SIM ONE, DO ONE, TEACH ONE: CONSIDERATIONS IN DESIGNING TRAINING CURRICULA FOR SURGICAL SIMULATION

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PREFACE

I am writing this while sitting in a Lear 35, on my way back to Montreal. Our pilot's name is Kyle, he seems impossibly young, and this is his first time flying this airplane. I am trying to conceal the "Do you really know what you're doing?" look in my eyes, which I have so often seen on patients' faces in sundry teaching hospitals filled with medical students and residents. Suddenly I am very thankful for his experienced co-pilot, Jane. And I am also thankful for the significant role simulation has played in his training. This isn't really the first time he's flying. I don't want him learning the basics on me, and patients rightfully don't want me practicing the basics on them. Although the role for simulation in surgery seems not only obvious, but rather imperative, it is only recently that it has started gaining more widespread use in our training, despite a long history in other high stakes industries.

The following is a manuscript-based thesis investigating optimal training curricula for surgical skills acquisition using simulation. The abstract was accepted for oral presentation at the Society of American Gastrointestinal and Endoscopic Surgeons (SAGES) 2011 Annual Meeting and was presented on April 2. The manuscript was submitted to Surgical Endoscopy on February 11, 2011.

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ABSTRACT

Background:

Although there is value in the use of simulation for the acquisition of fundamental surgical skills through goal-directed practice in a safe environment, there is little evidence guiding educators on how to best implement simulation within surgical skills curricula. This thesis reviews the application of the expert-performance model in surgery and the role of simulation in surgical skills acquisition. The focus is on implementation of deliberate practice, highlighting the principles of proficiency-based training, part-task training and overtraining.

In a randomized controlled trial, we investigated the impact of part-task training by examining whether practicing a basic laparoscopic simulator task (peg transfer, PT) facilitates learning of a more complex skill (intracorporeal suture, ICS). We examined overtraining by comparing ICS learning and PT retention in subjects that had standard PT training (passing proficiency) to subjects who overtrained on PT (expert proficiency) .

Methods:

Surgically naïve subjects were randomized to one of three PT training groups: control, standard training, and overtraining. All participants then trained in ICS. The learning curves for ICS were analyzed by estimating the learning plateau and rate using nonlinear regression. Skill retention was assessed by retesting participants one month after training.

Results:

Part-task training: ICS learning plateau rose with increasing PT training and there was a trend toward higher initial ICS scores and faster learning rates with increasing PT training.

Overtraining: At retention, there were no differences in PT scores. Overtrained participants saved time in learning ICS compared to controls, but PT overtraining took longer than the time saved on ICS training.

Conclusion:

In surgically naïve subjects, part-task training with peg transfer alone was associated with slight improvements in the learning curve for intracorporeal suturing. However, overtraining with peg transfer did not improve skill retention and peg training alone was not an efficient strategy for learning intracorporeal suturing.

RESUMÉ

Contexte:

Bien qu'il y ait un intérêt à utiliser la simulation pour développer des aptitudes fondamentales en chirurgie, par la pratique ciblée réalisée dans un environnement sécuritaire, il n’y a toutefois que peu de consignes indiquant aux éducateurs comment intégrer adéquatement la simulation dans les programmes d’acquisition de compétences chirurgicales. Cette thèse analyse l'application du modèle de performance d’expert en chirurgie ainsi que le rôle de simulation dans l'acquisition de compétences chirurgicales. Ce document est centré sur la mise en place de la pratique délibérée en mettant l’accent sur les principes d’entrainement basé sur des compétences, l’entrainement à l’exécution de tâches partielles et le surentraînement.

Dans une étude aléatoire contrôlée, nous avons étudié ces principes pour déterminer 1) si pratiquer une tâche psychomotrice de base (le transfert sur planche à chevilles, TPC**)** sur un simulateur FLS facilite l'acquisition de compétences plus complexes (la suture intracorporelle, SIC) et 2) nous avons comparé l'impact, sur la rétention de TPC et de l’apprentissage de SIC, de l’entrainement à un niveau d’expert et de l'entraînement à un niveau de passage.

Méthodes :

Des novices en chirurgie ont été aléatoirement distribués dans trois groupes d’entraînement : un groupe contrôle, un groupe d’entraînement standard et un groupe de surentraînement. Tous les participants se sont alors entraînés à réaliser des SIC. Les courbes d'apprentissage pour les SIC ont été analysées par régression non linéaire, pour estimer le plateau et les taux d'apprentissage. La rétention de compétences a été déterminée en réévaluant des participants un mois après l'entraînement.

Résultats :

Le plateau d'apprentissage des SIC a monté avec l'augmentation de l'entrainement au TPC. Aussi, il y a eu une tendance croissante des scores initiaux des SIC et les taux d'apprentissage ont été plus rapides avec l'augmentation de l'entraînement au TPC. Pour la rétention, il n'y a eu aucune différence entre les scores de TPC. De plus, quoique les participants surentraînés au TPC ont nécessité moins de temps pour l'entrainement des SIC comparativement au groupe de contrôle, le surentraînement au TPC a pris plus de temps que le temps qu'il n'en a gagné lors de l'entraînement aux SIC.

Conclusion :

Chez les novices en chirurgie, lorsque réalisé seul, l'entrainement au transfert sur planche à cheville, pour la réalisation de tâches partielles, a été associé à une faible élévation de la courbe d'apprentissage pour les sutures intracorporelles. Toutefois, le surentraînement au transfert sur planche à cheville n'a pas amélioré la rétention de compétence. Enfin, l'entrainement sur planche à cheville seul ne s'est avéré être une stratégie efficace pour apprendre à réaliser des sutures intracorporelles.

INTRODUCTION

While our history is filled with accounts of individuals with exceptional performance, it is only recently that the study of expertise has moved from anecdotal accounts to a more scientific approach. We now know that early descriptions of experts, starting with Sir Francis Galton's *Hereditary Genius*, over-emphasized extraordinary innate abilities [1]. Recent research suggests that experts' superior performance is acquired through learning and adaptation with a profound impact from goal oriented practice and only a limited role for hereditary abilities [2]. Such an empiric approach to expertise research lends itself to more practical and relevant applications, providing insights into the possibilities and limits of both the acquisition and maintenance of expert performance.

Research on surgical expertise is increasingly relevant, with interest from the general public, our governing bodies, and the medical field. The rapid pace of innovation in surgical procedures and technology, combined with the need to enhance patient safety, limited operating room resources and decreased resident work hours have driven the development of simulation technology and new paradigms for surgical education [3]. Aside from medico-legal aspects arising from the public's interest and willingness to invest in health care [4], doctors themselves are increasingly interested in development and maintenance of expertise. For example, the Society of American Gastrointestinal and Endoscopic Surgeons (SAGES) membership rated "What methods of simulation are most effective in helping surgeons learn techniques and skills for gastrointestinal and endoscopic surgery" in the top third of research priorities [5]. Further evidence for the importance of medical expertise research comes from financial agencies' increased funding for endeavours aimed at objective measurements of performance, and performance-based remuneration [6].

The objective measurement and understanding of surgical expertise acquisition and maintenance is thus, not surprisingly, at the forefront of surgical education programs. This thesis will first introduce the expert-performance approach and describe simulation as an application of this model for surgical skills acquisition. Since the primary objective of surgical practice for residents is developing efficient procedural knowledge [7], the literature on the principles for designing surgical skills training curricula will be reviewed. This will serve as an introduction to a manuscript reporting a randomized controlled trial we performed to investigate the implementation of these concepts.

