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## *Medicine Meets Virtual Reality 14*

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# Real-time Augmented Feedback Benefits Robotic Laparoscopic Training

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**Abstract.** Robotic laparoscopic surgery has revolutionized minimally invasive surgery for treatment of abdominal pathologies. However, current training techniques rely on subjective evaluation. There is a lack of research on the type of tasks that should be used for training. Robotic surgical systems also do not currently have the ability to provide feedback to the surgeon regarding success of performing tasks. We trained medical students on three laparoscopic tasks and provided real-time feedback of performance during training. We found that real-time feedback can benefit training if the feedback provides information that is not available through other means (grip force). Subjects that received grip force feedback applied less force when the feedback was removed. Other forms of feedback (speed and relative phase) did not aid or impede training. Secondly, a relatively short training period (10 trials for each task) significantly improved most objective measures of performance. We also showed that robotic surgical performance can be quantitatively measured and evaluated. Providing grip force feedback can make the surgeon more aware of the forces being applied to delicate tissue during surgery.

**Keywords:** robotic surgery, da Vinci, training, real-time feedback, haptic

## Introduction

The advent of robotic surgical systems, such as the da Vinci Surgical System (dVSS, Intuitive Surgical, Inc., Mountain View, CA), have overcome some of the limitations of manual laparoscopy. The addition of three-dimensional visualization has provided depth perception [1], while wrist-like articulations of the instruments have also been shown to improve surgeons' dexterity [2, 3]. Tremor abolition and motion scaling have been shown to enhance dexterity when using robotic systems [3]. Regarding training, the coordinated hand and instrument movements have improved the training time of residents [4-6], with fewer errors committed and less time taken for surgical task completion [3, 7-10].

However, there is a lack of research on what type of tasks should be used to properly train surgeons. A universal training protocol is absent and proficiency in using robotic systems is judged subjectively. Furthermore, current robotic systems do not have the ability to provide any feedback to the surgeon regarding the success of

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performing the task. Such feedback mechanisms could be especially beneficial for training with robotic systems. In the Motor Learning discipline, it has been repeatedly shown that external or augmented feedback is essential for skill acquisition [11-14]. Our goal was to investigate the use of real-time augmented visual feedback to improve training and performance while performing three different surgical tasks with the dVSS.

## 1. METHODS AND MATERIALS

### 1.1. *Subjects*

Twelve right-handed novice users of the dVSS, which were medical students ( $23.2 \pm 0.6$  yrs) of the University of Nebraska Medical Center, gave consent to participate in accordance with university guidelines.

### 1.2. *Tasks*

Subjects performed three tasks (Figure 1): bimanual carrying (BC), needle passing (NP), and suture tying (ST). In the BC task, subjects simultaneously picked up two 15 x 2 mm rubber pieces (one each with left and right graspers) from 30 mm (diameter) metal caps and placed them in two other metal caps 50 mm away. The subjects repeated the movement 6 times in succession. In the NP task, they passed a 26 mm surgical needle through 6 holes in a latex tube. In the ST task, they tied two knots with a 100 mm x 0.5 mm suture around one of the holes in the latex using the intracorporeal knot. All tasks were cyclic and designed to mimic actual laparoscopic surgical tasks that require significant bimanual coordination.

### 1.3. *Experimental protocol*

The subjects were randomly assigned to one of four feedback groups: speed (SP), grip force (GRIP), relative phase between left and right grasper movement (RP), and control (CTRL). Speed feedback was presented as two green vertical bars (left and right arm). When the speed increased, the bar enlarged vertically. Similarly, grip force feedback (or haptic feedback) was presented as two red vertical bars. Relative phase was presented as a red circular dial with a moving needle. The needle pointed to the right for an in-phase ( $0^\circ$ ) relationship and to the left for an out-of-phase ( $180^\circ$ ). When the right and left grasper moved in the same direction and with the same speed, then we had an in-phase relationship between the two sides. The opposite is an out-of-phase relationship. Part of the dial was shaded green indicating the desired relative phase for the task as calculated from expert data from a previous experiment.

