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ABSTRACT:

The goal of this study was to enhance robotic surgical training via real-time augmented visual feedback. Thirty novices (medical students) were divided into 5 feedback groups (speed, relative phase, grip force, video, and control) and trained during 1 session in 3 inanimate surgical tasks with the da Vinci Surgical System. Task completion time, distance traveled, speed, curvature, relative phase, and grip force were measured immediately before and after training and during a retention test 2 weeks after training. All performance measures except relative phase improved after training and were retained after 2 weeks. Feedback-specific effects showed that the speed group was faster than other groups after training, and the grip force group applied less grip force. This study showed that the real-time augmented feedback during training can enhance the surgical performance and can potentially be beneficial for both training and surgery.

Keywords: robotic surgery; performance; training; feedback

The advent of robotic surgical systems, such as the da Vinci Surgical System (dVSS, Intuitive Surgical, Inc, Sunnyvale, Calif), have revolutionized laparoscopic surgery by the addition of 3-dimensional visualization,[1] increased dexterity,[2,3] and tremor abolition and motion scaling.[3] As of 2000, there were more than 100 dVSS systems worldwide.[4] There are now more than 700 systems worldwide.[5] As of January 2001, it was estimated that the dVSS had been used to perform more than 2000 surgeries and that number is rising rapidly.[6] At our clinical facility alone, 204 laparoscopic procedures have been performed using the dVSS as of February 2005. According to hospitals that responded to a survey, 45% of dVSS procedures are cardiac, 33% are urologic, 11% are general surgery, 7% are gynecologic, and 4% are pediatric.[7] Therefore, there is a clear need to establish standardized training and evaluation for robotic laparoscopic surgery because of the growing prevalence of dVSS procedures.

Previously, we have developed quantitative measures to assess robotic surgical proficiency.[8-10] However, as quantitative measures are used to measure and assess performance during training, reduced feedback from expert mentors may actually impede skill acquisition. The most likely mechanism of surgical skill acquisition when a mentor is not present is discovery learning. Rather than showing the optimal solution for completing a task, the individual will try a variety of strategies to identify the best strategy.[11] Simplifying the learning environment (ie, simple surgical tasks) is one method in which learning can be facilitated. A second method is to provide augmented feedback.

In multiple disciplines, augmented feedback has been shown (including spinal cord injury and stroke rehabilitation) to be a useful tool in providing feedback and improving the performance.[12-17] Augmented feedback is designed to provide an additional feedback (visual, auditory, or otherwise) to an individual to help in controlling a particular aspect of a movement. The feedback provides information about internal physiological events, such as joint displacement, muscle activity, or force production. For example, in a study by Vander Linden et al,[13] subjects learned to control the amount of isometric force production during an isometric elbow extension task when given visual feedback. Shumway-Cook et al[17] also found that visual feedback was effective for retraining postural sway in stroke patients. However, augmented feedback has not been investigated as a means of enhancing training and surgical performance during robotic laparoscopic surgery. Furthermore, current robotic systems do not have the ability to provide any feedback to the surgeon regarding the success of performing the task. Such feedback mechanisms could be especially beneficial for training with robotic systems.

The goal of this study is to investigate the use of real-time augmented visual feedback to improve training and performance when executing 3 different surgical tasks using the dVSS. A real-time augmented feedback interface was developed and investigated as a means to enhance training during robotic surgical training tasks. We hypothesized that the subjects who will receive real-time augmented feedback will improve the performance in a greater extent. Specifically, we hypothesized that augmented visual feedback can improve the robotic surgical performance if the feedback is meaningful and supplementary, that is, the feedback provides information that is unavailable through inherent sensory information or feedback could not be perceived by vision and proprioception if the augmented visual feedback is not present.

Methods and Materials

Subjects

Thirty novice users (first- and second-year medical students; 25 ± 5.1 years of age) of the dVSS were recruited to participate in this study. Novice users had no prior experience using the dVSS. All participants were right-handed. Informed consent was obtained from each subject before participation in accordance with the Institution Review Board of the University of Nebraska Medical Center.

Tasks

Subjects performed and/or practiced 3 tasks using the dVSS throughout this study: bimanual carrying (BC), needle passing (NP), and suture tying (ST). The BC task required simultaneously picking up of 2 rubber pieces that are 15 × 2 mm in size (1 each with left and right graspers) from 30-mm (diameter) metal caps and placing them in 2 other metal caps 50 mm away (Figure 1A). The caps were arranged in a square configuration such that the left graspers removed pieces from the top left cap and placed them in the bottom left cap. The right grasper removed pieces from the bottom right cap and placed them in the top left cap. The subjects repeated the movement 6 times in succession. The NP task required passing a 26-mm surgical needle through 6 holes in a latex tube (Figure 1B). Subjects started from the proximal holes and proceeded to the distal. The ST task required tying 2 knots with a 100-mm × 0.5-mm surgical suture using the intracorporeal knot (Figure 1C). The subjects performed the tasks by manipulating the dVSS from the surgeon's console (Figure 1D). All 3 tasks were cyclic tasks and were designed to mimic actual laparoscopic tasks that required significant bimanual coordination.

