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Surgical education

Verbal feedback from an expert is more effective than self-accessed feedback about motion efficiency in learning new surgical skills

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Abstract

Background: Teaching of technical surgical skills to undergraduate medical students in a laboratory setting away from the patient is not common practice. Because of the large volume of students and shortage of available teaching faculty new methods of teaching must be developed for this group of trainees. In this study we examined the effectiveness of computer-based video training, different types of computer-based motion efficiency feedback (with and without expert criteria), and expert feedback on learning of a basic technical skill in medical students.

Methods: Forty-five junior medical students were randomized into 3 groups and learned suturing and knot-tying skills. Group A received computer-generated feedback about the economy of their movements. Group B received the same motion economy feedback, as well as expert reference values. Group C received verbal feedback from an expert. All groups were pre-tested, allowed 18 practice trials, and post-tested, and their skill retention was retested after 1 month. Performance was assessed by expert analysis using an objective structured analysis of technical skill and by computer analysis (Imperial College Surgical Assessment Device [ICSAD]).

Results: All groups showed improvement from pre-test to post-test. However, only group C showed retention of skill on delayed performance testing.

Conclusions: Verbal feedback from an expert instructor led to lasting improvements in technical skills performance. Providing information about motion efficiency did not lead to similar improvements.

Keywords: Surgical education; Basic technical skills; Motion analysis; Computer-assisted feedback

While the acquisition of technical skill is only one part of surgical learning, it is of paramount importance to surgical trainees and their teachers as it is said to serve as the basis for the successful completion of properly planned surgery [1]. Because of the ethical concerns surrounding practice on patients, the proven effectiveness of bench top models [2–4], and the increased availability of affordable reusable materials, the initial stages of teaching technical surgical skills in the laboratory setting are emerging as an excellent adjunct to operating room instruction. Surgical skill acquisition in the laboratory provides a number of benefits to the learner, such as a low stress environment, the ability to practice and repeat procedures without consequence, and the opportunity for self-directed learning.

The objective assessment of technical skill acquisition is critical in providing feedback to trainees, in targeting deficiencies that can be remediated, and ultimately in attesting to a trainee's competence in a particular procedure. Motion analysis systems, such as the Imperial College Surgical Assessment Device (ICSAD), are receiving increasing attention for the evaluation of technical surgical skills. These systems are designed to track hand motion in 3 planes by monitoring magnetic markers attached to the dorsum of surgeon's hands and provide digital feedback with respect to the dexterity of the user. The ICSAD has repeatedly been

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shown to be construct valid, inferred by the procedure's ability to differentiate between varying levels of experience, in both open surgical and laproscopic tasks [5,6]. Furthermore, the ICSAD also has been shown to be a valid measure of surgical dexterity [7,8]. In addition, Aggarwal et al [9,10] have speculated that motion efficiency indexes derived from the ICSAD can potentially serve as a valuable source of feedback to the novice trainee. These systems are being employed in such fashion predominantly in virtual reality trainers, where they often serve as the sole feedback trainees receive concerning their performance.

As the teaching of fundamental technical surgical skills in the operating room is increasingly supplemented by training in the surgical skills laboratory, it is critical to develop effective methods of instruction and feedback. Feedback is an essential aspect of becoming an expert at a practiced skill [11]. This is certainly true in surgical skills where the delivery of external feedback has always been thought to be crucial to technical skill development of a novice surgeon. With clinician's time at a premium, alternate methods of instruction, feedback, and independent learning such as computer-assisted learning could prove to be an effective adjunct to the traditional apprenticeship model [12–14]. Summers et al [14] have demonstrated the effectiveness of computer-assisted learning in basic surgical technical skills. However, to date the effectiveness of motion analysis systems, such as the ICSAD, as a feedback adjunct to computer-assisted learning has not been evaluated. There are theoretical reasons arguing for and against the potential utility of motion analysis as feedback in early learning. First, it has been argued that in the very early stages of training optimization of efficiency of motion is the primary goal of the learner [15]. In contrast, because computer-based evaluation does not address the cognitive aspects of skills performance, it is possible that it will not serve as an informative source of feedback. Hence, it is possible that feedback regarding economy of motion will serve as a sufficient source of information for the acquisition of proper technical performance.