LITERATURE REVIEW: THE EXPERT-PERFORMANCE APPROACH TO SURGICAL SKILLS SIMULATION CURRICULA

THE EXPERT-PERFORMANCE MODEL

Ericsson and Smith’s expert-performance model, comprised of three crucial stages, strives to identify the mechanisms mediating expert-performance [1] and may thus aid in designing curricula that ultimately produce experts. The first stage requires the identification of representative tasks of expert-performance and their replication within a controlled laboratory setting. The second stage involves empirical analysis to identify the mechanisms underlying experts’ superior performance. The last stage examines the effect of a specific practice activity to elucidate factors that may influence the acquisition of these expert-performance mechanisms.

Since perceptual-motor tasks can be designed to capture the essence of specific surgical tasks [4], simulators lend themselves well to applying Ericsson’s expert-performance approach as they allow measurement and empirical analysis of representative tasks in a controlled setting [1, 8]. Simulation is gaining popularity in surgical training. It offers low-stakes, learner-centered education, with task-based simulation allowing beginners to acquire fundamental skills prior to their clinical experience through practice in a safe environment. Furthermore, simulator practice allows repetition of a task and can be interrupted as needed, providing an opportunity for immediate feedback. Furthermore, through retrospective analyses of recorded performance, simulator-based research may define goals for practice by identifying performance aspects that can be trained and improved [4]. Simulation also provides an opportunity for objective skills assessment [9] through validated performance metrics [10]. Performance in some simulators correlates with intraoperative performance [3, 11-12] and simulator training can improve both initial technical performance [13-17] and its maintenance [18]. Simulators thus provide a good platform both for implementing deliberate practice, potentially improving clinical performance, and measuring this impact. It is therefore no surprise that much of the research of surgical expertise centers around expert and novice performance in a variety of simulators.

THE EXPERT SURGEON

Traditionally expertise research in medicine equated clinical experience with expertise [6]. Medical experts were initially defined based on their years of experience or academic rank [19]. Surprisingly, then, multiple studies found no differences in diagnostic accuracy [20-21], cognitive processes [21] or procedural completion or complication rates [22] based on extent of physician experience. Three decades of research on medical expertise have continued to fail to demonstrate a link between length of practice and reproducibly superior performance [6], with at most only weak correlations between performance and years of professional experience [4, 23-24] . More recent discussions of surgical expertise recognize that expertise is not merely experience.

Ericsson's expert-performance model defines expert-performance as the highest level of skill acquisition and the final result of a gradual improvement in performance through deliberate practice in a given domain. However, while most professionals reach a stable, average level of performance and maintain this status for the rest of their careers, experts are those with consistently better outcomes [6]. This is supported by findings that while clinical volume is related to outcomes, there is still great variation in the performance of surgeons with high case volumes [6, 25]. Similar to experts in other domains, expert surgeons have superior pattern recall and recognition and use both forward and backward reasoning with a highly structured knowledge base [26-27]. They also demonstrate greater automaticity, superior self-monitoring and less distractibility [27-28]. It again becomes evident that such findings are at least in part explained by the importance of deliberate practice in the development of expertise, with the number of hours spent in deliberate practice, rather than just hours spent operating, impacting the level of performance achieved. We now recognize that previous surgical expertise research focused too much on experience and that there is a difference between experienced clinicians and clinicians with superior performance [29]. If we follow the expert-performance model, superior performance is linked to planning, complex reasoning, self-monitoring and evaluation [6].

The challenge in today's surgical expertise research is describing what practice activities led to the acquisition of these complex mechanisms. Identifying this optimal type of practice is crucial for surgical education, where the effectiveness of simulator-based training is recognized to depend on curriculum quality, rather than on the simulator used[30].

PRINCIPLES OF SURGICAL SKILLS TRAINING

Motor skills acquisition

Fitts and Posner's theory of motor skills learning is currently the most popular basis for understanding surgical skills acquisition. According to Fitts and Posner the learning of complex motor skills, such as the performance of surgical tasks, occurs through three stages that highlight the interdepence of cognitive and motor skills [9]. First, during the cognitive phase, learners try to understand the mechanics of the task through reading and watching demonstrations. In the subsequent associative phase, learners actually perform the task, attempting to develop associations between the cognitive elements they've acquired in the first phase and the psychomotor steps involved in the task. Lastly, following practice, learners' psychomotor movements become automated as they reach the autonomous phase.

Recent research on surgical skills acquisition encourages using applications of the Fitts-Posner model as the framework for the development of surgical skills curricula [8, 31-32]. It seems that trainees learn best when they follow a sequence of steps based on this approach, and moving the early phases outside of the operating room seems an obvious and desirable goal. Learners in the cognitive phase acquire knowledge about the task steps through didactic teaching and watching demonstrations. Technical skills training on the simulator with feedback and assessment of the learner's progress allow for the cognitive skills to be translated into task performance during the associative phase. Trainees finally reach the autonomous stage when they achieve a previously defined proficiency target. While these overarching principles are agreed upon, there is much debate regarding the specifics of what the training in the associative phase should consist of to optimize the acquisition and maintenance of surgical expertise.

Deliberate practice

The cornerstone of expertise development within the expert-performance model is that expertise requires extensive goal oriented deliberate practice [2]. Although early accounts suggested that exceptionally gifted individuals could rapidly achieve expert-performance, as in the case of famed child prodigies, numerous expertise studies in a variety of domains have reproducibly quantified the preparation time required for attainment exceptional performance as 10 years or 10,000 hours [2]. However, research in fields varying from Morse Code operation to typesetting to sports has shown that with mere repetition, performance tends to plateau at less than maximal levels [2, 33]. Mere repetition is ineffective; developing expertise requires active practice, aimed at clear goals, and a drive to learn and to improve [34]. Furthermore, even very experienced individuals can augment their performance through deliberate efforts to improve [2]. Simply lengthy enough practice is clearly not sufficient - the structure of that practice is crucial.

To address the quality of practice, Ericsson et al. introduced the concept of deliberate practice, which consistently led to improvements in performance [2]. In order to qualify as deliberate practice, training must meet four main criteria. First, the participants must strive to improve a specific aspect of performance for a representative task of expert-performance. Secondly, participants need valid, thorough and immediate feedback on their performance. Another fundamental prerequisite for deliberate practice is the opportunity to repeatedly perform the task within a controlled environment. Lastly, it appears ideal that training sessions be limited to around an hour, allowing sufficient concentration to sustain active efforts to improve performance [6]. According to the expert-performance model, it is therefore both the quantity and the quality of practice, providing goal directed training with opportunities for repetition with immediate feedback, that are fundamental prerequisites for the development of expert-performance [35]. This holds true in studies of surgical skills acquisition, where increases in amount of practice were associated with increases in performance [36]. Furthermore, enhanced performance resulting from simulator training depended directly on whether the training procedure incorporated the characteristics of deliberate practice [36].

As we have discussed, simulators provide an obvious platform for the sustained, deliberate practice required for the development of expertise [2].

While there is great interest in the role of simulation in surgical skills training and evaluation [9], as well as evidence for skill transfer to the clinical environment [11-12], less is known about how best to integrate simulation into the surgical curriculum. The remainder of this thesis will discuss some important considerations when designing deliberate practice for the development of surgical expert-performance: proficiency-based training, part-task training, and overtraining.

