

How much feedback is necessary for learning to suture?

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Abstract

Background Many laparoscopic simulation training systems exist and have been shown to transfer learning of surgical skills to the operating room. The manner in which the training is structured to maximize learning has not been examined. There are many aspects to the acquisition of laparoscopic skills during training, one of which is the availability of knowledge of results (KR). Knowledge of results is information about the outcome of motor skill execution, usually provided to individuals at the end of the execution. The timing and nature of KR can affect how well people learn new motor skills. In addition, detailed instruction during learning can also affect skill acquisition. We studied the effects of KR and instruction on the learning curve of a suturing and knot-tying task. We hypothesized that KR was necessary for skill acquisition, and that detailed instruction would help trainees to learn to perform the task more correctly and reach a performance plateau earlier. In addition, the overall workload of a trainee during training would decrease as skills improved, especially when KR and coaching were provided.

Methods Nine medical students with no previous laparoscopic surgical experience were randomly and evenly divided into three groups with different KR conditions: (1) no KR, (2) KR, (3) KR + instruction. Each subject attended a training session for 1 h each day, 6 days a week for 4 consecutive weeks. Performance measures such as task

time, smoothness of instrument, and path length were recorded for each trial. Workload was assessed using the NASA-TLX questionnaire.

Results While KR was necessary for learning to suture, continual instruction had limited additional benefits. However, KR + instruction did reduce subjects' perceived overall workload.

Conclusions Surgical training could be carried out effectively with only knowledge of results. These results have implications for the staffing of surgical skills laboratories.

Keywords Knowledge of results · learning curve · suturing · knot-tying

The introduction of minimally invasive surgery more than two decades ago has reaped many rewards for both patients and practitioners. Laparoscopic surgery has had a significant impact on all surgical disciplines and forms a large part of most surgical practice [3]. The many benefits include improved patient satisfaction, smaller incisions with better cosmesis, shorter hospital stays and improved hospital budgets [6].

There are many inherent difficulties associated with laparoscopic surgery, such as the fulcrum effect of the instruments, altered haptic feedback, and the loss of depth perception that occurs with two dimensional monitors. These difficulties make the training of laparoscopic surgeons more challenging and complex, while increasing the surgeon's workload [1]. Workload is the mental and physical requirements placed on an individual while performing a task. The amount of mental workload experienced is predicted by how much information has to be processed and how many decisions need to be made.

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The physical workload is dependent on the physical demands of the task (e.g., excessive and prolonged muscular load, awkward and constrained postures, and repetitive movements) [4].

Considering the complexity of training and the exponential increase in volume of laparoscopic procedures, many surgeons have raised concerns about the lack of a standardized training curriculum [3, 7, 8]. Concerns for patient safety have also led to calls for learning basic laparoscopic skills outside the operating room in a skills laboratory, prior to a surgeon's commencing surgical procedures [12].

The particular cognitive and motor skills required for laparoscopic surgery are amenable to simulator training, a modality of training that is becoming increasingly important as surgical residents have less exposure and experience in the operating room due to shorter working hours imposed by the eighty-hour-work-week restriction [8]. Furthermore, the heavy financial burden of surgical training needs to be considered. The estimated cost of training a surgical resident in 1998 was \$47,970 USD per resident per year [2]. This was calculated as follows: the time a resident took to perform a surgical procedure was calculated and compared to the time taken to perform the same procedure by an experienced surgeon. The difference in time was considered "lost time." A monetary value was assigned to this time based on the cost of staffing and providing utilities for the operating room. When this figure was extrapolated to all surgical residents in training in the United States, a figure of \$53 million was the result. It may be considered, then, that providing adjuvant training for residents outside the operating room could reduce this cost [2]. Also, it has been demonstrated that training outside the operating room on bench models can lead to improved surgical performance by surgical residents [11].