Setting goals has long been accepted as a motivation technique to achieve superior performance. According to one educational theory, goals serve to guide learning, monitor and regulate one's efforts, and as a basis for evaluating one's performance [16]. Medical education has also adopted this practice. Curriculum objectives are identified and explicitly stated to students prior to courses with the assumption that this will guide student learning. While this technique may be effective for the acquisition of knowledge, little evidence exists on the effect of goals in the acquisition of technical surgical skill. Common practice would suggest that stating objectives would have a positive effect on performance; however, in a recent study by Gonzalez et al [17], using attending physician's technical performance as benchmarks, setting goals had no effect on the outcome of technical skills acquisition.

In this study, we compared the impact of two types of motion efficiency feedback (with and without expert criterion) with verbal feedback given by an expert on the acquisition of a simple surgical task. It was hypothesized that economy of motion feedback with expert criterion would lead to better learning than without expert criterion. It was also hypothesized that the verbal expert feedback was most critical to early skill acquisition.

Methods

Participants

Forty-five first-year undergraduate medical students with no prior knot-tying or instrument-tying experience were recruited from a single educational institution to participate in this study. All participants read and signed informed consent approved by the local ethics board.

Study design

All participants enrolled in the actual study observed an instructional video directing them in the steps of interrupted suturing and instrument knot tying. Participants were pretested in the suturing and knot-tying skill and then randomized into 1 of 3 study groups. The participants in both groups were matched for age (mean 24.5 years; participants in their first and second year of medical school were equally represented in all 3 groups).

Group A (motion analysis feedback: no criterion): Participants in this group were informed of the number of movements they made while performing the skill, as determined by the ICSAD, following each practice trial. They were provided with no additional instruction with regards to the procedure of the suturing task, nor were they able to review the instructional video. This type of feedback was selected based on an informal pilot survey delivered prior to the initiation of the study to 10 medical students. This survey aimed to determine which of the 5 possible motion efficiency measures derived from the ICSAD is most easily understood. The survey revealed that for 4 of the 10 students, the number of movements was the most understood variable, followed by total time, and spatial path, which were viewed as most easily understood by 2 students each, and finally average velocity per movement and time per movement, which were viewed as the most easily understood by 1 student each. Based on this informal survey, the number of movements was used as a primary source of computer-generated feedback.

Group B (motion analysis feedback: criterion): Participants in this group were informed of the number of movements they made after every trial, as determined by the ICSAD. Standard references in the form of the number of movements taken for an expert surgeon to complete the same task were also provided. No further instruction was given in regards to the mechanics of the suturing task, nor were participants in this group allowed to review the instructional video.

Group C (expert feedback): An expert instructor answered questions and provided performance feedback following each practice trial. Feedback consisted of constructive ways to improve performance and followed closely the script used in development of the instructional video. Demonstrations by the instructor were permitted.

Each participant then completed 18 practice trials followed by an immediate post-practice test. A retention test consisting of 5 simple interrupted sutures and knot tying using the same bench model employed during the practice trials was administered 1 month later. Participants were instructed not to practice the skills between the initial trials and the delayed post-test.

Apparatus

Participants sutured using 3-0 silk sutures (Sofsilk, Tyco, Mansfield, MA) on an artificial bench model resembling real tissue (The University of Toronto Surgical Skills Centre, Mt. Sinai Hospital, Toronto, Ontario, Canada). The ICSAD was used for the collection of hand motion efficiency data, which was then used as a source of feedback information. This evaluation method relies on quantifying hand motion characteristics using a commercially available magnetic tracking system (IsotrackII, Polhemus, Colchester, VT) to track the position of magnetic markers placed on the dorsal aspect of each of the participants' hands.

Analysis: Two separate technical performance assessment methods were applied: expert-based and computer-based.