Proficiency-based training

Traditionally, assessment and certification of technical skills in medicine uses procedural numbers as a substitute for competency. This approach is however fraught with problems, mainly due to inconsistencies in the numbers of procedures needed to achieve competency for any given task in the surgical literature [22, 37]. This heterogeneity in mastering technical skills is likely due to individual learning differences, whether in starting knowledge and abilities, motivation, or, perhaps most importantly, the quality of the educational experience, supervision and feedback. Training curricula based on number of cases can lead to an inadequate skill set, with some individuals insufficiently trained, and can be inefficient, with some learners spending unnecessary time training.

By defining performance targets, proficiency-based training produces uniform skill, regardless of individual skill acquisition learning curves. Proficiency-based training is effective even for very novice participants, ensuring competence is reproducibly attained while removing the guesswork out of how many cases one may need to become proficient. Research showed that medical students can achieve outstanding success at tasks normally reserved for more advanced surgical residents [38]. Proficiency-based training improves motivation and can improve attendance in the skills laboratory [39], which is one of the key components to the success of a simulator skills curriculum [40]. In addition to, or perhaps *because* it promotes deliberate practice, proficiency-based training leads to improved performance compared to the same duration of training without goals [41]. It also results in superior clinical performance with fewer procedural complications [17, 42-44]. Proficiency-based training also offers exceptional technical skill retention [45]. Experts thus recognize that achieving a measurable level of competency based on validated measures of skill is superior to case numbers as a surrogate for proficiency [22, 32, 40]. It is increasingly thought that the future of medical certification will move away from mere experience to demonstrated competence, based on achieving appropriate proficiency targets [46]. How to best define these proficiency targets, however, remains unclear [30] and was one of the issues investigated in our study.

Part-task training

Expertise in medicine is unique, requiring mastery of a wide variety of fields: motor, cognitive, and interpersonal [47]. Surgery in particular involves complex procedural tasks, and the acquisition and mastery of such composite skills is the challenge residency training curricula are charged with. Part-task training is a learning strategy whereby a complex task is deconstructed into simpler components for practice. Trainees gain proficiency in the individual components before progressing to the more complex task [48]. The data on the role of part-task training for surgical skills acquisition, however, is conflicting.

Part-task training is thought to develop more effective unitizing of components of a complex task, as demonstrated though faster reaction times in the acquisition and retention of procedural skills [49]. One surgical application of this principle, and the simulator used in our study, is the McGill Inanimate System for Training and Evaluation of Laparoscopic Skills (MISTELS). Performance metrics have been developed and validated for this laparoscopic skills box-trainer, with passing scores for each of its five tasks and the overall program reliably established [10]. The five tasks increase in difficulty from task 1 (peg transfer task) to task 5 (suture with intracorporeal knot). The peg transfer task develops depth perception, eye-hand coordination, working with a fulcrum effect and the coordinated use of both hands. These are the skills required to transfer and position a needle between needle holders during the intracorporeal knot task. Supporting Clawson’s findings that part-task training should start with the part of the task that develops the most effective strategic skills [49], preliminary work in our lab showed better intracorporeal suturing performance in students who used a part-task strategy by first training with the peg transfer task, compared to non-trained controls. This suggests transferability of skills from the peg transfer to the suturing task, highlighting that a part-task training strategy may be beneficial in teaching complex surgical skills [3].

Whole-task training, in which learners train by performing a task in its entirety, is supported by research as well. It seems whole-task training yields superior results in learning complex surgical skills, specifically those composed of several discrete skills [50] or involving a high degree of inter-limb coordination [51]. Overall it seems that part-task training is most beneficial when the complexity of the whole task is high but the organization is low, meaning the task components are not highly integrated. Conversely, whole-task training seems better when the task is highly organized[52]. In our study we aimed to elucidate the role of part-task training with the peg transfer task on the learning of the more complex intracorporeal suturing task in the MISTELS simulator.

Overtraining

As we have already discussed, while it is now accepted that interval practice to a set proficiency criteria provides ideal training, there is less agreement about how best to define that proficiency level [37]. Proficiency is often defined by attaining a passing score. This target is considered an acceptable level of competency, and is usually determined using the distribution of scores attained by a large number of surgeons with varying skill levels [10, 37].

There may however be a benefit to overtraining *beyond* the passing level, in that practice to a level defined instead by expert-performance may improve retention of the learned skill [53]. Overtraining enhances procedural task performance [54] and it is thought that “the single most important determinant of skill and knowledge retention is the amount of ‘overlearning’ or additional training beyond that required for initial proficiency” [9]. We cannot alter that the longer the period of non use of a motor skill, the greater the decay [9, 55-56] however, retention of motor skills appears to depend on the degree to which the skill was perfected [54, 57-58]. It is believed that training to expert proficiency levels enhances skill transfer compared to less rigorous training [32, 54], possibly due to stronger stimulus-response bonds and enhanced automaticity developing with increased repetitions [56]. This advantage of overtraining seems to apply not only when training on complex tasks, but also improves retention during part-task training [49]. Participants’ continuing advancement of their skills during overtraining [54], possibly due to increased opportunity for feedback [58], resonates again with Ericsson’s findings that deliberate practice allows for improvement of performance even in individuals already performing at a high level. The data supporting this idea, however, are limited [56] and there is a paucity of literature comparing overtraining to standard training. The effects of overtraining on skill transfer and skill retention are thus the last concept we examined in our study.

SUMMARY

The psychomotor challenges inherent to surgery are evident by steep procedural “learning curves” documented in the literature. Constraints ranging from reduced resident work hours, increased operating room costs, public and payers' increasing concern with medico-legal aspects of health care to the ethics of learning basic skills on patients have all led to the increasing use of simulators in surgical training. Effective training requires the development of training curricula optimizing both the efficiency of learning and the retention of acquired skills [49]. Despite this understandable interest in the acquisition and maintenance of surgical expertise, the ideal implementation of such programs remains elusive.

Ericsson's now pervasive expert-performance model highlights the need for prolonged deliberate practice in order to develop and maintain expert-performance. This literature review sought to elucidate the means to best establish deliberate practice to specifically optimize surgical skills acquisition. Proficiency-based training emphasizes crucial deliberate practice components by encouraging goal-oriented repetition of representative tasks in a feedback-rich setting. Part-task training allows improved learning of complex tasks, such as those often required of surgeons, through transfer of skills from simple to difficult tasks and unitization of procedures. Overtraining is an even further application of the expert-performance model, showing performance improvement even in those with already high-level performance. Furthermore, overtraining encourages improved retention of superior performance. Integration of these three principles into surgical simulator training curricula thus seems key to the acquisition and maintenance of surgical skills. As you will see below, our study strove to quantify the impact of such interventions, so we may better understand the factors integral to initiating and sustaining deliberate practice in the quest for expertise. This type of scientific assessment of surgical expertise may allow identification of the factors affecting performance, potentially leading to an evidence-based approach for identifying those factors that need and, as importantly, those that need not, be given particular attention in the development of surgical skills training curricula [27].

> The struggle to perform well is universal: each of us faces fatigue, limited resources, and imperfect abilities in whatever we do. But nowhere is this drive to do better more important than in medicine, where lives may be on the line with any decision [59].

MANUSCRIPT: MASTERY VERSUS STANDARD PROFICIENCY TARGET FOR BASIC LAPAROSCOPIC SKILL TRAINING: EFFECT ON SKILL TRANSFER AND RETENTION

INTRODUCTION

Although there is considerable interest in the use of simulation for the acquisition of fundamental surgical skills through goal-directed practice in a safe environment, little evidence guides educators on the establishment of simulator training goals. The identification of an optimally effective and efficient training strategy for simulator-based laparoscopic skills training is important both to practicing surgeons and trainees. A recent Delphi process led by the Society of American Gastrointestinal and Endoscopic Surgeons (SAGES) ranked the question "What methods of simulation are most effective in helping surgeons learn techniques and skills for gastrointestinal and endoscopic surgery" in the top third of research priorities[5]. Furthermore, the availability of organized skills curricula is an important factor in selecting programs for prospective surgical residents[60].