In the field of motor skill acquisition and learning, the provision of feedback of performance is known to be an essential part of the learning process; the absence of feedback may even halt learning altogether [7]. How and when this information is presented can have variable effects on performance and learning [9, 10]. For the purposes of this study we examined two major forms of feedback: knowledge of results (KR) and knowledge of performance (KP). Knowledge of results is information provided to individuals about the endpoint of their motor movement, such as the time it took them to perform a particular task. Knowledge of results does not provide any information as to how the movement itself was carried out. Knowledge of performance, in contrast, refers to information pertaining to the movement pattern that the individual performs. It is the method by which an instructor may point out various mistakes in the steps an individual takes to perform a particular task rather than critiquing the

endpoint of the movement. To optimize learning in the surgical simulation environment, it is important to know which forms of feedback are necessary during the skill acquisition stage. In addition, because the workload in laparoscopic surgery is higher than in traditional open surgery [1], KR and workload may both affect the rate of learning in laparoscopic surgery.

In this study, we evaluated the effects of three different levels of feedback on the learning curve of novice subjects for suturing and tying an intracorporeal knot: (1) no feedback, (2) knowledge of results, and (3) KR and KP in the form of instruction.

Methods

Subjects

Nine medical students (4 women, 5 men) were randomly assigned to one of three groups, each consisting of three individuals. There were four first-year students and five second-year students. Eight were right handed and one was left handed.

Apparatus

The apparatus used in this study was the ProMIS laparoscopic simulator (Haptica, Inc.).

Task

A standardized laparoscopic knot-tying and suturing task was used. The model consisted of a 6.0 cm long Penrose drain attached with Velcro to a steady surface. A 4.0 cm × 0.5 cm slit was placed in the drain, and two targets were marked in black ink on either side of the slit. The suture used was 17 cm of 3.0 silk suture on a curved needle. The subjects' task was to suture through the targets and then perform one knot with two half hitches.

Procedure

Prior to commencing the study, all subjects were coached for 2 h on the basics of knot-tying and suturing outside the laparoscopic simulator. This initial training was given to facilitate learning of laparoscopic suturing. Without these basic skills, initial learning of suturing rather than laparoscopic suturing per se may have artificially lengthened the learning process. All subjects were given adequate time to practice knot tying and suturing repeatedly until they could perform these maneuvers with ease.

Having acquired the suturing and knot-tying skills, an introductory session on laparoscopic surgery was given. This session consisted of instruction on the basics of laparoscopic surgery and a video demonstration of a laparoscopic suturing and knot-tying task. The subjects were then given 30 min to familiarize themselves with the instruments and the simulator.

Following the initial orientation session, subjects attended the laboratory for 1 h a day, 6 days per week over 4 consecutive weeks to practice the task. Throughout the 4 weeks, group 1 received no KR or KP feedback. Group 2 received KR feedback at the end of each practice session, consisting of information on time taken for task completion, smoothness of tool manipulation, and path length of tool. This information, provided by the simulator, was the only information this group of subjects received. No feedback was provided on how well they were performing relative to other individuals. Group 3 received both KR and KP in the form of instructions. They were instructed continually on how to improve skill in addition to the same knowledge of results that group 2 received. These individuals were also given detailed explanations of their results and were provided with target performance goals. They were observed closely, and any potential mistakes were corrected early in their learning experience. Workload assessment was conducted at the end of each session using the NASA-TLX computerized questionnaire [5]. Overall workload was assessed based on physical demand, temporal demand, mental demand, self judgment of performance, level of effort, and level of frustration.

Dependent measures

During each hour-long training session the performance of each subject was recorded by the ProMIS optical tracking system. For all sessions, all knots performed by each subject were recorded for each of the three performance variables (i.e., time, instrument path length, and smoothness of the instruments). Each knot was also examined and scored for tightness, completeness, and distance of needle penetration from the targets. An error score was calculated for the knot tying and suturing as defined in Table 1. The maximum error score that could be achieved was 10. A subjective workload measure was also collected for each session.

Data analysis

When considering the effectiveness of learning, one way to compare groups would be to look at the variability. As an individual improves at a particular task, the variability in

Table 1 Suture error chart

Error	Points
Reversed knot 1st knot	1
Reversed knot 2nd knot	1
Reversed knot 3rd knot	1
Distance from markers 0–2.5 mm	0
Distance from markers 2.5–5 mm	1
Distance from markers > 5 mm	2
Knot breaks easily	1
Edges of drain not opposed	1
Knot incomplete	10

performance between repetitions of the task decreases because the individual becomes more consistent in executing the movements. The variance per session was calculated for each subject for each day in the time taken, smoothness, path length, and number of errors. The learning curves for each individual were also analyzed. Data were analyzed using analysis of variance (ANOVA) and post-hoc Tukey analysis.