Experimental Protocol

Novices performed 21 trials of each task divided into 4 training blocks (Figure 2): 3 pretraining trials (PRE), 10 training trials with augmented visual feedback, 3 posttraining trials (POST), and 5 retention trials (RET) for each task. Pretraining, training, and POST trials were performed during 1 session. Retention trials were performed 2 weeks after the first session. Task order was randomized between subjects but was the same between training blocks. The last 3 trials of PRE, POST, and RET were used for data analysis. Subjects were not allowed to practice with the dVSS before the experiment.

Subjects were randomly assigned to 1 of 5 feed- back groups: speed (SP, n = 6), grip force (GRIP, n = 6), relative phase between left and right grasper movement (RP, n = 6), video (VID, n = 6), and con- trol (CTRL, n = 6). Real-time augmented feedback was overlaid on the video screen of the surgeon's console using a CORIOgen Eclipse video overlay unit (TV One USA, Erlanger, Ky). Speed feedback was presented as 2 green vertical bars (left and right arm; Figure 3A). When the speed increased, the bar enlarged vertically. Speed has been shown to increase with improved performance.8 Speed feedback provides a means to directly emphasize speed for improved performance. Grip force feedback (or haptic feedback) was presented as 2 red vertical bars (Figure 3B).

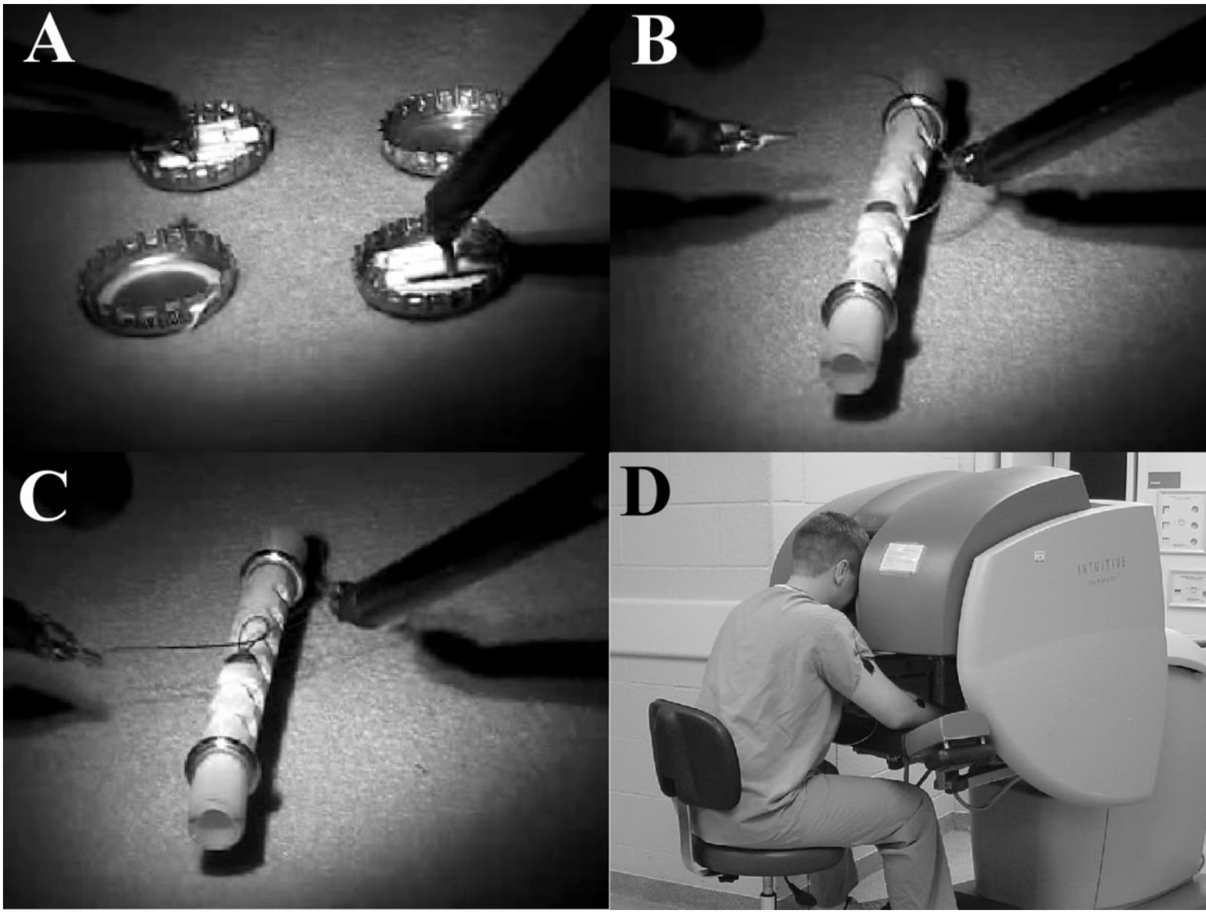

Figure 1. Experimental setup. A, Bimanual carrying. B, Needle passing. C, Suture tying. D, Subject seated at surgeon's console of dVSS.

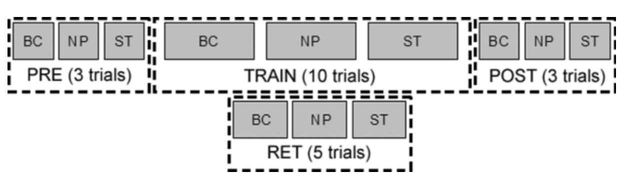

Figure 2. Training paradigm for novices. Each novice performed each task in 3 training blocks: 3 PRE trials, 10 TRAIN trials, and 3 POST trials. Subjects also performed 5 RET trials 2 weeks later. Task order was randomized between subjects but was the same between training blocks. PRE indicates pretraining; TRAIN, training; POST, posttraining; RET: retention.

Previously, it has been shown that subjects learn to control the amount of isometric force contraction when provided with visual feedback.[13] Reduced grip force translates to reduced force applied to delicate tissue that may otherwise damage the tissue.[18,19] Relative phase feedback was presented as a red circular dial with a moving needle (Figure 3C). The needle pointed to the right for an inphase (0°) relationship and to the left for an out-of-phase (180°) relationship. When the right and the left grasper moved in the same direction and with the same speed, it is considered to be an inphase relationship. The opposite is an out-of-phase relation- ship. Part of the dial was shaded green indicating the desired relative phase for the task as calculated from expert data from a previous experiment. Furthermore, coordination training via visual feedback has been used to improve the stability of the coordination pat- terns.