All subjects performed the 3 tasks for 3 pre-training trials (PRE), 10 training trials with feedback, and 3 post-training trials (POST). Prior to PRE trials, subjects were given verbal instruction on how to complete the task. Subjects were not allowed to practice before the experiment. Speed, grip force, and relative phase feedback were displayed visually in real-time during the training trials using a custom program written in Labview (National Instruments, Inc., Austin, TX). The feedback was overlaid on the visual display of the dVSS surgeon's console so subjects were able to see the feedback

while performing the tasks. The control group received no real-time feedback during the training trials.

#### 1.4. Data Collection and Analysis

Position and velocity of dVSS instruments were collected at 75 Hz. Eight dependent variables were analyzed for differences in performance with training: time to task completion (TTC in sec), distance traveled (**D** in mm), mean speed (**S** in mm/sec), grip force (**F**), median curvature ( $\kappa_{med}$  in  $\text{mm}^{-1}$ ), 95% confidence intervals of curvature ( $\kappa_{CI}$  in  $\text{mm}^{-1}$ ), mean relative phase ( $\Phi_{mean}$  in deg), and standard deviation of relative phase ( $\Phi_{SD}$ ). **D**, **S**, **F**,  $\kappa_{med}$ , and  $\kappa_{CI}$  were measured for right and left grasper. **F** was provided by the dVSS Application Programmer's Interface and is a unitless measure related to force applied by the graspers of the robot. Relative phase measured the coordination between the right and left grasper ( $0^\circ$  = in phase,  $180^\circ$  = out of phase). Group means were compared using two-way mixed ANOVAs, with condition (PRE, POST) as the within factor and feedback (SP, GRIP, RP, CTRL) as the between factor. Post-hoc pairwise comparisons with Bonferroni corrections were performed when factors were significant. All values reported are mean  $\pm$  std. error. The statistical analysis was performed for each task and dependent variable.

## 2. RESULTS

### 2.1. *Bimanual Carrying*

Condition (PRE vs POST): TTC was significantly shorter POST training ( $p < 0.0005$ ; Table 1). Right and left **S** were both significantly faster POST training ( $p < 0.0005$ ). Right and left **F** were both significantly lower POST training (R:  $p < 0.0005$ , L:  $p = 0.016$ ). Right and left  $\kappa_{med}$  were significantly smaller POST training indicating straighter movements (R:  $p = 0.004$ , L:  $p = 0.004$ ). Right and left  $\kappa_{CI}$  were significantly smaller POST training indicating less varying curvature (R:  $p < 0.0005$ , L:  $p = 0.001$ ). **D**,  $\Phi_{mean}$  and  $\Phi_{SD}$  were not significantly different.

Feedback (SP vs GRIP vs RP vs CTRL): Right **F** was significantly different between groups ( $p = 0.003$ ), and specifically significant smaller (0.193 units) for GRIP as compared to SP. Right and left  $\kappa_{CI}$  were significantly different between groups (R:  $p = 0.021$ , L:  $p = 0.009$ ), with right  $\kappa_{CI}$  significantly greater ( $0.125 \text{ mm}^{-1}$ ) for GRIP as compared to RP, and with left  $\kappa_{CI}$  significantly greater ( $0.070 \text{ mm}^{-1}$ ) for GRIP as compared to CTRL. All other measures were not significantly different.

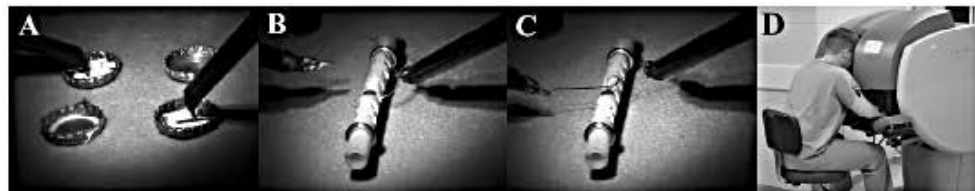


Figure 1: Experiment Setup. A) Bimanual Carrying. B) Needle Passing. C) Suture Tying. D) Subject seated at surgeon's console of dVSS.



