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Skills learning in robot-assisted surgery is benefited by task-specific augmented feedback

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Abstract

Background: Providing augmented visual feedback is one way to enhance robot-assisted surgery (RAS) training. However, it is unclear whether task specificity should be considered when applying augmented visual feedback.

Methods: Twenty-two novice users of the da Vinci® Surgical System underwent testing and training in three tasks: simple task - bimanual carrying (BC), intermediate task - needle passing (NP), and complex task - suture tying (ST). Pre-training (PRE), training, and Post-training (POST) trials were performed during first session. Retention trials were performed 2 weeks later (RET). Participants were randomly assigned to one of four feedback training groups: relative phase (RP), speed, grip force, and video feedback group. Performance measures were time to task completion (TTC), total distance traveled (D), speed (S), curvature, relative phase and grip force (F).

Results: Significant interaction for TTC and curvature showed that the RP feedback training improved temporal measures of complex ST task compared to simple BC task. Speed feedback training significantly improved the performance in simple BC task in terms of TTC, D, S, curvature and F even after retention. There was also a lesser long-term effect of Speed feedback training on complex ST task. Grip force feedback training resulted in significantly greater improvements in TTC and curvature for complex ST task. For the Video feedback training group, the improvements in most of the outcome measures were evident only after RET.

Conclusions: Task-specific augmented feedback is beneficial to RAS skills learning. Particularly, the RP and grip force feedback could be useful for training complex tasks.

Keywords: concurrent feedback, da Vinci® Surgical System, task-complexity, motor learning

INTRODUCTION

Robot-assisted surgery (RAS) skills learning has been in great demand since the advent of robot-assisted surgical systems like the da Vinci® Surgical System (dVSS; Intuitive Surgical, Sunnyvale, CA). The dVSS has been used in over 1000 facilities world-wide.[1] The advantages of dVSS include seven degrees of freedom at the instrument tip, increased depth perception with three dimensional images[2], increased dexterity[3] and precision[4], decreased surgical residents' training time[5], improved economy of motion for experts[6], enhanced eye–hand coordination, and comfortable seating posture.[7] In spite of these advantages, educating and training novice surgeons to perform RAS has received limited attention.

Providing effective RAS skills learning to novices is both critical and challenging. According to Adam's Closed Loop Theory[8] feedback plays a critical role while learning new skills. When a user performs a task, he/she will get task-intrinsic feedback from his own senses like vision, auditory, proprioception, touch, and vestibular. One of the major limiting factors in the process of educating novice surgeons about RAS is the lack of task-intrinsic touch feedback from the instrument tips at the surgical table while they manipulate their wrists at the console. One of the ways to overcome such limitation is providing the novice with an augmented feedback that could be either concurrent (while performing the procedure) and/or terminal (after performing the procedure). Concurrent feedback, can be provided in terms of speed of movement, the grip force at the console[9,10], or even verbal instructions by the trainer. Terminal feedback can be provided by showing a video of the performance of the subject or of an expert to be used as a model.

In fact, providing augmented visual feedback has been shown to enhance surgical performance in novice surgeons.[11] The benefits of augmented visual feedback for robotic laparoscopic training have been previously reported by our group.[12] Particularly, when novice medical students were provided grip force feedback, they were able to better adjust their grip force during surgical skill training. Judkins and colleagues[13] showed that concurrent augmented feedback during training can also enhance the surgical performance. Particularly, a feedback-specific effect was shown, in which the group that received the speed feedback training was faster than groups that received relative phase, grip force or video feedback after training. Similarly, the grip force feedback group applied less grip force compared to the other three groups. These effects were observed across three kinds of tasks with increasing complexity: bimanual carrying, needle passing and suture tying. However, it is not known if these feedback effects were task-specific, i.e. would these effects be observed for both simple and complex tasks? Previous studies have also not explored if such task-specific feedback effects can be sustained over a retention period. This is essential to estimate true learning effects once the feedback is removed to the novice surgical learner.

Task-specificity of augmented visual feedback could play an essential role in developing optimal training strategies. For example, providing augmented visual feedback while performing simple tasks (e.g. bimanual coordination) could not be as beneficial compared to providing the same feedback while performing a more complex task (e.g. suture tying). Moreover, whether the augmented visual feedback for a particular task will be useful or not will depend on the type of feedback. Hence understanding the relationship between the task-specificity and feedback-specificity in terms of skills learning could play a critical role in designing effective training programs for novice surgeons in RAS.