[20] When performing each task, the video feedback group watched prerecorded video of an expert with more than 5 years of experience using the dVSS. Subjects watched at least 3 trials of each task but were allowed to watch the videos as many times as they preferred throughout the training trials. The control group received no additional feedback during the training trials.

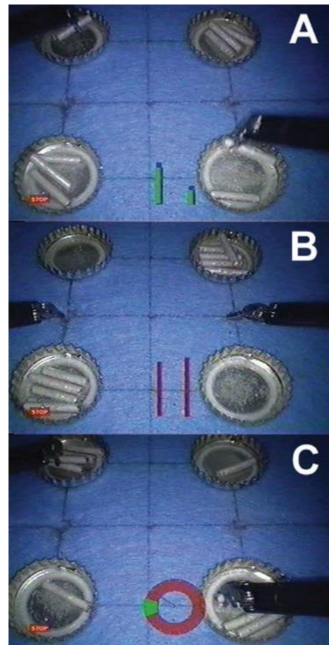

Figure 3. Real-time augmented feedback. A, Speed feedback is presented as 2 (left and right) vertical green bars. B, Grip force feedback is presented as 2 (left and right) vertical red bars. C, Relative phase feedback is presented as a dial and needle with a shaded green area (inphase to the right; out-of-phase to the left pictured) indicating the desired relative phase.

Data Analysis

All objective measures of performance were based on kinematic measures of the instrument tips of the dVSS. Kinematics of the dVSS were collected using the Application Programmer's Interface (API) provided by Intuitive Surgical, Inc (Sunnyvale, CA). A custom LabView (National Instruments, Inc, Choncord, Mass) program was written to interface to the dVSS via an Ethernet connection. Data was streamed at approximately 75 Hz (determined by API). All postprocessing of data were performed in MATLAB 6.5 (Mathworks, Inc, Natick, Massachusetts). All kinematic data were down sampled to 5 Hz using a cubic spline to enforce a constant sampling rate between data points. Variables of interest streamed from the API were position (x, y, and z location) of the right and left instruments tips and the grip force applied by the left and right grasper.

Before the collection of the data for the training tasks, a local coordinate system was defined for all kinematics (x-left/right, y-forward/backward, z-up/down). This was necessary to provide real-time augmented visual feedback (discussed previously). All measurements computed from the robot kinematics were calculated from position, velocity, and acceleration of the instrument tips. All measurements were calculated for the left and right instruments (or graspers) unless noted. Velocity and acceleration of the instrument tips were directly calculated by computing the first and second derivatives of the positions of the instrument tips, respectively.