In light of the psychomotor challenges inherent to laparoscopic surgery, which are evident by steep procedural "learning curves", simulation plays an increasingly crucial role in surgical skills training. The McGill Inanimate System for Training and Evaluation of Laparoscopic Skills (MISTELS), shown in Figure 1, was developed and validated for the evaluation of fundamental laparoscopic skills[10]. Furthermore, novices who trained on the MISTELS simulator improved their operative performance. The simulator has become increasingly relevant to surgical training as it was recently incorporated as the manual skills component of the Fundamentals of Laparoscopic Surgery (FLS) program [61] and FLS certification is now required to be eligible for certification by the American Board of Surgery[62]. While the use of FLS as an assessment tool is well established, there is also great interest in the role of simulation in surgical skills training. There is evidence for transfer of skills acquired through FLS training and other simulations to the clinical environment [11, 14], but less is known about how best to integrate simulation into the surgical curriculum. The present study addresses two aspects of skills training: (1) part task training and (2) setting proficiency targets.

Part-task training is a learning strategy whereby a complex task is deconstructed into smaller components for practice. Trainees gain proficiency in the individual components before progressing to the more complex task [48] and it is thought that a higher level of skill can be attained if participants master individual components before integrating them into the whole task[52]. The five FLS tasks increase in difficulty from task 1 (peg transfer, Figure 2a) to task 5 [suture with intracorporeal knot (ICS), Figure 2b]. The peg transfer task develops depth perception, eye-hand coordination, working with a fulcrum effect and the coordinated use of both hands. These same skills are required to transfer and position a needle between needle drivers during the ICS task. In preliminary work, we found a greater improvement from baseline ICS scores in students who first performed forty repetitions of the peg transfer task, compared to non-peg trained controls. This suggested transferability of skills from the peg transfer to the ICS task and that a part-task training strategy may be beneficial[3]. That study, however, only examined the first two suturing trials and not the learning curve. Since then, our understanding of how to measure performance during learning has become more sophisticated. Applying a nonlinear regression curve-fitting technique to analyze the learning curve for early performance yields an estimation of the performance plateau and rate of improvement [63]. Using this technique, we found that the peg transfer learning plateau was lower [63] and the rate of improvement was slower[64] in medical students with low self-reported interest in a surgical career, suggesting that learning plateau and rate may be useful outcomes for educational interventions designed to impact the learning curve.

A second issue in design of simulation curricula is setting training goals. The development of expertise requires sustained, deliberate practice over long periods of time[2]. For performance assessment, it is accepted that interval practice to a set proficiency criterion should be used as a training benchmark, rather than a standard number of cases or time in a simulator [32]. Increasingly, there is recognition that numbers are poor surrogates for competence and the focus should shift to assessing performance instead of counting numbers[65]. However, there is less agreement about how best to define that proficiency level. Acceptable FLS simulator performance is currently defined by attaining a “passing score”. This target is considered an acceptable level of competency, and was determined using the distribution of scores attained by a large number of surgeons with varying skill levels[10].

There may however, be a benefit to overtraining *beyond* the passing level, in that practice to a mastery level ,defined instead by expert performance, may improve retention of the learned skill[53]. The FLS training curriculum emphasizes both overtraining and the importance of the peg transfer task by recommending residents train to expert proficiency on the peg transfer task before proceeding to the other simulator tasks [66]. Ebbinghaus first described overtraining in 1885, showing that prolonging the initial training period in a task beyond what is necessary for good immediate recall results in improved long-term retention[67]. Furthermore, improved skill retention is obtained if several successful performances of a task are achieved prior to termination of a segment. Stopping practice while a trainee is still in the “steep” part of the learning curve has been associated with less retention over time [68]. Retention of motor skills also appears to depend on the degree to which the skill was perfected [57] and it is often stated that “the single most important determinant of skill and knowledge retention is the amount of ‘overlearning’ or additional training beyond that required for initial proficiency”[9]. It is also believed that training to expert proficiency levels enhances skill transfer compared to less rigorous training[15]. The data supporting this idea, however, are scarce [56] and this hypothesis has not been formally compared to a control group undergoing traditional surgical simulator training.Compared to standard training, expert-level proficiency training requires a significantly greater investment of time both for the learner and teacher. This investment may be justified if it can be shown to enhance skill retention and transfer of knowledge to a new or more complex skill. The effectiveness of overtraining, which can be measured using the transfer of effectiveness ratio (TER, see the "Outcomes and data analysis" section below), will decrease as time spent peg-training increases [48]. It is therefore important to identify a part-task training goal that maximizes efficiency.

The objective of this study was to investigate whether proficiency based training to expert levels in a fundamental simulated laparoscopic skill (peg transfer) facilitates learning a more complex skill (ICS).We hypothesized that for the FLS simulator tasks: (1) part-task training in the peg transfer task would facilitate learning the more complex task (ICS); and (2)compared to standard peg transfer training to the "passing" FLS level, overtraining to an expert level would result in improved skill transfer to the complex task (ICS) and improved peg transfer retention.

METHODS

Study design

This was a prospective, randomized 3-arm study. After informed consent, participants watched a video demonstrating the simulator tasks and underwent baseline simulator testing for the peg transfer (PT) and ICS tasks. Subjects were randomized after gender stratification to one of three PT training groups (control, standard training and overtraining). The proficiency targets for each group are described in the “Simulator assessment” section below.

The control group proceeded to the suture task without further practicing of the PT task. The standard training group practiced the PT task until a passing proficiency level was achieved, then proceeded to the ICS task. The overtraining group practiced the PT task until expert levels were achieved, and then proceeded to the ICS task. The number of repetitions and total amount of time spent on the peg practice were recorded. All subjects were then trained in ICS with proctoring and scoring done by a researcher blinded to randomization status. All subjects repeated the ICS task either until a passing proficiency score was achieved, or up to a maximum of 80 repetitions. The score for each repetition of the task was then calculated, and the total time spent on the suture task was also recorded.

To assess retention of laparoscopic skills, subjects were re-evaluated one month after the completion of the ICS task training. They performed the PT task either until passing proficiency was reached or until a maximum of ten repetitions were executed.

Study setting and participants

The study was conducted at the Steinberg-Bernstein Centre for Minimally Invasive Surgery and Innovation at the Montreal General Hospital. McGill University undergraduate, graduate and medical students, as well as non-surgical residents, were invited to participate in the study. Surgical residents that undergo FLS training through their curriculum were excluded. Ethical approval for simulator research was obtained from the local Research Ethics Board at the McGill University Health Centre. Informed consent was obtained from all participants. Subjects filled out a questionnaire regarding factors thought to influence early performance in laparoscopy, including gender, handedness, and experience with video games, carpentry, sewing and competitive sports (Appendix I). Baseline simulator scores, as well as scores and practice times for the PT and ICS tasks were recorded (Appendix II). All assessments were shared with each participant as feedback, but were not shared with the program director or clinical supervisors, nor used in formal evaluation or for the purposes of promotion.

Simulator and tasks

The FLS simulator and the individual tasks have been described previously [3, 61]. They were chosen for this study both because they have been extensively validated, and because of their clinical relevance as the manual skills portion of the FLS program. Briefly, the simulator consists of a trainer box with an opaque cover, a built-in camera and 2 trocars (Figure 1). It can be attached to any monitor with an s-video connection. The 5 tasks include peg transfer, circle cut, placement of a ligating loop, and simple suture tied with extra and intra-corporeal techniques [66].

