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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.

36   **Methods:** Twenty-two novice users of the da Vinci® Surgical System underwent testing and

37   training in three tasks: simple task - bimanual carrying (BC), intermediate task - needle passing

38   (NP), and complex task - suture tying (ST). Pre-training (PRE), training, and Post-training

39   (POST) trials were performed during first session. Retention trials were performed 2 weeks later

40   (RET). Participants were randomly assigned to one of four feedback training groups: relative

41   phase (RP), speed, grip force, and video feedback group. Performance measures were time to

42   task completion (TTC), total distance traveled (D), speed (S), curvature, relative phase and grip

43   force (F).

44   **Results:** Significant interaction for TTC and curvature showed that the RP feedback training

45   improved temporal measures of complex ST task compared to simple BC task. Speed feedback

46   training significantly improved the performance in simple BC task in terms of TTC, D, S,

47   curvature and F even after retention. There was also a lesser long-term effect of Speed

48   feedback training on complex ST task. Grip force feedback training resulted in significantly

49   greater improvements in TTC and curvature for complex ST task. For the Video feedback

50   training group, the improvements in most of the outcome measures were evident only after

51   RET.

52   **Conclusions:** Task-specific augmented feedback is beneficial to RAS skills learning.

53   Particularly, the RP and grip force feedback could be useful for training complex tasks.

54

55   <u>Keywords</u>: concurrent feedback, da Vinci® Surgical System, task-complexity, motor learning

56

57

58   **INTRODUCTION**

59   Robot-assisted surgery (RAS) skills learning has been in great demand since the advent

60   of robot-assisted surgical systems like the da Vinci® Surgical System (dVSS; Intuitive Surgical,

61   Sunnyvale, CA). The dVSS has been used in over 1000 facilities world-wide.[1] The advantages

62   of dVSS include seven degrees of freedom at the instrument tip, increased depth perception

63   with three dimensional images[2], increased dexterity[3] and precision[4], decreased surgical

64   residents' training time[5], improved economy of motion for experts[6], enhanced eye–hand

65   coordination, and comfortable seating posture.[7] In spite of these advantages, educating and

66   training novice surgeons to perform RAS has received limited attention.

67   Providing effective RAS skills learning to novices is both critical and challenging.

68   According to Adam's Closed Loop Theory[8] feedback plays a critical role while learning new

69   skills. When a user performs a task, he/she will get task-intrinsic feedback from his own senses

70   like vision, auditory, proprioception, touch, and vestibular. One of the major limiting factors in the

71   process of educating novice surgeons about RAS is the lack of task-intrinsic touch feedback

72   from the instrument tips at the surgical table while they manipulate their wrists at the console.

73   One of the ways to overcome such limitation is providing the novice with an augmented

74   feedback that could be either concurrent (while performing the procedure) and/or terminal (after

75   performing the procedure). Concurrent feedback, can be provided in terms of speed of

76   movement, the grip force at the console[9,10], or even verbal instructions by the trainer. Terminal

77   feedback can be provided by showing a video of the performance of the subject or of an expert

78   to be used as a model.

79   In fact, providing augmented visual feedback has been shown to enhance surgical

80   performance in novice surgeons.[11] The benefits of augmented visual feedback for robotic

81   laparoscopic training have been previously reported by our group.[12] Particularly, when novice

82   medical students were provided grip force feedback, they were able to better adjust their grip

83   force during surgical skill training. Judkins and colleagues[13] showed that concurrent augmented

84   feedback during training can also enhance the surgical performance. Particularly, a feedback-

85   specific effect was shown, in which the group that received the speed feedback training was

86   faster than groups that received relative phase, grip force or video feedback after training.

87   Similarly, the grip force feedback group applied less grip force compared to the other three

88   groups. These effects were observed across three kinds of tasks with increasing complexity:

89   bimanual carrying, needle passing and suture tying. However, it is not known if these feedback

90   effects were task-specific, i.e. would these effects be observed for both simple and complex

91   tasks? Previous studies have also not explored if such task-specific feedback effects can be

92   sustained over a retention period. This is essential to estimate true learning effects once the

93   feedback is removed to the novice surgical learner.

94   Task-specificity of augmented visual feedback could play an essential role in developing

95   optimal training strategies. For example, providing augmented visual feedback while performing

96   simple tasks (e.g. bimanual coordination) could not be as beneficial compared to providing the

97   same feedback while performing a more complex task (e.g. suture tying). Moreover, whether the

98   augmented visual feedback for a particular task will be useful or not will depend on the type of

99   feedback. Hence understanding the relationship between the task-specificity and feedback-

100   specificity in terms of skills learning could play a critical role in designing effective training

101   programs for novice surgeons in RAS.