The purpose of the current study was two-fold. First, we investigated if augmented feedback effects were task-specific (dependent on complexity level of the task). Second, we investigated if such task-specific feedback effects sustained over a 2-week retention period. We hypothesized that the effect of a specific type of feedback was affected by the type of task and this effect was influenced by retention period. We intended to investigate the task-specificity within four different types of feedback but not between the types of feedback as it was reported in our earlier study.[13]

METHODS

This study was approved by the University of Nebraska Medical Center's Institutional Review Board. Details of methodology have been elaborately presented in an earlier study.[11] Briefly, 22 novice users (age: 25±5 years) of the dVSS participated in this study. Participants performed and practiced three tasks using the dVSS throughout this study: simple task - bimanual carrying (BC), intermediate task - needle passing (NP), and complex task - suture tying (ST). Participants performed 21 trials of each task divided into four training blocks (three pretraining trials (PRE), 10 training trials with augmented visual feedback, three posttraining trials (POST), and five retention trials (RET) for each task. Pretraining, training, and posttraining trials were performed during one session. Retention trials were performed two weeks after the first session (Figure 1). Task order was randomized between subjects but was the same between training blocks.

Participants were randomly assigned to one of four feedback groups: 1) relative phase between left and right instrument tips movement (n = 5), 2) speed of instrument tips (n = 5), 3) grip force (n = 6), and 4) video (n = 6). Concurrent augmented feedback was overlaid on the video screen of the participating surgeon's console using a CORIOgen Eclipse video overlay unit (TV One USA, Erlanger, KY). Speed and Grip Force feedback for both arms were presented as 2 colored vertical bars overlaid on the video screen of the surgeon's console. Relative phase feedback was shown using a red circular dial with a moving needle. The needle pointed to the right for an in-phase (0°) relationship and to the left for an out-of-phase (180°) relationship between both the arms. For the relative phase feedback, part of the dial was also shaded green indicating the desired relative phase for the task as calculated from expert data from a previous experiment. While the speed, grip force and relative phase feedback groups obtained concurrent augmented visual feedback, the video feedback group obtained a terminal augmented visual feedback. Participants watched prerecorded video of an expert with more than 5 years of experience using the dVSS as many times as they preferred. It was hypothesized that the video feedback group can compare their own performance from the information provided by their task-intrinsic feedback with the expert's performance provided by the augmented visual feedback. Such an augmented feedback through expert modeling video is believed to teach the learner invariant characteristics of the movement.

Performance measures were time to task completion (TTC), total distance traveled, speed, curvature, relative phase and grip force. A 3 (task: BC, NP, ST) x 3 (Condition: PRE, POST, RET) repeated measures ANOVA was used for each feedback task for each dependent variable. The level of significance was set at 0.05. Post hoc pair-wise comparisons with Bonferroni corrections were performed when factors were significant.

RESULTS

Relative Phase Feedback Training

Significant main effects for task were found for all the variables excluding distance travelled by right- and left-side of instrument tips ($P < 0.05$; Table 1). Significant main effects for condition were found for TTC, average speed of right tip, median curvature of both instrument tips and grip force on the right-side ($P < 0.05$; Table 2). In general, the participants took less TTC, were faster and straighter for the BC task compared to ST and NP tasks, and during POST and RET conditions compared to PRE condition. Additionally, significant interaction was noted for TTC ($P < 0.05$; Figure 2-A1). Particularly, the participants took longer time to complete ST compared to NP. However, after the relative phase feedback training, the TTC was less for ST than NP task. Another significant interaction ($P < 0.05$) for left-side curvature showed that though the curvature values decreased from PRE to POST for all the three tasks, the reduction continued only for the ST task from POST to RET (Figure 3-E1).

Speed Feedback Training

Significant main effects for task were found for all the variables ($P < 0.05$; Table 1). Significant main effects for condition were found for TTC, average speed and median curvature of left- and right-side of instrument tips ($P < 0.05$; Table 2). The generic effects were similar to those observed during Relative Phase Feedback Training. Significant interaction ($P < 0.05$) was found for TTC (Figure 2-A2), distance travelled by the right-side (Figure 2-B1) and average speed of the left-side (Figure 3-D). In general, these interactions revealed that while the improvements in different measures occurred from PRE to POST for all the three tasks, the improvements mainly sustained from POST to RET for the BC task and barely for the ST task.