In this study, FLS tasks 1 (PT) and 5 (ICS) were used (Figure 2). For the PT task, 6 plastic rings are grasped from a pegboard on the subject’s non-dominant side, transferred to a grasper in the dominant hand, and then placed around a post on the corresponding dominant-side pegboard. The process is then reversed, requiring transfer from the dominant to the non-dominant hand.

In the ICS task, a 2-0 silk suture with a curved needle is introduced through a trocar and positioned using the needle holders, then the stitch is placed through target points on a slit penrose drain, and the suture is tied using an instrument tie. This is a complex task with clear clinical relevance that requires both laparoscopic dexterity and knowledge of how to tie a knot [3].

Simulator assessment

All subjects were trained and evaluated within the same environment under standardized conditions. For the PT task, subjects were proctored and scored by trained evaluators. All of the ICS proctoring and scoring was done by a single surgical education researcher blinded to PT practice status.

Standard passing scores for the five FLS tasks and the program overall have been established [10, 53]. Subjects are scored for efficiency (time) and precision. There are task-specific penalty scores for errors or lack of precision and a cutoff time is assigned to each task. Less time to complete a task and fewer errors thus translate into higher scores. We calculated the FLS scores for each task repetition for statistical analysis, but during training sessions we used Ritter and Scott's modified method for real-time scoring, rather than the standard FLS testing format scoring system [69]. This allowed rapid assessment of whether a subject achieved the desired proficiency level, based on completion time and error detection for each repetition.

Proficiency for the standard training group was defined by completion of the PT task within 65 seconds with no errors on three consecutive or five non-consecutive trials during two separate sessions. This ensured that the subject achieved the standard passing FLS score for the PT task and documented learning by verification of retention between sessions. As in a previous study[12], the time criterion for the standard practice group was increased from Ritter et al's 48 seconds [69] to 65 seconds (48 seconds plus 2 standard deviations, similarly to their proficiency target definitions for the other FLS tasks) to define a more practical goal for novices. Proficiency for the overtraining group was defined by completion of the PT task within 48 seconds with no errors[69]on three consecutive or five non-consecutive trialsduring two separate sessions, as per published expert-level performance benchmarks [53, 70].

The ICS task was repeated until a standard passing score was achievedwith no errors, on three consecutive or five non-consecutive trialsduring two separate sessions. It was expected that some participants would not reach proficiency [71], so practice ceased at a maximum of 80 trials[70] if a subject was unable to reach the target proficiency score for either task.

Outcomes and data analysis

Part-task training

The primary outcome was the plateau for the ICS learning curve. Scores for each ICS trial were plotted to produce a learning curve for each subject. Nonlinear regression was used to fit the exponential function and estimate an asymptote and rate parameter for each curve (Matlab 7.8, Matlab Inc., Natick, MA)[72]. These estimates were used to define two parameters of interest for each learning curve: the “learning plateau”, or asymptote, which represents the theoretical best score a subject could achieve with infinite practice and “learning rate”, the number of trials necessary to achieve 95% of the learning plateau, which represents the speed with which a subject learns the task (Appendix III). We assessed whether ICS learning plateau differed in the three PT practice groups using ANOVA with statistical significance defined as $p<0.05$. Statistical analysis was performed using SPSS (SPSS 11 for MAC OS X release 11.0.4, SPSS Inc., Chicago, IL). To further evaluate the impact of part task training using PT on the ICS learning curve we used ANOVA to compare the initial ICS score and learning rate. Data are presented as mean (SD).

Overtraining

Retention of learning was analyzed by comparing the PT scores in the three groups one month after completion of ICS training. The percentage change in PT performance at the retention session was compared using ANOVA.

The effectiveness of overtraining was evaluated using the transfer of effectiveness ratio (TER), which estimates simulator effectiveness by comparing time invested in PT practice with time saved in ICS training:

$$TER = \frac{time\ to\ passing\ ICS\ (controls) - time\ to\ passing\ ICS\ (PT\ training)}{time\ in\ PT\ training}$$

This mathematical model, initially developed to measure transfer of training using flight simulators [73], is now a commonly-used method for measuring training effectiveness [74]. Using this formula, a TER of 2 means that every hour spent training with the PT task saves 2 hours learning the ICS task [68].

Power analysis

Power analysis was conducted based on a pilot study in 7 subjects, which suggested that peg-trained subjects had better initial performance, higher learning plateau and faster rate of learning for the ICS task, with an additional advantage for overtraining compared to standard training (Appendix IV). Using the pilot data shown in Table 3 and learning plateau as the primary outcome, the sample size required for an alpha of 0.05 and a power of 80% was 16 subjects per group. In order to account for attrition, we aimed to enrol 25 subjects in each group.

RESULTS

Participant characteristics

Figure 3 shows the flow of participants. 99 simulator-naïve subjects enrolled and 77 participants completed the study: 28 controls, 26 standard and 23 overtrained. Participants did not differ in their demographic characteristics or baseline simulator scores (Table 1).Completers and drop-outs were similar in baseline characteristics including simulator scores.

Part-task training

The learning plateau for the ICS task rose with increasing PT practice (86(2) vs. 87(2) vs. 89(2), $p<0.01$). Post-hoc analysis showed significantly higher learning plateaus with overtraining compared to both control ($p<0.01$) and standard training ($p<0.01$), as well as for standard training compared to control ($p=0.05$). There was a trend toward higher initial ICS score (24(20) vs. 24(21) vs. 35(20), p=0.13) and faster learning rate (15(4) vs. 14(4) vs. 13(4) trials, p=0.10) with PT overtraining.

As the standard and overtraining groups reached clinically similar PT performance by the end of practice (103(2.4) vs. 108(1.7), $p<0.01$), and the effects on ICS learning curve were similar, we also analyzed the effects of no training (controls) with that of any PT practice (standard and overtrained participants together) on the IC suturing learning curve. Both the learning plateau for IC suturing (86(2) vs. (88(2), $p<0.01$) and the learning rate (15(4) vs. 13(4) trials, $p=0.05$) showed statistically significant improvement with PT training.

Overtraining

74 subjects completed retention testing. Table 2 shows the effects of overtraining on PT scores. Both standard and overtrained participants had a small drop in their PT scores at retention testing, but the relative drop in performance was similar in the two practice groups.

ICS training took 53(17) minutes for controls, 47(15) minutes for standard and 42(17) minutes for overtrained participants (*p*=0.05); post hoc analysis revealed that the overtrained participants saved an average of 11(5) minutes in IC suture training compared to controls (*p*=0.04). PT training however took 20(10) minutes for standard training and 39(20) minutes for overtraining (*p*<0.01), leading to a TER of 0.165 for the overtraining group and 0.160 for the standard training group.

DISCUSSION

The identification of effective and efficient training strategies for simulator-based laparoscopic skills training has significant implications in how simulation is incorporated into residency programs. In the present study, part-task training of simulator-naïve subjects with the PT task alone was associated with slight improvements in the learning curve for the ICS task. However, PT alone was not an efficient strategy for learning the ICS task and there was no demonstrated one month retention benefit for PT overtraining.

Part-task training

While our study showed that part-task training with PT led to higher learning plateau and faster learning rate for ICS, the demonstrated differences are too small to be clinically relevant. Even if such a small difference in performance was significant in the simulator, we know that it would not transfer to the operating room [18, 75]. This lack of clinically relevant transfer from PT training to IC suturing was surprising as both we[3]and others have shown a benefit for training on basic tasks to improve IC suturing learning [76].