102   The purpose of the current study was two-fold. First, we investigated if augmented

103   feedback effects were task-specific (dependent on complexity level of the task). Second, we

104   investigated if such task-specific feedback effects sustained over a 2-week retention period. We

105   hypothesized that the effect of a specific type of feedback was affected by the type of task and

106   this effect was influenced by retention period. We intended to investigate the task-specificity

107   within four different types of feedback but not between the types of feedback as it was reported

108   in our earlier study.[13]

109

110   **METHODS**

111   This study was approved by the University of Nebraska Medical Center's Institutional

112   Review Board. Details of methodology have been elaborately presented in an earlier study.[11]

113   Briefly, 22 novice users (age: 25±5 years) of the dVSS participated in this study. Participants

114   performed and practiced three tasks using the dVSS throughout this study: simple task -

115   bimanual carrying (BC), intermediate task - needle passing (NP), and complex task - suture

116   tying (ST). Participants performed 21 trials of each task divided into four training blocks (three

117   pretraining trials (PRE), 10 training trials with augmented visual feedback, three posttraining

118   trials (POST), and five retention trials (RET) for each task. Pretraining, training, and posttraining

119   trials were performed during one session. Retention trials were performed two weeks after the

120   first session (Figure 1). Task order was randomized between subjects but was the same

121   between training blocks.

122   Participants were randomly assigned to one of four feedback groups: 1) relative phase

123   between left and right instrument tips movement (n = 5), 2) speed of instrument tips (n = 5), 3)

124   grip force (n = 6), and 4) video (n = 6). Concurrent augmented feedback was overlaid on the

125   video screen of the participating surgeon's console using a CORIOgen Eclipse video overlay

126   unit (TV One USA, Erlanger, KY). Speed and Grip Force feedback for both arms were

127   presented as 2 colored vertical bars overlaid on the video screen of the surgeon's console.

128   Relative phase feedback was shown using a red circular dial with a moving needle. The needle

129   pointed to the right for an in-phase (0°) relationship and to the left for an out-of-phase (180°)

130   relationship between both the arms. For the relative phase feedback, part of the dial was also

131   shaded green indicating the desired relative phase for the task as calculated from expert data

132   from a previous experiment. While the speed, grip force and relative phase feedback groups

133   obtained concurrent augmented visual feedback, the video feedback group obtained a terminal

134   augmented visual feedback. Participants watched prerecorded video of an expert with more

135   than 5 years of experience using the dVSS as many times as they preferred. It was

136   hypothesized that the video feedback group can compare their own performance from the

137   information provided by their task-intrinsic feedback with the expert's performance provided by

138   the augmented visual feedback. Such an augmented feedback through expert modeling video is

139   believed to teach the learner invariant characteristics of the movement.

140   Performance measures were time to task completion (TTC), total distance traveled,

141   speed, curvature, relative phase and grip force. A 3 (task: BC, NP, ST) x 3 (Condition: PRE,

142   POST, RET) repeated measures ANOVA was used for each feedback task for each dependent

143   variable. The level of significance was set at 0.05. Post hoc pair-wise comparisons with

144   Bonferroni corrections were performed when factors were significant.

145

146   **RESULTS**

147   **Relative Phase Feedback Training**

148   Significant main effects for task were found for all the variables excluding distance

149   travelled by right- and left-side of instrument tips ($P < 0.05$; Table 1). Significant main effects for

150   condition were found for TTC, average speed of right tip, median curvature of both instrument

151   tips and grip force on the right-side ($P < 0.05$; Table 2). In general, the participants took less

152   TTC, were faster and straighter for the BC task compared to ST and NP tasks, and during

153   POST and RET conditions compared to PRE condition. Additionally, significant interaction was

154   noted for TTC ($P < 0.05$; Figure 2-A1). Particularly, the participants took longer time to complete

155   ST compared to NP. However, after the relative phase feedback training, the TTC was less for

156   ST than NP task. Another significant interaction ($P < 0.05$) for left-side curvature showed that

157   though the curvature values decreased from PRE to POST for all the three tasks, the reduction

158   continued only for the ST task from POST to RET (Figure 3-E1).

159   **Speed Feedback Training**

160   Significant main effects for task were found for all the variables ($P < 0.05$; Table 1).

161   Significant main effects for condition were found for TTC, average speed and median curvature

162   of left- and right-side of instrument tips ($P < 0.05$; Table 2). The generic effects were similar to

163   those observed during Relative Phase Feedback Training. Significant interaction ($P < 0.05$) was

164   found for TTC (Figure 2-A2), distance travelled by the right-side (Figure 2-B1) and average

165   speed of the left-side (Figure 3-D). In general, these interactions revealed that while the

166   improvements in different measures occurred from PRE to POST for all the three tasks, the

167   improvements mainly sustained from POST to RET for the BC task and barely for the ST task.