Objective Measures

The objective performance measures were time to task completion (TTC), total distance traveled (D), speed (S), curvature (κ), grip force (F), and relative phase (Φ). Time to task completion is the time required to complete a given training task. Start and end time were identified as the time when the instrument tips were within 1 cm of the starting positions. Total distance traveled is the sum of Euclidean distances between each time sample. Speed is calculated as the magnitude of the velocity. The mean (S_{mean}) and standard deviation (S_{std}) of S were calculated for each trial.

Curvature measures the straightness of the path and is calculated at each point on the path by the following equation[21,22]:

$$\kappa = \frac{|\dot{r} \times \ddot{r}|}{|\dot{r}|^3} \quad (1)$$

where $\dot{r}$ is the velocity of a point *r* on the 3-dimensional path, and $\ddot{r}$ is the acceleration of point *r.* The median (κ_{med}) and 95% confidence interval (κ_{cl}) were calculated for each trial. The 95% confidence interval was calculated as defined by Campbell and Gardner.[23]

Relative phase was calculated to determine the coordination of the instrument tips in the dominant direction of movement (x for NP and ST, *y* for BC; tasks are described in the next section). It is measured as the difference in the phase angle between the left and right instrument as given in the following equation24:

$$\Phi = \varphi_A - \varphi_B$$
$$\Phi = \tan^{-1}\left(\frac{\dot{x}_A}{x_A}\right) - \tan^{-1}\left(\frac{\dot{x}_B}{x_B}\right) \quad (2)$$

where φA is the phase angle of point A, φ_B is the phase angle of point B, x_A is the position of point A in the *x* direction, x_B is the position of point B in the *x* direction, $\dot{x}_A$ is the speed of point A in the *x* direction, and $\dot{x}_B$ is the speed of point B in the *x* direction. Note that the atan2 function was used to calculate the inverse tangent in order for φ to range from –π to π. Circular statistics were used to calculate the mean (Φ_{mean}) and standard deviation (Φ_{std}) of relative phase as defined by Stergiou.[24]

Grip force (F) was provided by the dVSS API and represented a percentage of the maximum torque of the servos that drive the graspers. To verify the linearity of the grip force, a force sensing resistor (FSR) was squeezed while measurements from the dVSS and FSR were collected simultaneously. The resistance of the FSR is proportional to the force applied; therefore, grip force could be directly measured. da Vinci Surgical System and FSR grip force measures were compared using a linear regression fit. Right and left grip force measured by the dVSS was very well correlated (R^2 = 0.97 and 0.91, respectively) with FSR measurements. Mean grip force (F_{mean}) was calculated for each trial.

Statistical Analysis

Group means were compared using 2-way mixed analysis of variance (ANOVA), with condition (PRE, POST, RET) as the within-subject factor and feedback group and (SP, RP, GRIP, VID, CTRL) as the between-subject factor at $\alpha = 0.05$. Post hoc pairwise comparisons with Bonferroni corrections were performed when factors were significant. All values reported are mean ± standard error. The statistical analysis was performed for each task and dependent variable. Effects of feedback group are not reported because we were investigating learning effects. Condition effects provide overall learning effects. Interaction effects (feedback X condition) provide learning effects for individual feedback groups.

Results

Bimanual Carrying

Condition (PRE *vs* POST *vs* RET). All objective measures except right D and Φ_{std} were significant ($P < .05$; Table 1 and Figure 4). For POST and RET trials, subjects took less time, traveled a shorter distance, were faster and straighter, and used less grip force compared with PRE trials. Also, RET trials were slightly, although significantly, shorter in time, faster, straighter, and used less grip force than PRE trials.

Interaction effects. Time to task completion, right and left S_{mean}, left S_{std}, left κ_{CI}, Φ_{mean}, and right F_{mean} had significant interaction effects for the BC task ($P < .05$; Figure 5). Interaction effects for BC showed that performance improvements were feedback specific. The SP group completed the task in less time and increased speed more than the other groups during the POST trials compared with PRE and continued to increase speed during the RET trials. The GRIP group decreased grip force more than other groups during the POST trials compared with PRE and remained lower during RET trials.

Needle Passing

Condition (PRE *vs* POST *vs* RET). All objective measures except left F were significant ($P < .05$; Table 1 and Figure 4). For POST and RET trials, subjects took less time, traveled a shorter distance, were faster and straighter, and used less grip force compared with PRE trials. Also, RET trials were slightly, although significantly, shorter in time and distance compared with PRE trials.