Perhaps this unexpected finding reflects that PT alone may not be the best task to facilitate suturing. Learning surgical skills may be more complex than other motor skills, in part because of the greater degree of cognitive involvement[51] and IC suturing may simply be too complex to follow the rules of motor skills acquisition alone. Since motor task learning depends on the complexity of the skills underlying the task and the degree of cognitive and motor contributions [50], PT may simply be too easy a task, despite an intuitive belief that it serves as the foundation for all other FLS tasks.

Moreover, existing research suggests that the benefits of part-task training for surgical skills are very dependent on the specific tasks, with transfer actually being quite limited. It seems that learning a surgical task arises from training with that specific task and does not apply to other, even apparently similar, surgical tasks [47]. Furthermore, some literature supports that complex surgical tasks, especially those requiring a high degree of inter limb coordination, are best acquired when practiced as a whole [50-52].

Lastly, our findings can be explained by the fact that it isn’t merely the amount of practice, but also the type of practice that affects learning [4, 18, 30]. Differences between this study and our previous work may in part be explained by the current study providing proficiency targets, which promotes deliberate practice and improves technical skills acquisition [30, 39]. Since the expected changes for different practice regimens are relatively small, the introduction of a proficiency-based curriculum may have been enough to overshadow any previously described differences in learning IC suturing. Furthermore, feedback facilitates simulator skill acquisition and retention[30] and it is possible that the type of highly individualised instruction participants received during their ICS learning overwhelmed any changes that different PT training regimens may have demonstrated. This type of very intensive one-on-one supervision and tailored feedback is also very different from the previous literature, perhaps explaining our results.

Overtraining

Although high quality proficiency-based training and overtraining are often cited as the main determinants of skill durability [18], it is difficult to find data comparing the effects of overtraining with standard training on surgical skills acquisition. We did not find a benefit for overtraining in retention of the PT task. This unexpected finding may be explained by the use of the one month retention period. Existing literature describes great variability in the retention periods, varying from 2 weeks to 6 months [76-79]. In one study, the first signs of skill decay for IC suturing were only seen after 3 months with no training [79], suggesting that a longer time interval may have demonstrated more significant skill deterioration and thus may have better allowed us to assess the effect of overtraining on retention. It is notable that previous studies showed a much larger decay in skills than our study, ranging from 8% to 45% following completion of proficiency-based simulator curriculum[18].A longer retention interval may therefore have been needed if we believe that the PT task was too easy, leading to only a minute performance decay after a month, especially following experience with the more complex suturing task.

The lack of retention performance differences between the training regimens may also be explained by our attempt to ensure that learning had occurred and proficiency targets were not reached just by chance. Our requirement that all participants reach proficiency on several trials during two separate sessions may have led to some degree of overtraining in all our participants. In fact, our standard and overtrained participants reached very similar endpoints in their PT practice scores, making the two groups difficult to differentiate.

While overtraining did not affect retention of the PT task, it did provide some benefit to the learning curve for the more complex IC suturing task. The TER for was 0.165 for the overtraining group and 0.160 for the standard training group, suggesting that PT mastery practice took longer than the time saved on ICS training. This is similar to other work, which found that although training on basic skills decreased the number of repetitions to learn IC suturing, the overall time to finish the curriculum was not reduced[76].

This study has several limitations. Our subjects were a very diverse group of volunteers and their learning might not accurately depict the learning of the surgical residents to whom this curriculum would actually apply. Of particular concern is learner motivation, which plays a very important role in learning [80] and has been shown to correlate with achievement [81]. According to Ericsson, motivation is one of the most important determinants in the development of expertise [82]. The majority of the study participants were not aspiring to a surgical career and they may therefore not have been appropriately motivated or recognized the utility of the simulation exercises. This may reduce the generalizability of our results to a group of potentially more motivated surgical residents. Secondly, the proficiency target for the ICS may have been too easily reached, making it harder to differentiate ICS learning curves. Lastly, the ability to generalize these results beyond PT and IC suturing is limited.

In summary we found that part-task training with the peg transfer task alone did not lead to a clinically meaningful improvement in the learning curve for intracorporeal suture and that overtraining on the peg transfer task did not improve skill retention. As simulator-based surgical skills training increases, skills curricula must be refined to optimize the benefit to learners. Further investigation of proficiency-based training is needed to improve the teaching of technical skills, both in simulated and operating room environments.

CONCLUSION

During his presidential address at the Annual Meeting of the Central Surgical Society, Dr. Bell stated: “I consider the performance of surgical operations to be the most complex psychomotor activity that human beings are called upon to perform.”[65]. The challenge of acquiring and maintaining operative skills is thus daunting and the focus of much surgical education research.

Simulation is rapidly becoming a pillar of surgical skills training, motivated by the rapid development of new surgical technologies, reduced resident training opportunities and our ethical obligation to move basic skill learning away from patients, into a safe environment [3, 8-9, 83]. Our understanding of the expert-performance model emphasizes the necessity of deliberate practice for the development and maintenance of surgical skills.

Proficiency-based training, part-task training and overtraining are all principles that may aid in optimizing deliberate practice, but uncertainty persists as to specific aspects of their implementation within training curricula. We therefore investigated whether practicing a basic simulator task facilitates learning a more complex skill and found that part-task training was associated with slight improvements in the learning curve for the complex skill. We also compared standard training and overtraining proficiency targets for the simple task and found overtraining did not improve skill retention. Furthermore, it was inefficient method for the learning of a more complex simulator skill.

There are several other factors that can affect the effectiveness of surgical skills acquisition. While they were not discussed in this thesis as they were not investigated in our study, they should be kept in mind when designing training curricula. Practice distribution, for example, affects motor skill development. In distributed practice, learning a task is divided across several sessions with a period of rest in between, whereas in massed practice all learning occurs in one session. We used distributed practice in our study as the data fairly consistently support its superiority for motor skill acquisition [30], however there is still debate on the ideal timing of the training sessions. Performance feedback is another essential concept for simulator skill acquisition [40, 84-86]. Relevant to our study is the debate on whether concurrent feedback, provided during task performance, or summative feedback, provided at the end of task performance, is best. The frequency and duration of ideal feedback is also unclear[30]. We used both types of feedback in our study, remaining cognizant of the necessary balance between the facilitation of skill acquisition and learner motivation with feedback and the potential impairment of learning with excessive feedback. As it seems the amount of feedback provided in our study may have overshadowed possible training protocol differences, further studies comparing feedback interventions may be of interest. Lastly, performance assessment has a powerful effect on learning in general, and the effectiveness of skills curricula specifically [30]. Our subjects had access to rapid performance assessment with each task repetition, as described in the methods section. As this was not one of our study interventions, however, this thesis did not address the topic of performance assessment in any further detail. It needs however to be considered whenever developing a training curriculum, and it is in fact one reason why simulators with validated performance metrics, such as MISTELS, are of increasing interest in medical education.

The MISTELS simulator used in our study has clinical relevance as the manual skills component of the Fundamentals of Laparoscopic Surgery for which certification is required by the American Board of Surgery. The current FLS training curriculum emphasizes both overtraining and the importance of the peg transfer task by recommending residents train to expert proficiency on the peg transfer task before proceeding to the other simulator tasks [66]. The results from our study, however, suggest overtraining on peg transfer is inefficient and does not lead to clinically relevant improvements in learning a more complex FLS task. Our findings thus provide evidence that perhaps we should change our approach to FLS training.

