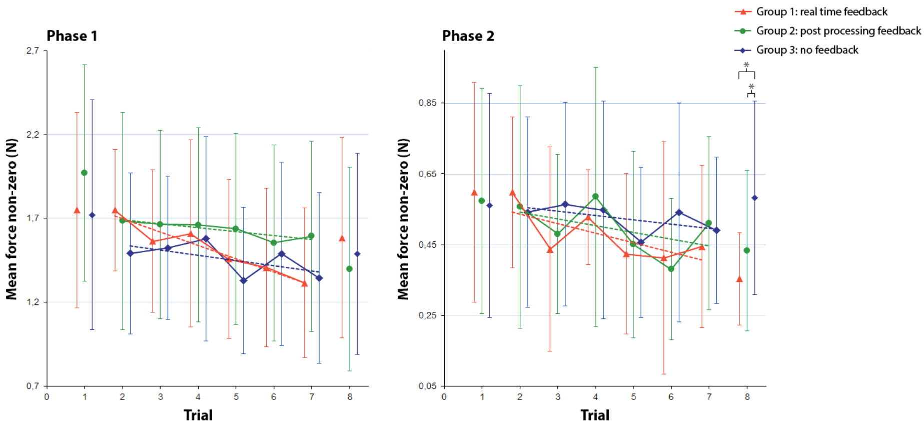



Figure 4. Learning curve for mean force non-zero: a phase 1 and b phase 2. The dotted lines are linear trend lines fitted to the mean data points of training trials 2–7. *P < 0.050 (one-way ANOVA and Bonferroni post hoc test)

# RESULTS

A total of 72 students were randomized (Fig. 2). Their baseline characteristics are shown in Table 1. There were no differences between groups, and no difference in performance between men and women. Trainees with a waiting period of more than 1 month between the pretrial training and the trial were divided between the three groups by randomization. There were no significant differences between the three groups at the start of the training (trial 1, premeasurement), either in time or interaction forces.

The mean time, mean force non-zero and mean maximum force during all trials are shown in Figs 3–5. In general, there were no structural differences measured between the three groups during the intervention (trial 2–7). For the postmeasurement task (trial 8), there were no differences in time or interaction forces during the needle-driving phase. In the knot-tying phase of the postmeasurement task, however, the mean force non-zero of both intervention groups (groups 1 and 2) was significantly lower than that in the control group (group 3). The maximum force in group 1 was significantly lower than that in group 3, but was not significantly different between groups 2 and 3. The mean time taken to complete trial 8 was similar in all three groups.

The improvement in group 1 was mainly seen during the knot-tying phase (Table 2), where time as well as all interaction forces improved significantly. During the needle-driving phase, group 1 alone showed a significant improvement in time. The interaction forces in phase 1 did not show any improvement. Group 2 improved significantly in all

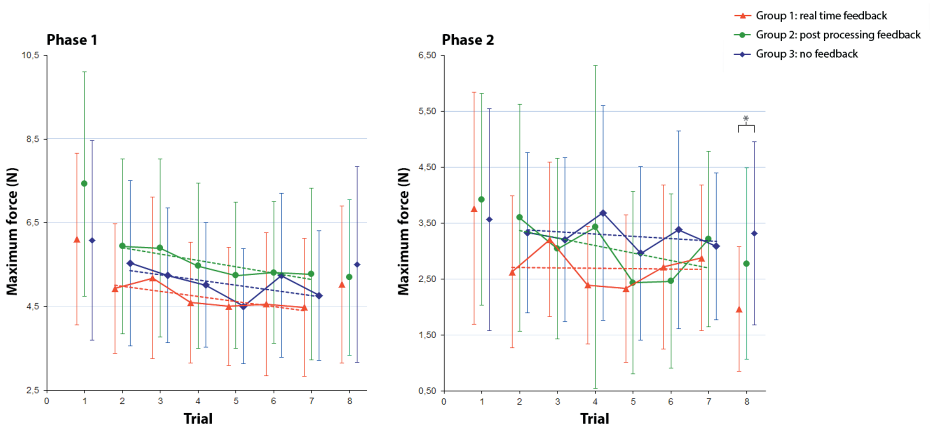



Figure 5. Learning curve for maximum force: a phase 1 and b phase 2. The dotted lines are linear trend lines fitted to the mean data points of training trials 2–7. *P < 0.050 (one-way ANOVA and Bonferroni post hoc test)