Results

Learning curves

Learning curves for each subject were plotted as logarithmic trendlines for time, path length, and smoothness measures (see Figure 1 for sample of learning curve in time). Analysis of variance on the slopes of these trendlines showed a significant main effect for each of the performance measures (time, path length, and smoothness: $F(2,8) = 8.24, 14.51, 7.32$; $p = 0.019, 0.005, 0.0245$, respectively). Post-hoc Tukey analysis showed a statistically significant difference between group 1 (no feedback) and group 2 (KR), and between group 1 and group 3 (KR and KP [KR + instruction]) for all three performance measures. Groups 2 and 3 were not different from each other.

Performance variance

The mean performance variances over the period of training (see Fig. 2, 3, and 4) were much greater for group 1 (No Feedback), especially over the first six sessions, than for either of the other groups. Results from ANOVA showed a significant main effect for each of the performance measures (time, path length, and smoothness: $F(46,144) = 9.057, 9.208, 7.329$; $p = 0.0002, 0.0002, 0.0009$, respectively). Post-hoc Tukey tests showed that for all three performance measures, a statistically significant difference between group 1 (no feedback) and group 2

Fig. 1 Total time versus trials

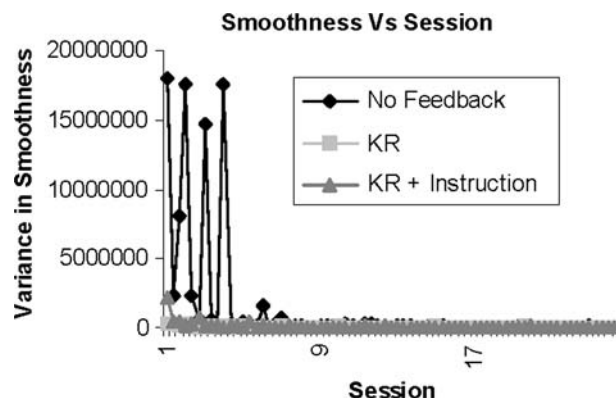
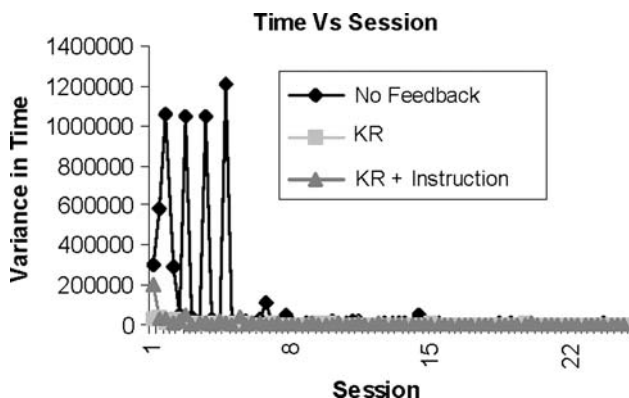
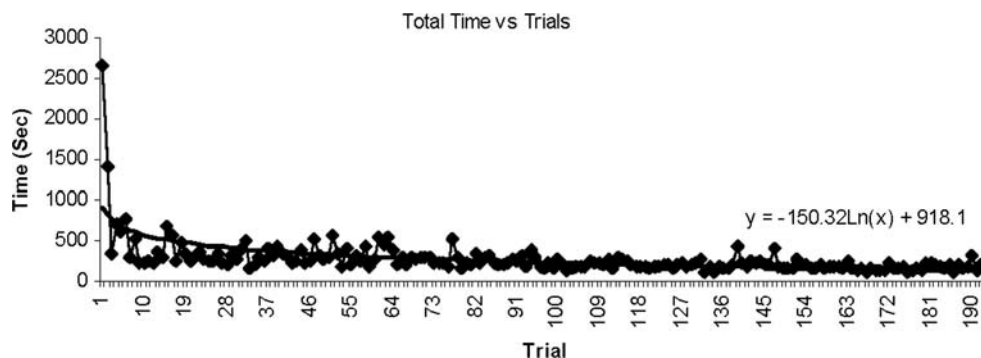