Expert-based assessment: Each pre-, post-, and retention test was videotaped. A previously validated evaluation method using a global rating form was used for expert-based evaluation [18–20]. A modified Global Rating Scale (GRS) was used to evaluate subjects in 5 main areas: respect for tissue; time and motion; instrument handling; flow of operation; and overall performance. Each section is graded on a 5-point scale with 1 being the minimum score and 5 the maximum score for a total maximum score of 25 [20]. Points 1, 3, and 5 on the Likert scale are anchored with explicit behavioral descriptors. Two independent, blinded, and experienced general surgeons conducted evaluations using the recorded videotapes. The evaluators were able to fast-forward though the tapes, a procedure which, while shortening evaluation time, has been shown to be as effective as viewing the entire skill at its natural pace [21]. Agreement between the evaluators was assessed by calculating an intra-class correlations. Normality of the modified GRS was assessed with the Shapiro-Wilk test, which showed that modified GRS scores were normally distributed. An analysis of variance (ANOVA) model with 3 groups (no ctiterion, criterion, terminal feedback) and 3 tests (pre-test, post-test, and retention-test) was used to assess the effects on the modified GRS scores.

Computer-based assessment: The positions of the markers were tracked at a 20 samples per second frequency (Hz), and the data were integrated over time in order to calculate the instantaneous velocity of each marker. Based on the resulting velocity profiles, 4 measures were obtained: number of movements, time per movement, total distance, and average speed of each movement. Although all 4 parameters can be used to describe hand motions associated with laparoscopic performance [22], only the number of movements and the time per movement have been used to describe performance related to open procedures [23].

Normality was assessed with the Shapiro-Wilk test, which showed that the data were not normally distributed ($P < .05$). Thus, Kruskal-Wallis tests was used to evaluate the group differences during pre-, post-, and retention tests, and the changes in performance during the 3 tests within each group. The Mann-Whitney U test with Bonferroni adjustments was used post-hoc to evaluate for significant group differences.

ICSAD-generated performance curves were analyzed using regression curve fitting. A variety of functions for the persistent changes of motor learning have been reported, including exponential, S-shaped, hyperbolic, and power law. The currently received position is that the power law is the universal law of learning for motor and cognitive tasks [24–26]. The inverse power function ($R^2 = .9$) accounted for maximum variance of performance and was thus used for our estimations of slope and asymptotic values of best fit and data analysis. Slope and asymptotic values were analyzed using a one-way ANOVA, with a priori contrasts, to assess for group differences.

Results

The inter-rater reliability of the modified GRS, as evaluated by intra-class correlation coefficient, was 0.90, indicating that evaluators were able to distinguish reliably between inferior and superior performances.

Expert-based assessment

The results of the expert assessment can be seen in Fig. 1. ANOVA revealed an interaction between group and test factors ($F = 7.83$, $P < .001$) where all 3 groups were identical in the pre-test ($P = .67$) and they all showed significantly improved performance on the immediate post-test (group A: $P < .001$; group B: $P < .001$; group C: $P < .001$). However, groups A and B, who received computer-based feedback motion efficiency data without and with expert criterion, showed no significant improvement between pre-test scores and delayed post-test scores (group A: $P = .10$; group B: $P = .91$) In contrast, group C (expert feedback) showed sustained improvement of scores between pre-test and delayed post-test ($P < .001$).

Computer-based assessment

The results of the computer based assessment are shown in Fig. 2. All 3 group performed at the same level during the pre-test, post-test, and retention-tests: $\chi^2 = 1.84$, $P = .40$; $\chi^2 = 1.37$, $P = .50$; $\chi^2 = 2.70$, $P = .27$. However, exam-