Grip Force Feedback Training

Significant main effects for task were found for all the variables with $P < 0.05$ excluding distance travelled by both instrument tips (Table 1). Significant main effects for condition were found for TTC, median curvature of both instrument tips with $P < 0.05$ (Table 2). The participants generally produced faster, straighter movement with lesser grip force during the BC task and during POST and RET conditions. Significant interaction ($P < 0.05$) was found for TTC (Figure 2-A2), distance moved by the right-side (Figure 2-B2) and the left-side (Figure 3-C1), and median curvature of the left-side (Figure 3-E2). These interactions suggested better learning for the ST task with greater improvements in the aforementioned outcome measures.

Video Feedback Training

Significant main effects for task were found for all the variables excluding distance travelled by the right-side of instrument tip ($P < 0.05$; Table 1). Significant main effects for condition were found for TTC, average speed, median curvature and relative phase of both instrument tips, ($P > 0.05$; Table 2). In general, the participants were faster, straighter, and exerted more grip force on the right-side during the NP and ST tasks compared to the BC task. They also produced less TTC, faster, and straighter movement on the right-side during the RET condition compared to the PRE condition.

DISCUSSION

The purpose of the current study was to investigate if augmented feedback mechanisms provided while performing three different surgical tasks using the dVSS were task-specific. We also investigated if the task-specificity of these augmented feedback mechanisms were retained over a two week period. We hypothesized that the effect of a specific type of feedback was affected by the type of task and the effect was influenced by learning. Overall, we wanted to establish the importance of feedback in RAS skills learning.

Relative Phase Feedback Training

Task-specific effects for relative phase feedback training showed more influence on complex tasks (ST) compared to intermediate (NP) and simple (BC) tasks. For instance, from PRE to POST, the TTC decreased by 60% for ST task compared to a decrease of 38% for NP task and 27% for BC task. Feedback-specific effects were also seen where participants arms were out-of-phase while performing BC task whereas they were in-phase for the ST task. The usefulness of this augmented feedback particularly for complex tasks could also be related to the information being perceived by the learner. The relative phase feedback showed the performance of the learner and that of the expert simultaneously. While this may not be important for simple and intermediate tasks, for complex tasks, this could play an important role in providing supplemental information to that provided by the learner’s task-intrinsic feedback.

Speed Feedback Training

Task-specific effects for speed feedback training showed that this feedback training had beneficial effects for simple tasks (like BC task). However, unlike the relative phase feedback training, the speed feedback training did not positively affect the complex tasks like ST task. Feedback-specific effects were also observed for speed feedback training with participants exhibiting less TTC and faster performance during simple tasks like BC. Though the task-specific main effects for speed feedback training echoed those of the relative phase feedback training, more speed training seemed to affect the left side kinematics. The lack of influence on complex tasks for speed feedback could also be attributed to the goal of the learner in terms of

Fitts' Law.[14] In other words, the learner might not emphasize on speed in order to accurately perform a complex task and hence providing speed feedback may not help in better performance.

Grip Force Feedback Training

Similar to the relative phase feedback training, the grip force feedback training showed beneficial effects for complex ST task especially in terms of TTC. Feedback-specific effects were also visible in terms of the grip force. As the task-complexity increased, the amount of grip force exerted bilaterally increased. Like speed feedback, the effectiveness of the grip force feedback can depend on the learner's characteristics (or goals). The learner may not want to exert excessive force to prevent damage to the suture pad, and hence can use the grip force feedback, particularly for the complex tasks.

Video Feedback Training

Video feedback training showed no distinct combined effects across tasks and conditions (no interaction effect). As expected, better performance was in general noted for simple tasks like BC.

The effect of a specific type of feedback was influenced by learning

Feedback-specific learning effects were noticed for all the types of feedback. Among the four types, maximal learning effects were noted for speed feedback training while minimal learning effects were noted for video-based feedback training. Though no further improvement resulted from POST to RET in any of the tasks with any of the augmented-feedbacks, the learning effects were retained throughout.

Task-specific augmented feedback is beneficial for RAS skills learning training

Results of the current study show that the feedback-specific effects are influenced by task-specificity and learning. Recently, Ronsse and colleagues (2010)[15] provided evidence for increased neural activity in sensory-specific areas when participants received coordination-based augmented visual feedback. Feedback dependent performance was also noted. Though the task and feedback were presented in a different manner, the coordination-based feedback closely resembles the relative phase feedback used in the present study. Among the tasks used in the current study, the BC and the ST tasks required more coordination between the arms. Also, significant improvement in performance was also observed for these tasks after relative phase feedback training suggesting task specificity of feedback effects. Knowledge of such task-specificity of feedback effects could be useful in other surgical domains as well.