Interaction effects. Time to task completion, right and left D, right and left S_{mean}, right and left S_{std}, left κ_{med}, left κ_{CI}, Φ_{mean}, Φ_{std}, and right and left F had significant interaction effects for the NP task ($P < .05$; Figure 5). Interaction effects for NP also showed that performance improvements were feedback specific. The SP group completed the task in less time and increased speed more than other groups during the POST trials compared with PRE and continued to increase speed during the RET trials. The GRIP group decreased grip force more than other groups during the POST trials compared with PRE and remained lower (right F) or returned to the level of other groups (left F) during RET trials.

Suture Tying

Condition (PRE *vs* POST *vs* RET). All objective measures except left S_{std}, right and left κ_{CI}, and Φ_{mean} were significant ($P < .05$; Table 1 and Figure 4). For POST and RET trials, subjects took less time, traveled a shorter distance, were faster and straighter, and used less grip force compared with PRE trials. Also, performance was maintained in RET trials compared with POST trials as shown by no significant difference between those conditions.

Table 1. Group means for PRE, POST, and RET during BC, NP, and ST movements for TTC, D, S_{mean}, S_{std}, κ_{med}, κ_{CI}, Φ_{mean}, Φ_{std} and F_{mean}[a]

	TTC	Left D	Right D	Left S_{mean}	Right S_{mean}	Left S_{std}	Right S_{std}	Left κ_{med}	Right κ_{med}	Left κ_{CI}	Right κ_{CI}	Φ_{mean}	Φ_{std}	Left F_{mean}	Right F_{mean}
BC															
PRE	47.0 ± 2.1[bc]	976 ± 16[bc]	866 ± 12	23.1 ± 0.8[bc]	20.7 ± 0.7[bc]	21.9 ± 0.8[bc]	20.7 ± 0.8[bc]	0.17 ± 0.01[bc]	0.22 ± 0.01[bc]	0.10 ± 0.01[bc]	0.16 ± 0.01[bc]	180.5 ± 0.5[bc]	0.45 ± 0.02	0.32 ± 0.01[bc]	0.28 ± 0.01[bc]
POST	31.6 ± 0.9[b]	927 ± 14[b]	851 ± 15	30.8 ± 0.8[bd]	28.2 ± 0.8[bd]	26.3 ± 0.5[bd]	24.8 ± 0.5[bd]	0.10 ± 0.00[b]	0.13 ± 0.01[bd]	0.08 ± 0.01[b]	0.12 ± 0.01[b]	178.3 ± 0.5[b]	0.43 ± 0.02	0.29 ± 0.01[b]	0.24 ± 0.01[b]
RET	29.5 ± 0.8[c]	909 ± 14[c]	839 ± 13	32.7 ± 0.9[cd]	30.2 ± 0.9[cd]	26.8 ± 0.5[cd]	25.6 ± 0.5[cd]	0.10 ± 0.00[c]	0.11 ± 0.01[cd]	0.07 ± 0.01[c]	0.10 ± 0.01[c]	178.8 ± 0.5[c]	0.41 ± 0.01	0.26 ± 0.01[c]	0.24 ± 0.01[c]
NP															
PRE	107.6 ± 5.2[bc]	954 ± 29[bc]	1130 ± 40[bc]	9.4 ± 0.3[bc]	11.1 ± 0.3[bc]	11.1 ± 0.2[bc]	10.6 ± 0.2[bc]	0.64 ± 0.03[bc]	0.40 ± 0.01[bc]	0.30 ± 0.02[bc]	0.15 ± 0.01[bc]	136.1 ± 7.6[c]	1.40 ± 0.05[c]	0.39 ± 0.01	0.53 ± 0.01[bc]
POST	59.9 ± 1.7[bd]	777 ± 19[b]	843 ± 20[bd]	13.0 ± 0.3[b]	14.3 ± 0.4[b]	13.0 ± 0.3[b]	12.7 ± 0.3[b]	0.35 ± 0.01[b]	0.27 ± 0.01[b]	0.19 ± 0.01[b]	0.13 ± 0.01[b]	144.3 ± 7.8	1.27 ± 0.06	0.38 ± 0.01	0.50 ± 0.01[b]
RET	55.7 ± 1.7[cd]	737 ± 16[c]	798 ± 17[cd]	13.2 ± 0.3[c]	14.6 ± 0.4[c]	12.8 ± 0.2[c]	12.7 ± 0.2[c]	0.35 ± 0.01[c]	0.27 ± 0.01[c]	0.19 ± 0.01[c]	0.13 ± 0.01[c]	161.5 ± 6.1[c]	1.13 ± 0.05[c]	0.37 ± 0.01	0.50 ± 0.01[c]
ST															
PRE	100.2 ± 6.6[bc]	956 ± 48[bc]	1051 ± 59[bc]	10.8 ± 0.6[bc]	11.0 ± 0.3[bc]	13.2 ± 1.5[bc]	11.7 ± 0.3[bc]	0.49 ± 0.02[bc]	0.37 ± 0.01[bc]	0.23 ± 0.02	0.15 ± 0.01	−2.0 ± 1.0	1.35 ± 0.03[bc]	0.69 ± 0.01[bc]	0.65 ± 0.01[bc]
POST	41.3 ± 1.8[b]	588 ± 18[b]	686 ± 21[b]	14.7 ± 0.5[b]	17.3 ± 0.5[b]	15.2 ± 0.5[b]	17.5 ± 0.4[b]	0.32 ± 0.02[b]	0.23 ± 0.01[b]	0.23 ± 0.02	0.14 ± 0.01	1.0 ± 3.0	1.54 ± 0.04[b]	0.63 ± 0.01[b]	0.60 ± 0.01[b]
RET	42.7 ± 1.6[c]	620 ± 20[c]	719 ± 23[c]	14.8 ± 0.4[c]	17.5 ± 0.5[c]	15.4 ± 0.4[c]	17.6 ± 0.4[c]	0.32 ± 0.01[c]	0.24 ± 0.01[c]	0.23 ± 0.02	0.15 ± 0.01	−2.4 ± 1.9	1.56 ± 0.03[c]	0.63 ± 0.01[c]	0.61 ± 0.01[c]