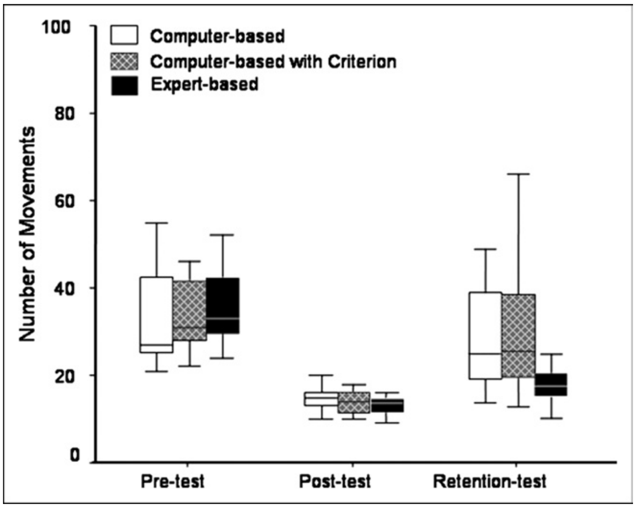

Fig. 1. Average modified GRS scores evaluated at pre-test, post-test and retention test.

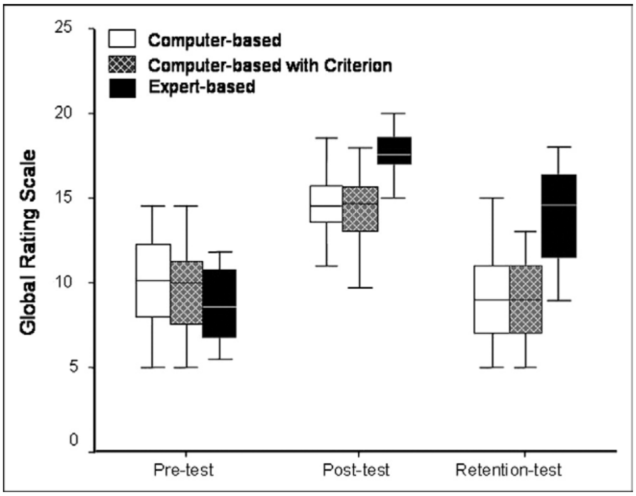

Fig. 2. Number of hand movements during performance of suturing and knot-tying skill at pre-test, post-test, and retention test. A smaller number indicates better performance.

ination of the changes in performance during the 3 tests within each group revealed that the groups differed significantly in the retention of the acquired skill. Groups A and B, who received motion efficiency feedback without and with expert criterion, showed significant differences between the 3 tests: $\chi^2 = 20.00, P < .05$; $\chi^2 = 19.10, P < .05$. Post hoc analyses revealed that initial improvements made in group A and group B from pre-test to post-test ($Z = -4.43, P < .05$; $Z = -4.36, P < .05$) were not carried to the retention test ($Z = -2.05, P = .32$; $Z = -1.0, P = .37$). Consequently pre-test and retention test results were similar for both groups: $Z = -1.91, P = .74$; $Z = -2.69, P = .54$. Participants in group C, who received expert feedback, demonstrated similar initial improvements from pre-test to post-test ($\chi^2 = 32.37, P < .05$; $Z = -4.84, P < .05$); however, these improvements were retained on the retention test ($Z = -4.06, P < .05$). Consequently, pre-test and retention test results were different: $Z = -3.29, P < .05$.

The results of group performance curves are shown in Fig. 3. The slope of the learning curves reflect the efficiency with which groups improved dexterity performance while the asymptotes/plateau of the learning curves reflected the maximal performance attained by the groups. All groups displayed improvement in number of movements. Examination of the slopes and asymptotes of the groups' hand movements and did not reveal statistically significant differences.

Comments

The last decade has seen advances in adjunctive methods of technical instruction. These methods have proliferated exponentially in the last few years with the improvement of virtual reality technologies. The perceived value of skills laboratory training has also escalated. It is often advocated that machine-based learning (virtual reality) and machine-assisted learning (hand motion analysis) offers the benefit of the provision of objective metrics of performance to the learner [10,27]. This ability to provide instantaneous feedback to the entry level trainee about their current proficiency level, without extensive expert contributions, seems very attractive and cost-effective. However, before the implementation of this technology to the current curricula, these educational tools must be validated and their effectiveness documented.