Fig. 2 Variance in time per session

Fig. 4 Variance in smoothness per session

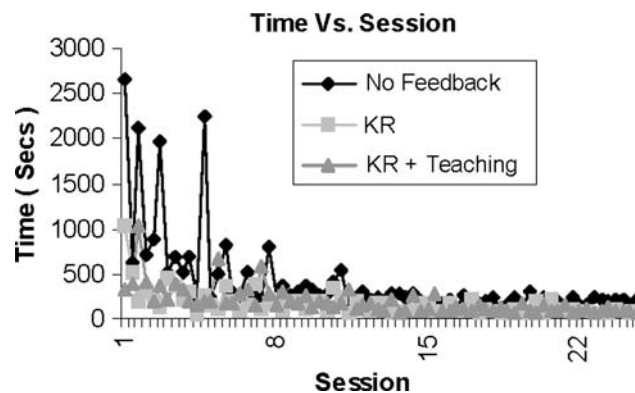
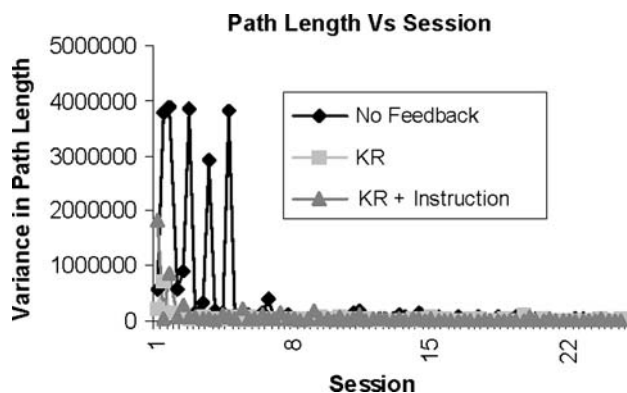


Fig. 3 Variance in path length per session

Fig. 5 Time of last trial versus session

(KR), and between group 1 and group 3 (KR + instruction). There was no difference between group 2 and group 3.

Last trials

The total number of knots performed by each subject within the 1-h training period varied with the amount of training. Therefore, the last complete trial in each session was taken as an indicator of each individual’s performance

per session (see Fig. 5, 6, and 7). Analysis of variance showed a main effect in each of the performance parameters (time, path length, and smoothness: $F(23,144) = 25.5, 26.2, 25.5$; $p = 0.025, 0.022, \text{ and } 0.022$, respectively). Post-hoc Tukey tests showed statistically significant differences between group 1 (no feedback) and group 2 (KR), and between group 1 and group 3 (KR + instruction), for all three performance parameters.

Perceived overall workload

Workload results showed a significant main effect ($F(2,8) = 11.11$; $p = 0.009$). Post-hoc Tukey tests showed that