NOTE: BC = bimanual carrying; NP = needle passing; ST = suture tying; TTC = time to task completion; D = distance traveled; S_{mean} = mean speed; S_{std} = standard deviation of speed; κ_{med} = median curvature; κ_{CI} = curvature confidence interval; Φ_{mean} = mean relative phase; Φ_{std} = standard deviation of relative phase; F_{mean} = mean grip force; PRE = pretraining trials; POST = posttraining trials; and RET = retention trials.

[a] All values are mean ± standard error.

[b] PRE-POST significantly different ($P < .05$).

[c] PRE-RET significantly different ($P < .05$).

[d] POST-RET significantly different ($P < .05$).

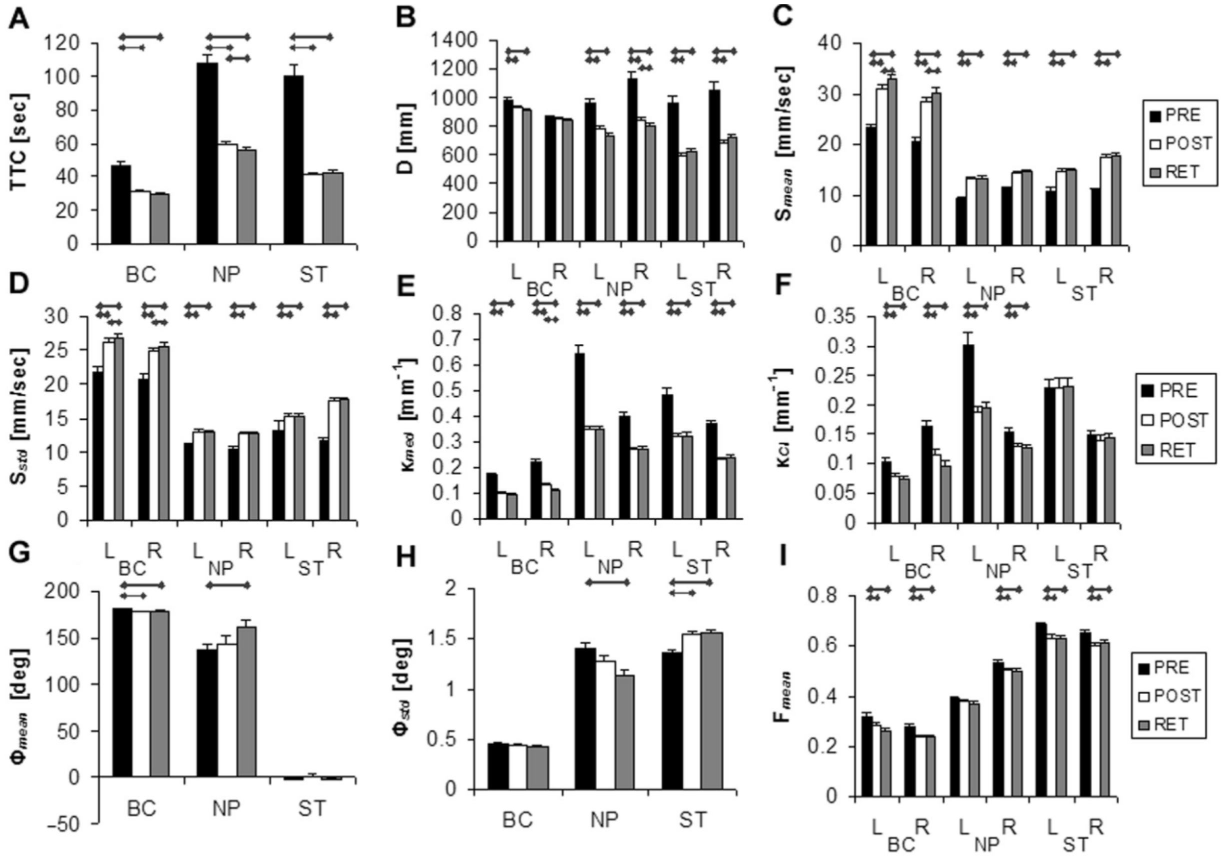

Figure 4. Group means for PRE, POST, and RET during bimanual carrying (BC), needle passing (NP), and suture tying (ST) movements for TTC (time to task completion; A), D (distance traveled; B), S_{mean} (mean speed; C), S_{std} (standard deviation of speed; D), κ_{med} (median curvature; E), κ_{CI} (curvature confidence interval; F), Φ_{mean} (mean relative phase; G), Φ_{std} (standard deviation of relative phase; H), and F_{mean} (mean grip force; I). PRE indicates pretraining; TRAIN, training; POST, posttraining; RET: retention.

Interaction effects. Right S_{std}, Φ_{std}, and right F had significant interaction effects for the ST task ($P < .05$; Figure 5). Even though there were relatively few interaction effects for ST, the performance improvements were feedback specific. Speed variability increased during the POST trials compared with PRE for the SP group. This is indicative of a larger range of speed. The GRIP group decreased grip force more than other groups during the POST trials compared with PRE but returned to the level of the other groups during RET trials.

Summary

In general, when feedback group is not considered (ie, main effect of training), nearly all objective measures improved POST training compared with PRE training and maintained improved performance during RET trials. This overall training effect resulted in subjects completing tasks in less time, shorter distance, faster speed, straighter movements, and less grip force. However, when feedback was considered, the SP and GRIP groups improved more in speed and grip force immediately after training. In some cases, that improvement returned to the same level as other groups during retention, but in other cases, these improvements were maintained. Specifically, the SP group improved speed at a faster rate than other groups, ie, faster during POST training. This improvement continued to increase during RET trials for the BC task but remained the same for the NP task. The GRIP group reduced grip force during POST training compared with other groups, but that reduced grip force was not maintained during RET trials.