168   **Grip Force Feedback Training**

169   Significant main effects for task were found for all the variables with $P < 0.05$ excluding

170   distance travelled by both instrument tips (Table 1). Significant main effects for condition were

171   found for TTC, median curvature of both instrument tips with $P < 0.05$ (Table 2). The

172   participants generally produced faster, straighter movement with lesser grip force during the BC

173   task and during POST and RET conditions. Significant interaction ($P < 0.05$) was found for TTC

174   (Figure 2-A2), distance moved by the right-side (Figure 2-B2) and the left-side (Figure 3-C1),

175   and median curvature of the left-side (Figure 3-E2). These interactions suggested better

176   learning for the ST task with greater improvements in the aforementioned outcome measures.

177   **Video Feedback Training**

178   Significant main effects for task were found for all the variables excluding distance

179   travelled by the right-side of instrument tip ($P < 0.05$; Table 1). Significant main effects for

180   condition were found for TTC, average speed, median curvature and relative phase of both

181   instrument tips, ($P > 0.05$; Table 2). In general, the participants were faster, straighter, and

182   exerted more grip force on the right-side during the NP and ST tasks compared to the BC task.

183   They also produced less TTC, faster, and straighter movement on the right-side during the RET

184   condition compared to the PRE condition.

185   **DISCUSSION**

186   The purpose of the current study was to investigate if augmented feedback mechanisms

187   provided while performing three different surgical tasks using the dVSS were task-specific. We

188   also investigated if the task-specificity of these augmented feedback mechanisms were retained

189   over a two week period. We hypothesized that the effect of a specific type of feedback was

190   affected by the type of task and the effect was influenced by learning. Overall, we wanted to

191   establish the importance of feedback in RAS skills learning.

192   **Relative Phase Feedback Training**

193   Task-specific effects for relative phase feedback training showed more influence on

194   complex tasks (ST) compared to intermediate (NP) and simple (BC) tasks. For instance, from

195   PRE to POST, the TTC decreased by 60% for ST task compared to a decrease of 38% for NP

196   task and 27% for BC task. Feedback-specific effects were also seen where participants arms

197   were out-of-phase while performing BC task whereas they were in-phase for the ST task. The

198   usefulness of this augmented feedback particularly for complex tasks could also be related to

199   the information being perceived by the learner. The relative phase feedback showed the

200   performance of the learner and that of the expert simultaneously. While this may not be

201   important for simple and intermediate tasks, for complex tasks, this could play an important role

202   in providing supplemental information to that provided by the learner's task-intrinsic feedback.

203   **Speed Feedback Training**

204   Task-specific effects for speed feedback training showed that this feedback training had

205   beneficial effects for simple tasks (like BC task). However, unlike the relative phase feedback

206   training, the speed feedback training did not positively affect the complex tasks like ST task.

207   Feedback-specific effects were also observed for speed feedback training with participants

208   exhibiting less TTC and faster performance during simple tasks like BC. Though the task-

209   specific main effects for speed feedback training echoed those of the relative phase feedback

210   training, more speed training seemed to affect the left side kinematics. The lack of influence on

211   complex tasks for speed feedback could also be attributed to the goal of the learner in terms of

212 Fitts' Law.[14] In other words, the learner might not emphasize on speed in order to accurately

213 perform a complex task and hence providing speed feedback may not help in better

214 performance.

215 **Grip Force Feedback Training**

216   Similar to the relative phase feedback training, the grip force feedback training showed

217 beneficial effects for complex ST task especially in terms of TTC. Feedback-specific effects

218 were also visible in terms of the grip force. As the task-complexity increased, the amount of grip

219 force exerted bilaterally increased. Like speed feedback, the effectiveness of the grip force

220 feedback can depend on the learner's characteristics (or goals). The learner may not want to

221 exert excessive force to prevent damage to the suture pad, and hence can use the grip force

222 feedback, particularly for the complex tasks.

223 **Video Feedback Training**

224   Video feedback training showed no distinct combined effects across tasks and

225 conditions (no interaction effect). As expected, better performance was in general noted for

226 simple tasks like BC.

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

228   Feedback-specific learning effects were noticed for all the types of feedback. Among the

229 four types, maximal learning effects were noted for speed feedback training while minimal

230 learning effects were noted for video-based feedback training. Though no further improvement

231 resulted from POST to RET in any of the tasks with any of the augmented-feedbacks, the

232 learning effects were retained throughout.

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

234   Results of the current study show that the feedback-specific effects are influenced by

235   task-specificity and learning. Recently, Ronsse and colleagues (2010)[15] provided evidence for

236   increased neural activity in sensory-specific areas when participants received coordination-

237   based augmented visual feedback. Feedback dependent performance was also noted. Though

238   the task and feedback were presented in a different manner, the coordination-based feedback

239   closely resembles the relative phase feedback used in the present study. Among the tasks used

240   in the current study, the BC and the ST tasks required more coordination between the arms.