Feedback and learning: theoretical perspective

There is a theoretical bases for providing computer-generated, external feedback as a means to augment the learning process. When acquiring new psychomotor skills, learners can use 2 forms of feedback to evaluate their performance: internal and augmented feedback [28,29]. Internal feedback, generated from proprioceptive and visual sources, provides information about the movement itself; augmented feedback, generated externally, provides information about the degree of success in meeting a movement goal and about various components involved in the completion of a movement. The appropriateness of augmented feedback is predicated on accurate measurement techniques that can be used to assess performance and the subsequent structuring of feedback based on these methods. Thus, in order to maximize learning, augmented feedback should serve as a valuable and informative source of information. Based on this information, the learner should be able identify the discrepancy between their own perceived internal feedback and the augmented feedback, and consequently close the gap to learn the motor skill.

Current findings

In this study we attempted to bridge the gap between using motion analysis as an evaluation tool and using motion analysis as an education tool. The effectiveness of motion analysis for the purpose of technical skills evaluation of novice trainees has been proven [30]. To date, the effectiveness of this method as a source of augmented performance feedback has been speculated upon [9,10,27] but not tested systematically. Therefore, we designed the current study to test the hypothesis that information about motion efficiency derived from the ICSAD, the most commonly used form of computer-assisted analysis of technical performance, constitutes a useful form of augmented performance feedback.

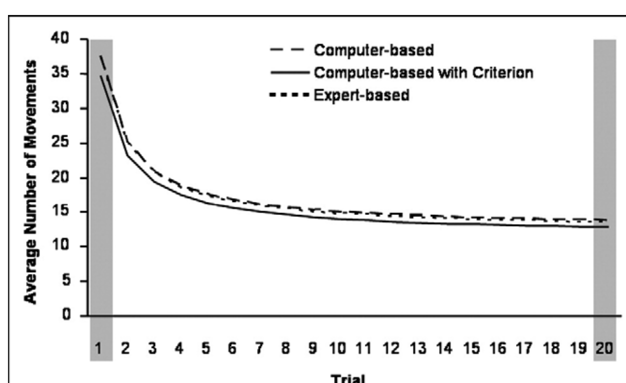

Fig. 3. Learning curves based on the average number of hand movements during the learning of a suturing and knot tying skill. Trials 1 and 20 (shaded) were used as pre-test and post-test, respectively, and the remaining 18 trials (trials 2 to 19) are referred to as the acquisition trials.

We have demonstrated that information about motion efficiency in the form of number of movements made during the learning of an instrument knot-tying skill, with or without expert derived criterion, was not as valuable to the learning process as expert feedback. We suggest that there are 2 possible explanations for these results. First, we speculate that the terminal expert feedback was more easily understood by the trainees, and therefore they learned the most as they were able to optimally encode the performed skill because they received consistent, constructive, and interpretive augmented feedback. On the contrary, although as suggested by our pre-experimental survey, the information about the number of movements provided could have been understood by the participants, perhaps they could not easily translate this information into a useful feedback with respect to how accurately the skill was performed. The second, more plausible, explanation for the observed pattern of results is that the information provided by the ICSAD, even if understood by the trainees, provides feedback about only 1 dimension of performance and thus is not suitable for optimal learning. In contrast, expert surgeons can provide a rich array of information about the performance that the computer-based methods cannot. For example, performance-related information such as spacing of the sutures, depth of skin penetration, amount of skin eversion, placement of the knot on the wound (to the side), and lengths of the free ends of the sutures are not addressed by computer-generated feedback. All of these factors increase the cognitive understanding of the skill, and are believed to result in better performance, leading to a superior outcome [31]. Therefore, it can be speculated that computer-generated augmented feedback about the efficiency of hand motions can provide valuable information about performance, but this information is only a portion of what constitutes good suturing and knot-tying techniques. Consequently, although both hypothesis are not mutually exclusive, our findings suggest that the information about movement economy provided by the ICSAD constitutes an insufficient source of augmented feedback.