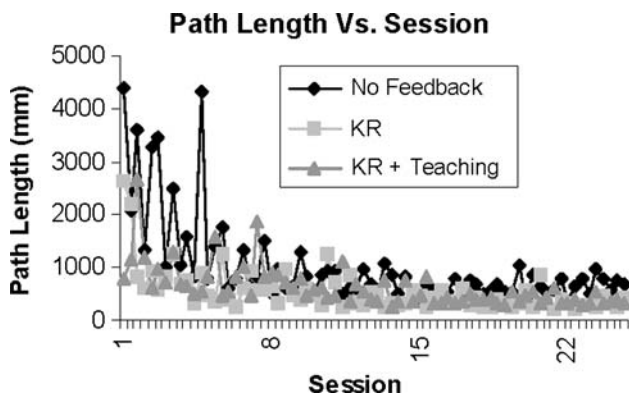


Fig. 6 Path length of last trial versus session

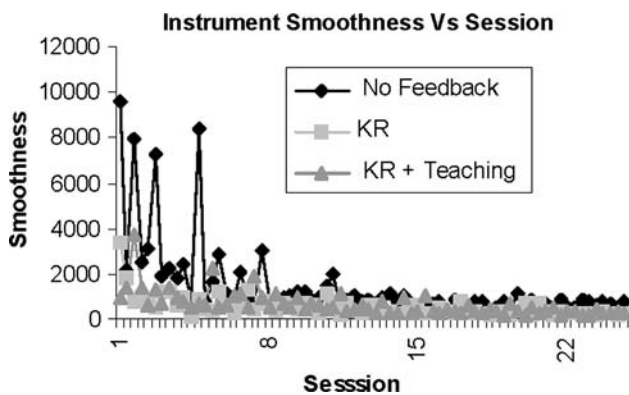


Fig. 7 Instrument smoothness of last trial versus session

workload for group 3 was significantly lower than for the other two groups (see Table 2). Groups 1 and 2 were not different from each other.

Error scores

Each knot was scored by the scoring system described above (Table 1). Analysis of variance showed a main effect in error ($F(23,144) = 10.65$; $p < 0.001$). Post-hoc Tukey analysis showed that the only difference was between group 2 and group 3. Group 3 made significantly fewer errors than groups 1 and 2 (Table 3).

Discussion

The aim of this study was to examine the effect of different forms of feedback on the acquisition of a surgical skill. The

Table 2 Average workload scores per group per session

Session	No KR	KR	KR + Instruction
Mean workload	63.55	54.11	37.26
Standard deviation	5.30	6.83	15.25

KR: knowledge of results

learning curves and performance variance over the training period showed that subjects' performance while learning to suture and tie knots improved when knowledge of results was provided, especially during the initial phase of learning. This is in keeping with other studies, which have noted the beneficial effects of KR [7]. However, there were no significant performance differences between subjects in group 2, which received KR feedback, and group 3, which received KR + instructions. These results indicate that while having KR results in shorter learning curves, the addition of performance feedback in the form of instruction does not result in a statistically significant benefit.

The examination of error scores shows that different levels of feedback had an effect on the number of errors made by the subjects across their learning experience. The results demonstrate that the group receiving performance feedback in the form of instruction had slightly lower error scores overall. It can be concluded that adding performance feedback to KR can lower the overall error score. A secondary beneficial effect of KP (instruction) was the reduction in the perceived workload of the individuals. It seems that having an instructor in the room can serve to motivate trainees, as well as lower anxiety levels, altering the subjective experience of learning. Future studies could test the hypothesis that optimal learning occurs with a unique balance between KR and instruction.

In examining the learning curves of all individuals, it can be seen that all reached plateau within the first 8 days of the study. In total, 24 h of training were provided to each individual. The purpose of extending the training well beyond the initial plateau was to determine if further improvements—or perhaps deteriorations—in skill would take place. In this study no further changes after the initial plateau occurred. Thus laparoscopic suturing can be learned in eight training sessions. This information could prove to be extremely valuable when building an efficient surgical skills acquisition curriculum.

Furthermore, if adding instructional feedback to a surgical skills training program provided only small beneficial effects, such as a reduction in perceived workload and more errors in the initial learning phase, a purely economic recommendation would be to omit this instructional component. The cost of having an instructor present to coach the novice learner at all times can be high. Omitting the instructor could save money while incurring little penalty to the trainee. Furthermore, without the need to have an

Table 3 Average error scores per group per session

Session	No KR	KR	KR + instruction
Mean score	2.50	2.64	1.96
Standard deviation	0.90	0.84	1.25

instructor present, the trainees would be free to learn on their own time. In a busy residency program constrained by limited working-hour restrictions, this would be very appealing.

From an educational point of view, however, other considerations need to be taken into account: how effective the training is, how much of the learned skills (and errors) are retained over time, and how motivated or discouraged the trainee becomes without mentoring. These factors have implications for the health of the residency program, as well as for the quality of the health care to be delivered by these trainees.

Limitations

There were limitations to this study. The small sample size limits the generalizability of the results. However, with the repeated-measures experimental design and the multiple trials over 24 h of training, we ensured statistical power of the test. Another limitation of the study was the absence of feedback regarding the quality of knots in the KR only group, whereas the KR + instruction group received this information as feedback. However, because current simulators do not provide this information in their report of performance, our results provide a realistic comment on the utility of these simulators.

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