parameters during both phases, except for time during the needle-driving phase. Group 3 showed no improvement, except in time during the knot-tying phase.

# DISCUSSION

Feedback about interaction forces has been shown to facilitate training of tissue-handling skills in novices[8,9]. The aim of this study was to determine whether training with real-time visual force feedback or postprocessing force feedback influenced the tissue-handling learning curve. Significant differences were found in force parameter outcomes between the pre- and post-tests of the intervention groups that received post-test and real-time feedback during training. There were no meaningful differences in interaction forces between either of the intervention groups and the control group during the training, when feedback was given (trial 2–7).

Data for the training session alone suggest no added value of either type of feedback on interaction forces during training. However, during the knot-tying phase of the postmeasurement, both intervention groups used significantly lower interaction forces than the control group. This improvement by the two intervention groups, not seen in the control group, implies a learning curve in tissue handling based on the given feedback. Despite there being no difference between the two groups, real-time force feedback means that trainees are able to develop tissue-handling skills without the need for a tutor by their side to give instructions.

| Table 2 Comparison of premeasurement (trial 1) and postmeasurement (trial 8) results | | | | |
|---|---|---|---|---|
| | Trial 1* | Trial 8* | Improvement (%) | P† |
| **Phase 1: needle-driving** | | | | |
| **Group 1** | | | | |
| Time (s) | 86(89) | 52(46) | 40 | 0.040 |
| Mean force non-zero (N) | 1.75(0.58) | 1.59(0.60) | – | 0.230 |
| Maximum force (N) | 6.11(2.04) | 5.03(1.87) | – | 0.056 |
| **Group 2** | | | | |
| Time (s) | 111(153) | 73(60) | – | 0.183 |
| Mean force non-zero (N) | 1.97(0.64) | 1.40(0.61) | 29 | 0.003 |
| Maximum force (N) | 7.43(2.68) | 5.19(1.86) | 30 | 0.001 |
| **Group 3** | | | | |
| Time (s) | 105(121) | 65(66 ) | – | 0.258 |
| Mean force non-zero (N) | 1.72(0.68) | 1.45(0.59) | – | 0.136 |
| Maximum force (N) | 6.08(2.38) | 5.38(2.27) | – | 0.258 |
| **Phase 2: Knot-tying** | | | | |
| **Group 1** | | | | |
| Time (s) | 298(101) | 218(73) | 27 | 0.003 |
| Mean force non-zero (N) | 0.60(0.31) | 0.36(0.13) | 40 | < 0.001 |
| Maximum force (N) | 3.76(2.08) | 1.96(1.09) | 48 | < 0.001 |
| **Group 2** | | | | |
| Time (s) | 328(149) | 234(83) | 29 | 0.010 |
| Mean force non-zero (N) | 0.57(0.32) | 0.41(0.20) | 28 | 0.033 |
| Maximum force (N) | 3.92(1.89) | 2.59(1.51) | 34 | 0.005 |
| **Group 3** | | | | |
| Time (s) | 270(100) | 210(73) | 22 | 0.019 |
| Mean force non-zero (N) | 0.56(0.32) | 0.58(0.27) | – | 0.717 |
| Maximum force (N) | 3.56(1.98) | 3.32(1.64) | – | 0.614 |

*Values are mean(s.d.). Group 1, real-time feedback; group 2, postprocessing feedback; group 3, no feedback. †Paired-samples t test.