241   Also, significant improvement in performance was also observed for these tasks after relative

242   phase feedback training suggesting task specificity of feedback effects. Knowledge of such

243   task-specificity of feedback effects could be useful in other surgical domains as well.

244   Using a force feedback emanating from the instrument tips, Reiley et al[16] found that

245   among novice robotic surgeons, the visual force feedback was associated with lower suture

246   breakage rates, peak applied forces, and standard deviations of applied forces compared to no

247   feedback condition for knot-tying. However, such differences ceased to exist in terms of time for

248   task completion. Though the task in the present study differed from that used by Reiley and

249   colleagues[16], the results still indicate that the effect of feedback is task-specific.

250   Limited training effect for video feedback could highlight the differences between

251   different modes of feedback. Particularly, in the relative phase, speed and grip force feedback

252   training modes, feedback was concurrently given while the task was being performed.

253   Conversely, the video feedback group was given terminal feedback after the task was

254   completed.

255   Several researchers have shown that action observation can affect action execution by

256   influencing parameters like task initiation time and force production while performing the

257   observed action.[17,18,19] While the video feedback training incorporated performing a task after

258   observing one's own actions, the influence of such observation seemed to be limited primarily to

259   simple tasks like BC. Hence, providing a concurrent augmented feedback could be more helpful

260   when compared to terminal feedback. However, it should be noted that the video demonstration

261   of the expert's performance combined with verbal instructions could increase the effectiveness

262   of the augmented visual feedback through video. This could be explored in future studies.

263   Interestingly, Sarlegna et al. (2010)[20] observed that visual feedback of the object motion

264   can influence the control of grip force independent of the task-complexity. However, results of

265   the current study partially agree with the aforementioned observation. Similar to the results

266   observed by Sarlegna et al. (2010) for the three tasks of different complexity, there were no

267   differences in the grip force control when the speed feedback training was administered. But

268   when the visual feedback was presented using relative phase, a smaller grip force resulted for

269   only while performing a simple BC task. Hence, task-complexity might influence the grip force

270   based on the type of visual feedback presented. Through analyses of electromyography,

271   Judkins and colleagues (2009)[21] commented that concurrent augmented visual feedback during

272   training could reduce physiological demands. However, association of this reduction with task-

273   specificity was not established. Future studies could investigate the task-specificity effect of

274   different types of visual feedback through electromyography. In a review article, Green and

275   Bavelier[25] highlighted that along with task-difficulty, motivation level of the learner, and the

276   feedback-type used in training can have a profound effect on learning new skills. Results of the

277   current study provide evidence for task- and feedback-specific effects on RAS skills training.

278

279

280   **CONCLUSIONS**

281   Our hypothesis that the effect of a specific type of feedback will be affected by the type

282   of task and learning held true primarily for the relative phase feedback and grip force feedback.

283   Previous researchers showed that feedback specific effects exist and these effects could

284   improve surgical performance outcomes.[13] The novelty in this study highlights the presence of

285   even task-specific feedback effect that could enhance the RAS skills performance. Not many

286   improvements in performance of the BC task were visible probably due to a ceiling effect.

287   However, the three concurrent feedback training modes improved the performance in the

288   intermediate (NP) and complex (ST) tasks. Particularly, the relative phase feedback training and

289   the grip force feedback training could be useful for training complex tasks. Our study results

290   also highlighted that concurrent feedback training could be better for performance enhancement

291   compared to terminal feedback training. Findings from the current study could also be translated

292   into other surgical domains to enhance skills and technique using feedback-specific and task-

293   specific effects.

294   ***Acknowledgements***: The authors would like to thank all participants in this study.

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386   **Figure Legends**

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389   Figure 1. Diagram explaining the flow of the study

390   Figure 2. Means (SE) for A (1-3). Time to Task Completion (s); B (1-2). Distance travelled by

391   right-side tip (mm) for visual feedback training types, Relative Phase (RP), Speed (SP), and

392   Grip Force (GR), feedback training during the three tasks: Bimanual Carrying (BC), Needle

393   Passing (NP) and Suture Tying (ST) and three conditions: Pre-training (PRE), Post-training

394   (POST) and Retention (RET)

395   Figure 3. Means (SE) for C (1-2). Distance travelled by left-side tip (mm); D. Average speed for

396   left-tip (mm/s); E (1-2). Curvature of left-tip (mm^{-1}); F. Grip force of left-tip (N) for visual feedback

397   training types, Relative Phase (RP), Speed (SP), and Grip Force (GR) feedback training during

398   the three tasks: Bimanual Carrying (BC), Needle Passing (NP) and Suture Tying (ST) and three

399   conditions: Pre-training (PRE), Post-training (POST) and Retention (RET)