The effectiveness of any simulator-based educational program is mainly dependent on the quality of its curriculum rather than on the simulator used [30]. Studies investigating different training protocols in surgical simulators may thus make important academic contributions to the surgical education literature and provide practical suggestions for those designing and implementing training curricula for surgical simulation.

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TABLES AND FIGURES

Table 1: Participant characteristics

	Control (n=28)	Standard training (n=26)	Overtraining (n=23)
Age	23.3(2.9)	24.3(2.5)	23.7(2.5)
Male gender	13 (46%)	10 (39%)	7 (30%)
Right handedness	24 (86%)	25 (96%)	22 (96%)
Baseline peg transfer score	63(24)	56(22)	66(12)
Baseline intracorporeal suture score	15(21)	12(18)	18(22)

Data presented as mean (SD).

Table 2: Effects of peg transfer overtraining on skill retention

	Last peg practice score	First retention score	*p*	Percentage change at retention
Standard training	103(2)	99(3)	<0.01*	-3.6(3.6)%
Overtraining	108(2)	101(7)	<0.01*	-5.6(6.6)%
p	<0.01*	0.09		0.2

Data presented as mean (SD).

* represents statistical significance, defined as $p<0.05$.

Table 3: Pilot study results - Peg transfer training affects initial intracorporeal suturing score, learning plateau and rate

Peg-training group	n	Initial ICS score	ICS Learning plateau	ICS Learning rate
Control	2	0.1 (0.13)	60.0 (35.9)	20.9 (2.3)
Standard training	3	9.9 (17.1)	79.4 (15.6)	16.7 (6.3)
Overtraining	2	24.7 (34.9)	105.8 (7.4)	15.0 (6.8)

Data presented as mean (SD).
ICS=intracorporeal suture.

Table 4: Akaike Information Criterion (AIC) sums for the intracorporeal suturing task

Peg-training group	General power curve	Power curve	Exponential curve	APEX curve	Inverse curve
Control	1391.6	1401.2	1328.6	1328.3*	1348.8
Standard training	1099.9	1183.8	1088.8	1157.6	1043.3*
Overtraining	1350	1425.8	1318.5*	1404.5	1340.4
All subjects	3841.5	4010.8	3735.9	3890.4	3732.5*

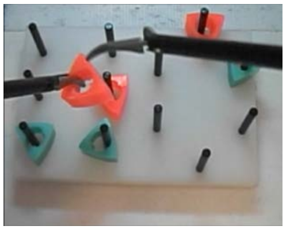
* represents best fit (lowest AIC, see Appendix III) for the group

Figure 1: MISTELS simulator setup

Figure 2: MISTELS tasks

a. Task 1: Peg transfer


1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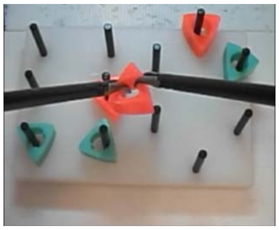
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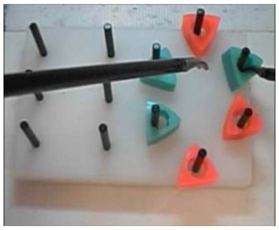
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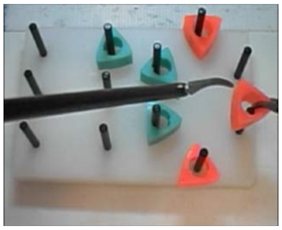
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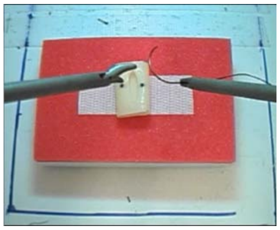
b. Task 5: Intracorporeal suturing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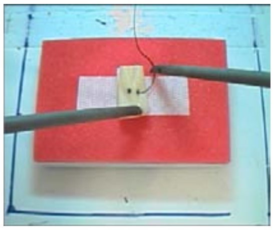
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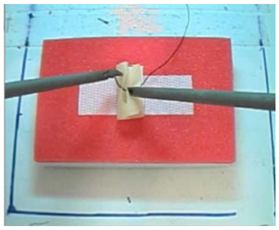
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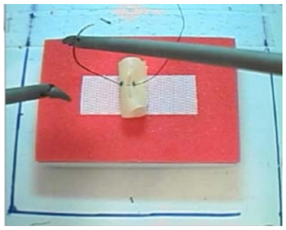
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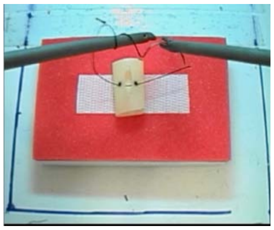
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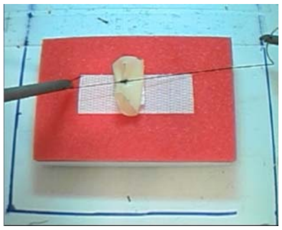
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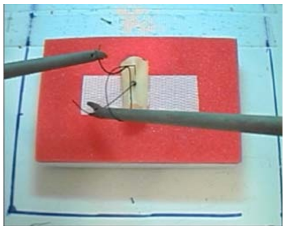
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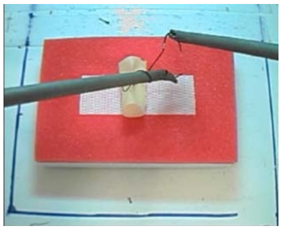
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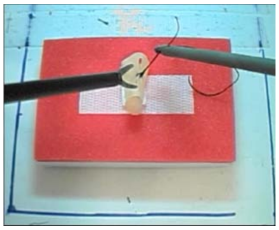
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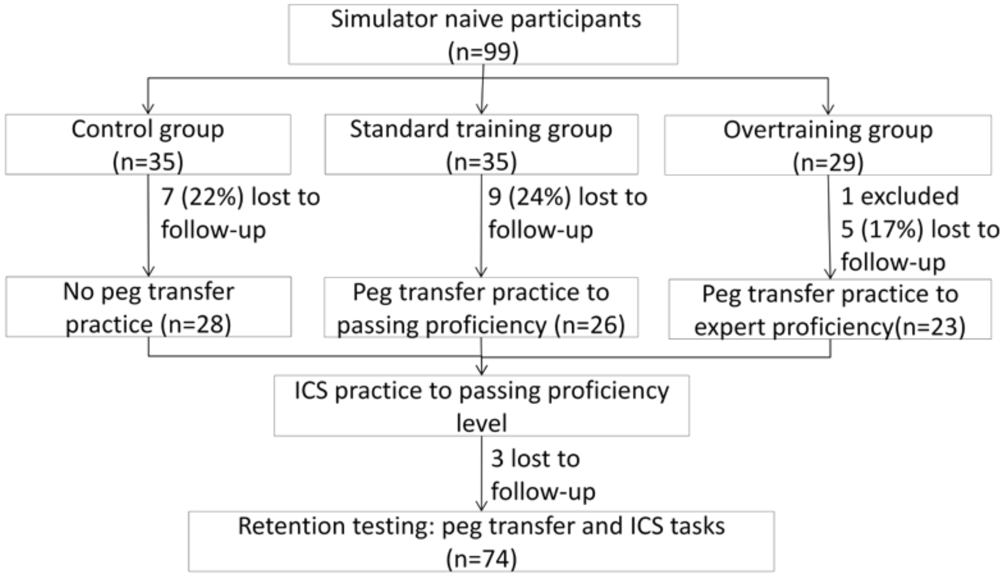
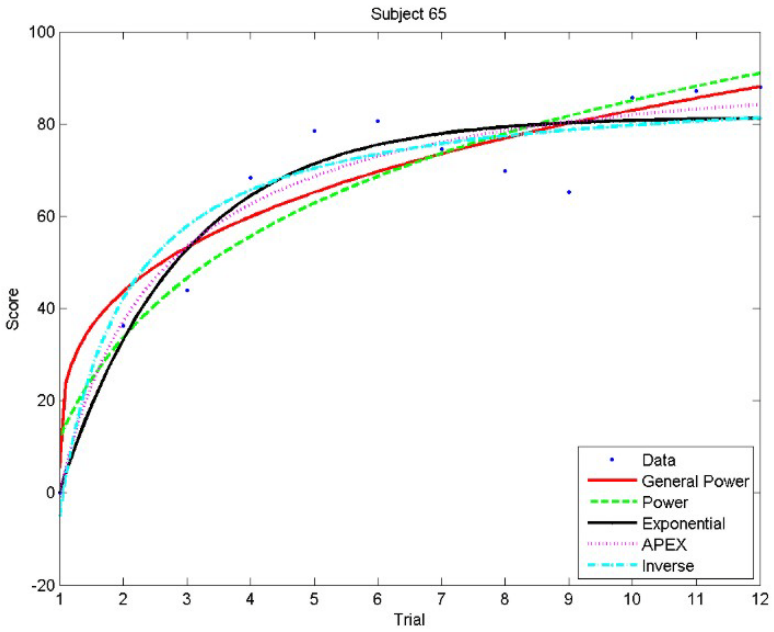
Figure 3: Flow of participants