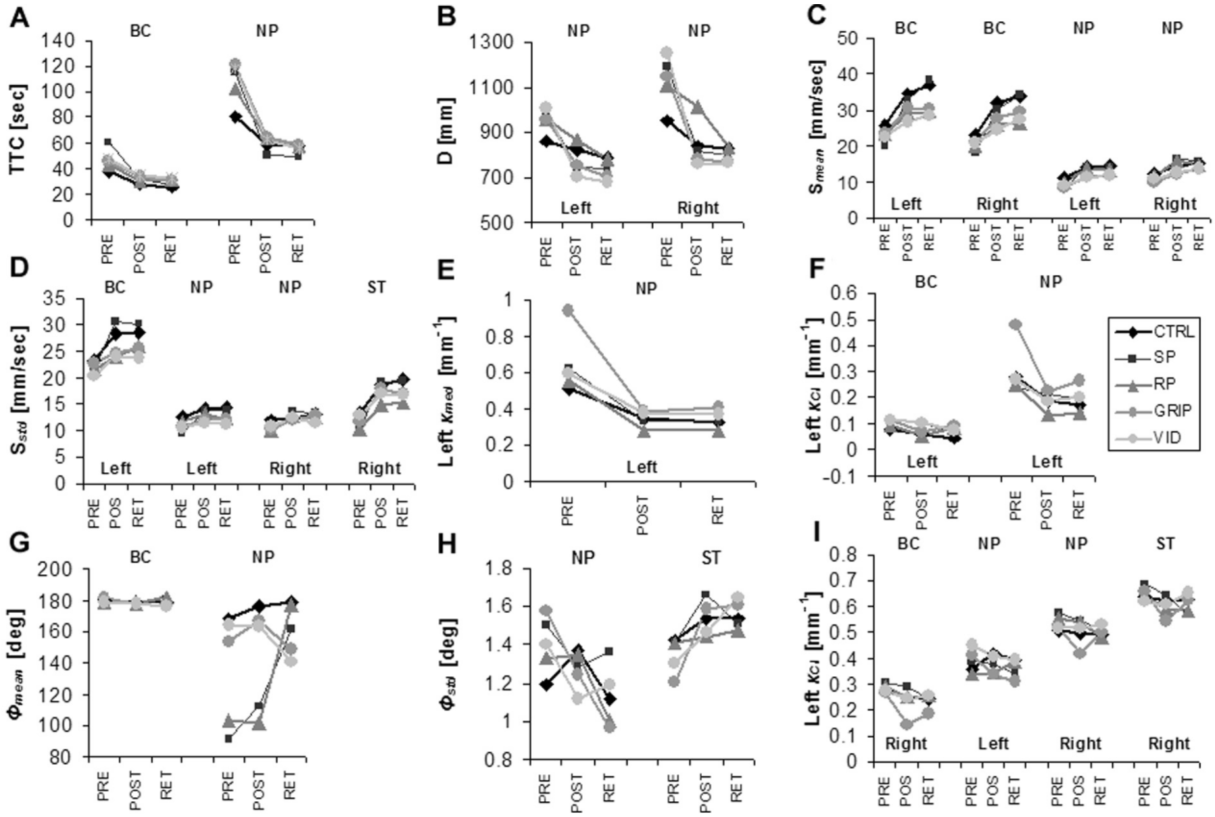

Figure 5. Significant interaction effects during bimanual carrying (BC), needle passing (NP), and suture tying (ST) movements for TTC (time to task completion; A), D (distance traveled; B), S_{mean} (mean speed; C), S_{std} (standard deviation of speed; D), κ_{med} (median curvature; E), κ_{CI} (curvature confidence interval; F), Φ_{mean} (mean relative phase; G), Φ_{std} (standard deviation of relative phase; H), and F_{mean} (mean grip force; I).

Discussion

Nearly all performance measures significantly improved posttraining. Other studies have shown that residents can be trained faster on robotic surgery compared with manual laparoscopy.[3,25,26] These studies attribute the faster learning to the intuitive movements of the dVSS; that is, the grasper movements match the hand movements. This study, as well as our previous work [8,27] (also T.N.J., et al, unpublished data, 2007), found similar results in that performance improvements occurred with relatively little training (10 trials per task).

This study has shown that real-time augmented feedback during training can impact surgical performance based on the type of feedback given. Particularly, grip force feedback, which is not directly available to the subject, can reduce 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 who received grip force feedback, whereas other feedback groups did not significantly decrease grip force after training. However, reduced grip force was not maintained during RET. Previously, it has been found that augmented feedback aids performance when task-intrinsic feedback (naturally occurring sensory feedback) is not available.[12,28] Studies in synesthesia (substituting one sense for another) have also shown that visual feedback can enhance perception of haptic information.[29,30] These studies showed that visual feedback improved force perception of virtual elastic springs. In our study, augmented visual feedback aids performance by making the surgeon aware of the force applied because the dVSS does not inherently provide haptic (force) feedback. 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; however, further training may be necessary to retain performance improvements from grip force feedback. Alternatively, it may be necessary to provide real-time grip force feedback at all times to reduce the risk of injury to tissue during surgery. Further investigation is needed to determine the frequency at which such feedback is needed.