Using a force feedback emanating from the instrument tips, Reiley et al[16] found that among novice robotic surgeons, the visual force feedback was associated with lower suture breakage rates, peak applied forces, and standard deviations of applied forces compared to no feedback condition for knot-tying. However, such differences ceased to exist in terms of time for task completion. Though the task in the present study differed from that used by Reiley and colleagues[16], the results still indicate that the effect of feedback is task-specific.

Limited training effect for video feedback could highlight the differences between different modes of feedback. Particularly, in the relative phase, speed and grip force feedback training modes, feedback was concurrently given while the task was being performed. Conversely, the video feedback group was given terminal feedback after the task was completed.

Several researchers have shown that action observation can affect action execution by influencing parameters like task initiation time and force production while performing the observed action.[17,18,19] While the video feedback training incorporated performing a task after observing one’s own actions, the influence of such observation seemed to be limited primarily to simple tasks like BC. Hence, providing a concurrent augmented feedback could be more helpful when compared to terminal feedback. However, it should be noted that the video demonstration of the expert’s performance combined with verbal instructions could increase the effectiveness of the augmented visual feedback through video. This could be explored in future studies.

Interestingly, Sarlegna et al. (2010)[20] observed that visual feedback of the object motion can influence the control of grip force independent of the task-complexity. However, results of the current study partially agree with the aforementioned observation. Similar to the results observed by Sarlegna et al. (2010) for the three tasks of different complexity, there were no differences in the grip force control when the speed feedback training was administered. But when the visual feedback was presented using relative phase, a smaller grip force resulted for only while performing a simple BC task. Hence, task-complexity might influence the grip force based on the type of visual feedback presented. Through analyses of electromyography, Judkins and colleagues (2009)[21] commented that concurrent augmented visual feedback during training could reduce physiological demands. However, association of this reduction with task-specificity was not established. Future studies could investigate the task-specificity effect of different types of visual feedback through electromyography. In a review article, Green and Bavelier[25] highlighted that along with task-difficulty, motivation level of the learner, and the feedback-type used in training can have a profound effect on learning new skills. Results of the current study provide evidence for task- and feedback-specific effects on RAS skills training.

CONCLUSIONS

Our hypothesis that the effect of a specific type of feedback will be affected by the type of task and learning held true primarily for the relative phase feedback and grip force feedback. Previous researchers showed that feedback specific effects exist and these effects could improve surgical performance outcomes.[13] The novelty in this study highlights the presence of even task-specific feedback effect that could enhance the RAS skills performance. Not many improvements in performance of the BC task were visible probably due to a ceiling effect. However, the three concurrent feedback training modes improved the performance in the intermediate (NP) and complex (ST) tasks. Particularly, the relative phase feedback training and the grip force feedback training could be useful for training complex tasks. Our study results also highlighted that concurrent feedback training could be better for performance enhancement compared to terminal feedback training. Findings from the current study could also be translated into other surgical domains to enhance skills and technique using feedback-specific and task-specific effects.

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REFERENCES

1. Intuitive Surgical-Company Profile. http://www.intuitivesurgical.com/company/, Intuitive Surgical. Accessed March 29, 2011.

2. Ballantyne G, Moll F. The da Vinci telerobotic surgical system: the virtual operative field and telepresence surgery. *Surg Clin North Am* 2003 Dec;83(6):1293-304, vii.

3. Moorthy K, Munz Y, Dosis A, Hernandez J, Martin S, Bello F, Rockall T, Darzi A. Dexterity enhancement with robotic surgery. *Surg Endosc* 2004 May;18(5):790-5.

4. Dakin G, Gagner M. Comparison of laparoscopic skills performance between standard instruments and two surgical robotic systems. *Surg Endosc* 2003 Apr;17(4):574-9.

5. Hernandez J, Bann S, Munz Y, Moorthy K, Datta V, Martin S, Dosis A, Bello F, Darzi A, Rockall T. Qualitative and quantitative analysis of the learning curve of a simulated surgical task on the da Vinci system. *Surg Endosc* 2004 Mar;18(3):372-8.

6. Chandra V, Nehra D, Parent R, Woo R, Reyes R, Hernandez-Boussard T, Dutta S. A comparison of laparoscopic and robotic assisted suturing performance by experts and novices. *Surgery* 2010 Jun;147(6):830-9.