Motion analyses feedback and learner-centered education

How do these findings fit with our current understanding of the learner-centered approach to teaching technical aspects of surgical skills to novices? In recent years, we have witnessed tremendous growth in the adoption of computer-assisted learning in training curricula [32]. This includes the use of computer based video instructions [14,32], as well as virtual reality systems [33–35]. These attempts have been mainly propelled by the perceived need to objectify and centralize learning of technical aspects of surgery outside of the operating room. Providing a mode of consistent feedback, which is sufficiently accessible to the user and does not require the presence of an expert, is essential to the learner-centered approach.

For example, virtual reality simulators, capable of providing post-trial and on-line information about the performance of a skill, may prove to be excellent teaching tools that promote learner-centered learning. However, a recent study by Gonzalez et al [17] suggested that structured feedback does not facilitate the learning process for certain laparoscopic skills. In their study, 1 group of trainees was given specific goals and augmented feedback about their performance, while a second group did not receive similar goals or feedback. In a test of laproscopic skill using target manipulation and diathermy as well as target transversal tasks on the minimally invasive surgical trainer–virtual reality trainer, 37.5 % and 62.5% of the feedback group was able to achieve attending level of performance, compared to 25% and 50% of the control group. The results were not significantly different between groups. Similarly, in our study, it is possible that the augmented feedback was not well understood, or alternatively it did not contain any additional information about the performance than the trainees' internally generated feedback [36].

Can augmented motion efficiency feedback be a valuable asset to surgical education in general? While it is clear that expert feedback cannot be replaced by this technology, perhaps there would be merit in combining self-evaluation with instructional videos. It has been shown that by reviewing instructional videos throughout practice trials students have been able to train themselves to a level of accuracy and dexterity equal to that of students who received expert terminal feedback for basic surgical skills [14]. This learning method requires accurate self-evaluation to close gap between learner and expert skill performance. While it has been shown that, in general, medical and surgical trainees are relatively poor self-evaluators [37–39], recent evidence in simulation-based surgical skill training has shown that estimates of performance and accuracy of error estimation improves with repetition [40]. Perhaps the availability of pre-recorded expert demonstrations and motion efficiency feedback, along with appropriate instruction in self-evaluation will prove to be a more complete and effective educational method. However, this is clearly an issue that must be explored further.

Motion analysis evaluation and novice trainees

Motion analysis systems have repeatedly been shown to be a reliable measure of dexterity [7,8] and differentiate between levels of expertise [5,6]. In the present study, the ICSAD did not detect differences between the experimental groups at post-testing and retention testing as compared to modified GRS scores (Figs. 1 and 2). Most likely, the ICSAD and modified GRS assess different constructs of the same skill. The fact that expert reviewers were able to detect differences in performances between the group trained by an expert and the 2 groups trained with the use of motion efficiency feedback implies that training mode affected suturing performance. For example, skills such as positioning of the needle on the driver, eversion of the skin, pronantion and supination of the wrist, spacing of the sutures, and overall confidence and appearance may have influenced the expert judgment without impacting the efficiency of motions, as these constructs are not directly evaluated by the ICSAD. This implies that although all participants, regardless of the mode of training, learned how to economize their motions, those trained by experts acquired other aspects of the skill. Therefore, the importance of these results is that motion analysis scores alone may not be sufficient to assess novices. Thus, quality assessment should still be the emphasis at the initial stages of training, while motion efficiency may play a more important role in more advanced stages of training.

Limitations and future research directions

Although we have demonstrated that the presence of an expert and subsequent expert feedback throughout the entire learning phase led to better acquisition and retention of skills, it is possible that similar results might have been obtained with feedback during the initial 5 to 10 trials corresponding to the sharp changes in the learning/performance curves. Following the initial learning phase, the expert interaction could be replaced with computer-generated feedback. That is, once learners have learned to perform the skill safely and accurately, it is possible that computer-generated feedback could shorten learning curves in the absence of expert tutors, thus saving crucial faculty time. The possibility of bridging expert feedback with computer-based feedback has yet to be explored, but is viewed as a potential topic for further research.

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