In addition, the speed feedback group significantly increases speed while performing each task. Bimanual carrying and NP tasks showed a significant increase in speed after training for subjects who received speed feedback, whereas other feedback groups increased speed after training but to a lesser extent. The ST task did not show any significant differences in speed compared with other groups. This is likely because of the complexity of the ST task. When subjects were asked whether they felt the feedback was helpful, a common response was they did not pay much attention to it because they were trying to complete the task. During the BC task, the speed feedback group continued to increase speed during RET. The BC task was the simplest task; therefore, it is possible that the subjects quickly learned to accomplish the task and could focus on increasing speed. During the NP task, speed was maintained at the same level during RET as POST. This is probably because of the moderate complexity of the NP task. The speed-accuracy trade-off is a well-known phenomenon in motor control that states that as speed increases, accuracy decreases and vice versa.[11] The required accuracy of the NP task possibly limited the speed of movements.

Other feedbacks (RP and VID) did not benefit or impair the performance compared with the control group (no feedback). Subjects reported that the RP feedback was difficult to control and did not pay attention to it after time. Although the VID feedback may have showed a better technique, this feedback did not have a specific goal (eg, reduce grip force) associated with it. These 2 groups did not differ from the CTRL group in which they all significantly improved performance posttraining and retained that performance level during RET. We previously showed that relatively little training (10 trials of each task) is necessary to improve performance.8 Like other studies that used robotic surgical systems,[3,25,26] these improvements can be attributed to the intuitive control of the dVSS.

Feedback seems to be parameter specific as grip feedback revealed better results for grip force and speed feedback revealed better results for speed. It is possible that there is a need for variable feedback mechanisms based on the surgical task being performed. It was found that real-time feedback for robotic laparoscopic training can benefit robotic surgical training. Furthermore, a relatively short training period is required to gain this added benefit. The speed feedback group maintained or continued improvements in speed 2 weeks after training. However, grip force improvements were not maintained during RET. Further investigation is needed to determine whether an additional training with grip force feedback may help retain performance.

Acknowledgments

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