Task	Mean Difference (PRE-POST)						
	TTC	Right D	Left D	Right S	Left S	Right F	Left F
BC	19.4 *	-42.5	-21.6	-11.52 *	-11.93 *	0.059 *	0.033 *
NP	42.4 *	296.3 *	154.6 *	-2.39 *	-3.93 *	0.066 *	-0.005
ST	60.5 *	532.7 *	531.5 *	-6.55 *	-5.31 *	0.086 *	0.07 *
	R. $\kappa_{med}$	L. $\kappa_{med}$	R. $\kappa_{CR}$	L. $\kappa_{CR}$	$\Phi_{mean}$	$\Phi_{SD}$	
BC	0.40 *	0.28 *	0.093 *	0.048 *	1.90	-0.036	
NP	0.24 *	0.99 *	0.008	0.164 *	-14.49	0.099	
ST	0.53 *	0.49 *	0.058 *	0.018	-9.18	-0.158 *	

Table 1: Within subject pairwise comparisons between conditions for all tasks and dependent variables. Mean differences are shown as PRE – POST. \* indicates significance at the  $p=0.05$  level.

**Interaction effects:** Interaction effects show if types of feedback affected condition performance in a different manner. Right and left D had significant interaction effects (R:  $p=0.02$ , L:  $p=0.05$ ). For both, the SP group traveled farther POST training as compared to other feedback groups. Left S also had a significant interaction effect ( $p=0.042$ ). The SP group moved faster POST training as compared to other feedback groups. Right and left F had significant interaction effects (R:  $p=0.003$ , L:  $p=0.004$ ). In both cases, F was significantly smaller POST training for the GRIP group as compared to other feedback groups (Figure 2). No other interactions were found.

## 2.2. Needle Passing

**Condition (PRE vs POST):** TTC was significantly shorter POST training ( $p<0.0005$ ; Table 1). Right and left D were significantly smaller POST training (R:  $p<0.0005$ , L:  $p=0.001$ ). Right and left S were both significantly faster POST training ( $p<0.0005$ ). Right F was significantly lower POST training ( $p<0.0005$ ). Right and left  $\kappa_{med}$  were significantly smaller POST training indicating straighter movements (R:  $p=0.001$ , L:  $p<0.0005$ ). Left  $\kappa_{CR}$  was significantly smaller POST training indicating less varying curvature ( $p<0.0005$ ). Left F, right  $\kappa_{CR}$ ,  $\Phi_{mean}$  and  $\Phi_{SD}$  were not significantly different.

**Feedback (SP vs GRIP vs RP vs CTRL):** TTC was significantly different between groups ( $p=0.037$ ). RP took significantly more than CTRL. Right D was significantly different between groups ( $p=0.011$ ), with being significantly smaller for GRIP and SPEED as compared to RP. Right and left S were significantly different between groups (R:  $p=0.017$ , L:  $p=0.024$ ). Right S was significantly faster for CTRL as compared to GRIP. Left S was also significantly faster for CTRL as compared to GRIP. Right F was significantly different between groups ( $p=0.017$ ). Right F was significant smaller for GRIP as compared to SP. Right and left  $\kappa_{med}$  were significantly different between groups (R:  $p=0.041$ , L:  $p=0.041$ ). Right  $\kappa_{med}$  was significantly greater for GRIP as compared to CTRL. Left  $\kappa_{med}$  was significantly greater for GRIP as compared to CTRL. Right and left  $\kappa_{CR}$  were significantly different between groups (R:  $p=0.003$ , L:  $p=0.001$ ). Right  $\kappa_{CR}$  was significantly smaller for CTRL and RP as compared to GRIP. Left  $\kappa_{CR}$  was significantly smaller for CTRL and RP as compared to GRIP. All other measures were not significantly different between groups.