All participants in this study were surgical novices who received pretrial training in which they performed six intracorporeal sutures without any force-related feedback. This might have influenced the effect seen on the learning curve, leading to an underestimation of the effect of visual force feedback during training. The difference in time between the pretrial training session and the session in this study varied between 1 week and 2 months owing to the capacity of the skills laboratory and limited hours of the instructor who took the measurements during the pretrial training session. Although a previous study[16] showed that tissue-handling skills can diminish after 1 month, randomization resulted in no differences between the three groups in time between the pretrial training and the study itself, so this effect was likely to be similar in each group.

Before the start of the study it was speculated that the novices should have some insight into the altered depth perception, the fulcrum effect and the use of long, rigid instruments in order for them to be able to focus completely on tissue handling. These are all factors that the novice surgeon must appreciate before tissue handling, so the present experimental design attempted to reproduce this. It is accepted, however, that these factors could influence the trainee's tissue-handling skills. If novices had passed through the steepest part of their learning curve because they had already learned to adjust to depth perception, the fulcrum effect and the use of long, rigid instruments before start of the trial, this would obviously affect the learning curve measured in the present study. It may be that the learning curve for fine-tuning tissue handling is much longer than the eight trials measured in this study. Other studies investigating the learning curves for suturing or knot-tying have identified an exponential decline in knotting time and increase in knot quality, mainly achieved after 20–30 knots[17], and a suturing learning curve that reaches a plateau after 8 days of training, with a total training time per individual of 24 h[18].

Previous studies[19,20] have shown a benefit of short regular training over massed practice for simple as well as complex laparoscopic training tasks. They suggest that in learning difficult skills, such as laparoscopic techniques, cerebral processing saturates rapidly and concentration diminishes. Fatigue then limits further learning. In the present study, novices performed eight suturing tasks consecutively. This protocol might have limited learning owing to fatigue, although the effect should be similar in the three groups.

Based on the pilot study[8] it was expected that there would be a difference in the interaction forces used during the needle-driving phase, in favour of the feedback groups. No relative or absolute differences between the three groups were found, however. The most likely reason is that the task performed in this study (complete suture task) was more complex than the needle-driving task alone used in the pilot study. As needle-driving in this study was only a part of the total task, it seems that trainees were satisfied when the needle had been driven through the tissue successfully and then focused on the more complex knot-tying part of the task. Because the complete suture task requires a larger cognitive component than the needle-driving task alone, it is likely that a greater focus on forces exerted on the needle during the short needle-driving phase results in a greater reduction in force, as shown previously[8]. This suggests that complex tasks should be divided into smaller, simpler tasks, which are trained individually to create optimal learning circumstances.

Learning motor skills involves cognitive, associative and autonomous stages: the trainee tries to understand different steps of the task; practices the skill, integrating the knowledge of the task into the appropriate motor behaviour; and then the skill is performed without cognitive awareness[21]. Feedback is thought to play a major role in the first two stages, but especially during the associative phase. It is during these stages that real-time visual force feedback should be incorporated into laparoscopic skills training. In the autonomous stage, force parameters could still be measured as ways of assessing the level of the trainee, for example as part of an examination.

Trainees who practise exercises that mimic clinical situations seem to have better clinical outcomes than those who are not trained[22]. Regarding tissue-handling skills specifically, a previous study showed that acquired tissue manipulation skills learned with visual force feedback are transferrable to a different task[9]. Making trainees aware that high exerted forces in a box trainer are related to errors in surgical performance allows them to adjust and improve their technique, and this is likely to be beneficial in clinical surgery. Future research might include other outcome measures related to the strength of the knot, tension of the loop and tear of the tissue as indicators of the quality of the suture performed.

## ACKNOWLEDGMENTS

The authors would like to thank all participants and Gertjan Hultzer en René Rodenburg from the skillslab of the Leiden University Medical Center for providing all necessary facilities to perform this study.

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Submitted