7. Narazaki K, Oleynikov D, Stergiou N. Robotic surgery training and performance: identifying objective variables for quantifying the extent of proficiency. *Surg Endosc* 2006 Jan;20(1):96-103.

8. Adams, JA. A closed-loop theory of motor learning. *Journal of Motor Behavior* 1971; 3(2):111-150.

9. Rosen J, MacFarlane M, Richards C, Hannaford B, Sinanan M. Surgeon-tool force/torque signatures—evaluation of surgical skills in minimally invasive surgery. *Stud Health Technol Inform*. 1999;62:290-296.

10. Rosen J, Massimiliano S, Hannaford B, Sinanan M. Objective laparoscopic skills assessments of surgical residents using Hidden Markov Models based on haptic information and tool/tissue interactions. *Stud Health Technol Inform*. 2001;81:417-423.

11. Oleynikov D, Solomon B, Hallbeck S. Effect of visual feedback on surgical performance using the da Vinci surgical system. *J Laparoendosc Adv Surg Tech A* 2006 Oct;16(5):503-8.

12. Judkins T, Oleynikov D, Stergiou N. Real-time augmented feedback benefits robotic laparoscopic training. *Stud Health Technol Inform* 2006;119:243-8.

13. Judkins T, Oleynikov D, Stergiou N. Enhanced robotic surgical training using augmented visual feedback. *Surg Innov* 2008 Mar;15(1):59-68.

14. Fitts P. The information capacity of the human motor system in controlling the amplitude of movement. *Journal of Experimental Psychology* 1954; 47(6): 381–391. (Reprinted in *Journal of Experimental Psychology: General*, 121(3):262–269, 1992).

15. Ronsse R, Puttemans V, Coxon J, Goble D, Wagemans J, Wenderoth N, Swinnen S. Motor Learning with Augmented Feedback: Modality-Dependent Behavioral and Neural Consequences. *Cereb Cortex* 2010 Oct 28.

16. Reiley C, Akinbiyi T, Burschka D, Chang D, Okamura A, Yuh D. Effects of visual force feedback on robot-assisted surgical task performance. *J Thorac Cardiovasc Surg* 2008 Jan;135(1):196-202.

17. Tia B, Mourey F, Ballay Y, Sirandré C, Pozzo T, Paizis C. Improvement of motor performance by observational training in elderly people. *Neuroscience Letters* 2010: 480(2), 138-142.

18. Brass M, Bekkering H, Wohlschlager A, Prinz W. Compatibility between observed and executed finger movements: comparing symbolic, spatial, and imitative cues, *Brain Cogn* 2000; 44:124–143.

19. Wulf G, Shea C, Lewthwaite R. Motor skill learning and performance: a review of influential factors, *Med Educ* 2010; 44:75–84.

20. Sarlegna F, Baud-Bovy G, Danion F. Delayed visual feedback affects both manual tracking and grip force control when transporting a handheld object. *J Neurophysiol* 2010 Aug;104(2):641-53.

21. Judkins T, Oleynikov D, Stergiou N. Electromyographic response is altered during robotic surgical training with augmented feedback. *J Biomech* 2009 Jan 5;42(1):71-6.

22. Green C, Bavelier D. Exercising your brain: a review of human brain plasticity and training-induced learning. *Psychol Aging* 2008 Dec;23(4):692-701.

Figure Legends

Figure 1. Diagram explaining the flow of the study

Figure 2. Means (SE) for A (1-3). Time to Task Completion (s); B (1-2). Distance travelled by right-side tip (mm) for visual feedback training types, Relative Phase (RP), Speed (SP), and Grip Force (GR), feedback training during the three tasks: Bimanual Carrying (BC), Needle Passing (NP) and Suture Tying (ST) and three conditions: Pre-training (PRE), Post-training (POST) and Retention (RET)

Figure 3. Means (SE) for C (1-2). Distance travelled by left-side tip (mm); D. Average speed for left-tip (mm/s); E (1-2). Curvature of left-tip (mm^{-1}); F. Grip force of left-tip (N) for visual feedback training types, Relative Phase (RP), Speed (SP), and Grip Force (GR) feedback training during the three tasks: Bimanual Carrying (BC), Needle Passing (NP) and Suture Tying (ST) and three conditions: Pre-training (PRE), Post-training (POST) and Retention (RET)