**Interaction effects:** Right and left F had significant interaction effects (R:  $p=0.006$ , L:  $p=0.027$ ). In both cases, F was significantly smaller POST training for the GRIP group as compared to other feedback groups (Figure 2). Right  $\kappa_{CR}$  had a significant

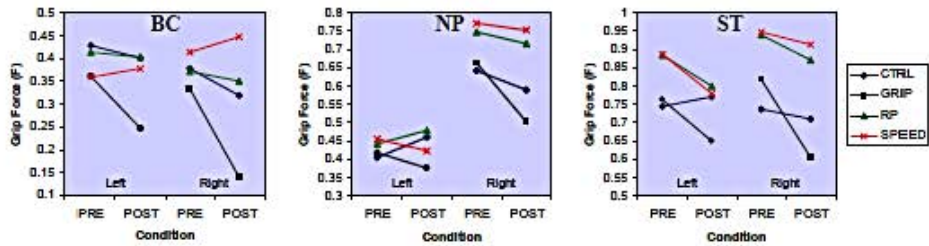


Figure 2: Interaction effect of Right and Left F during the BC, NP, and ST tasks. F is significantly smaller POST training for the GRIP feedback group compared to all other feedback groups.

interaction effect ( $p=0.041$ ). GRIP made more varied movements POST training than other groups. No other measures had interaction effects.

### 2.3. Suture Tying

Condition (PRE vs POST): TTC was significantly shorter POST training ( $p<0.0005$ ; Table 1). Right and left D were significantly smaller POST training (R:  $p=0.001$ , L:  $p<0.0005$ ). Right and left S were both significantly faster POST training ( $p<0.0005$ ). Right and left F were significantly lower POST training (R:  $p=0.001$ , L:  $p=0.001$ ). Right and left  $\kappa_{med}$  were significantly smaller POST training indicating straighter movements ( $p<0.0005$ ). Right  $\kappa_{CI}$  was significantly smaller POST training indicating less varying curvature ( $p=0.003$ ).  $\Phi_{SD}$  was significant larger POST training indicating more varied coordination patterns. Left  $\kappa_{CI}$  and  $\Phi_{mean}$  were not significantly different.

Feedback (SP vs GRIP vs RP vs CTRL): Right F was significantly different between groups ( $p=0.001$ ). Right F was significant smaller for CTRL and GRIP as compared to RP, and also for CTRL and GRIP as compared to SP. Right and left  $\kappa_{CI}$  were significantly different between groups (R:  $p=0.002$ , L:  $p=0.029$ ). Right  $\kappa_{CI}$  was significantly larger for GRIP and SP as compared to RP. Left  $\kappa_{CI}$  was significantly larger for CTRL as compared to RP. No other significant differences were found.

Interaction effects: Right F had significant interaction effects ( $p=0.026$ ). Right F was significantly smaller POST training for the GRIP group as compared to other groups (Figure 2). No other measures had interaction effects.

## 3. CONCLUSIONS

This study has shown that real-time augmented feedback during training can impact surgical performance based on the type of feedback given. It has been found previously that augmented feedback aids performance when task-intrinsic feedback (naturally-occurring sensory feedback) is not available [12, 14]. Particularly, grip force feedback, which is not directly available to the subject, reduces the forces applied while performing each task even after feedback is removed. All tasks showed a significant decrease in grip force after training for subjects that received grip force feedback while other feedback groups did not significantly decrease grip force after training. Thus, it is important for surgeons to be aware of the amount of force being applied to tissue so as not to damage the tissue during surgery. Grip force feedback during training may be an



effective means to train the surgeon to use sufficient force. Furthermore, feedback seems to be parameter specific, as grip feedback revealed better results for grip force. It is possible that there is a need for variable feedback mechanisms based on the surgical task being performed.

Nearly all performance measures significantly improved post-training. Other studies have shown that residents can be trained faster on robotic surgery as compared to manual laparoscopy [4-6]. These studies attribute the faster learning to the intuitive movements of the dVSS; that is, the grasper movements match the hand movements. In addition, our study demonstrated that these performance improvements can be the result of relatively little training (10 trials per task).

We found that real-time feedback for robotic laparoscopic training can benefit robotic surgical training. Real-time haptic (force) feedback proved most beneficial and may reduce tissue injury. A relatively short training period is required to gain this added benefit. Future work will confirm that these subjects retain the skills learned after several weeks of no training. Furthermore, the quantitative improvements that we observed will be correlated with subjective evaluation by an expert robotic surgeon.

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