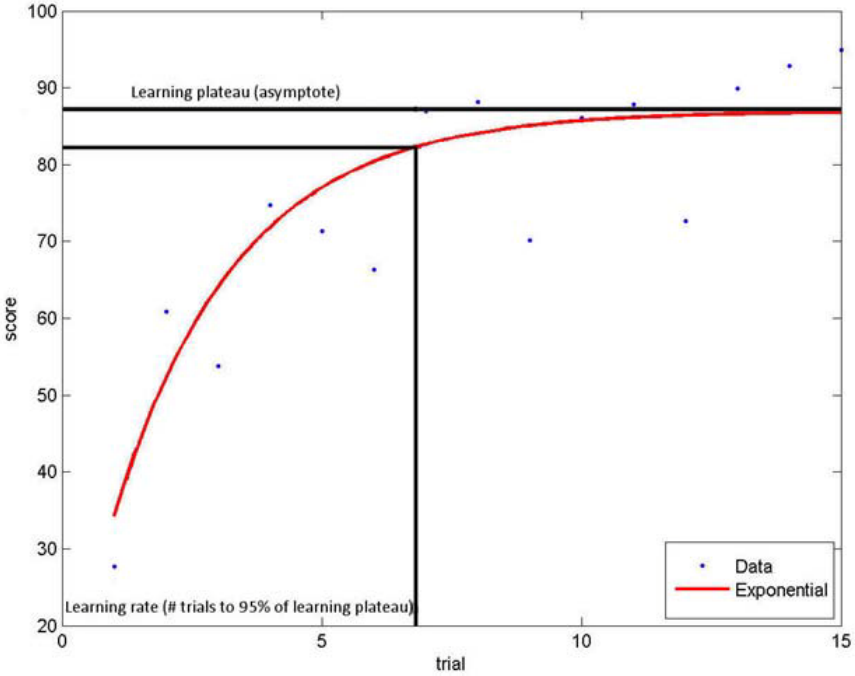
Legend:
ICS=Intracorporeal suture

Figure 4: Curve fitting technique for describing the learning curve

a. Example of curve fitting for a subject's intracorporeal suturing learning



b. Estimate of the learning plateau and learning rate



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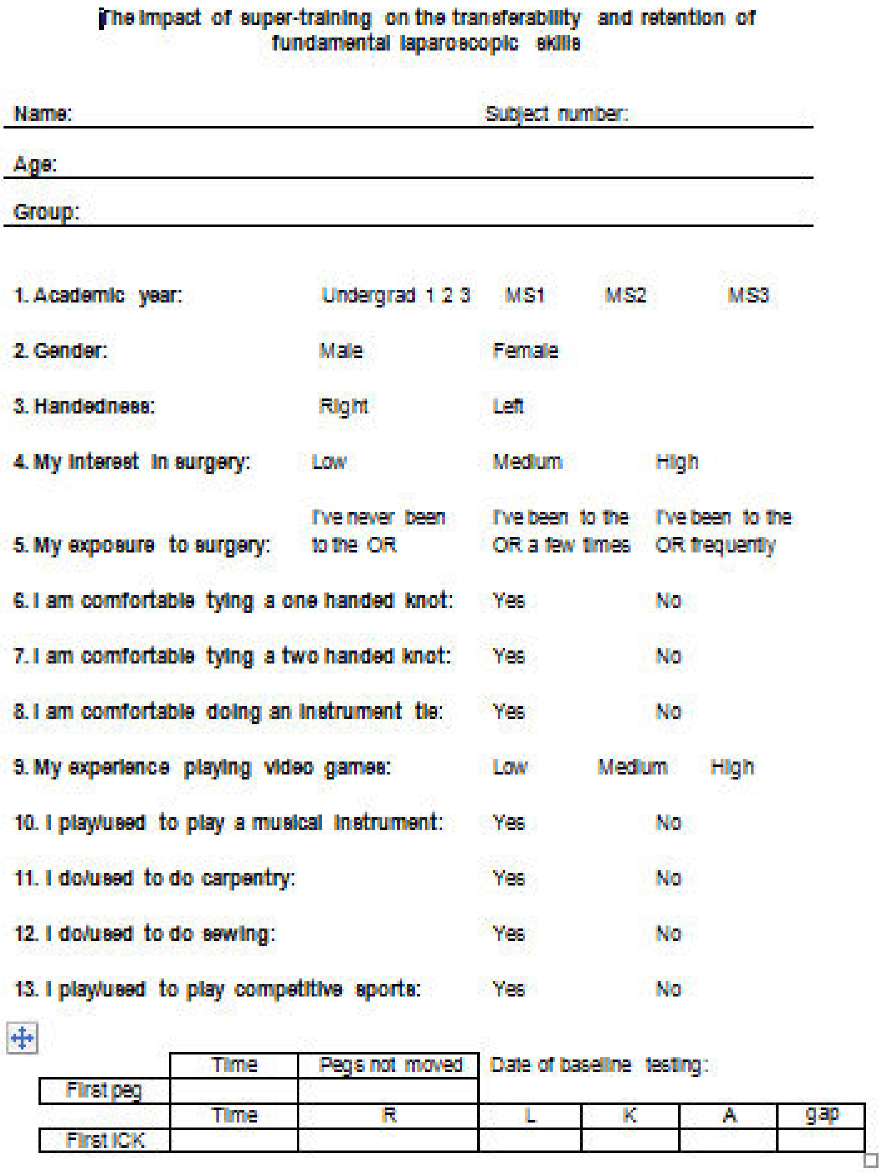
I recognize that this research would not have been possible without the financial assistance of the Surgical Scientist Program, and express my gratitude to Dr. John Hinchey and the Surgical Scientist Committee.

Last, but certainly not least, I wish to thank my family for all their love, patience and unrelenting cheerleading. I would be lost without you.

APPENDICES

APPENDIX I: RESEARCH INSTRUMENTS - DEMOGRAPHICS DATA



The impact of super-training on the transferability and retention of fundamental laparoscopic skills

Name: Subject number:

Age:

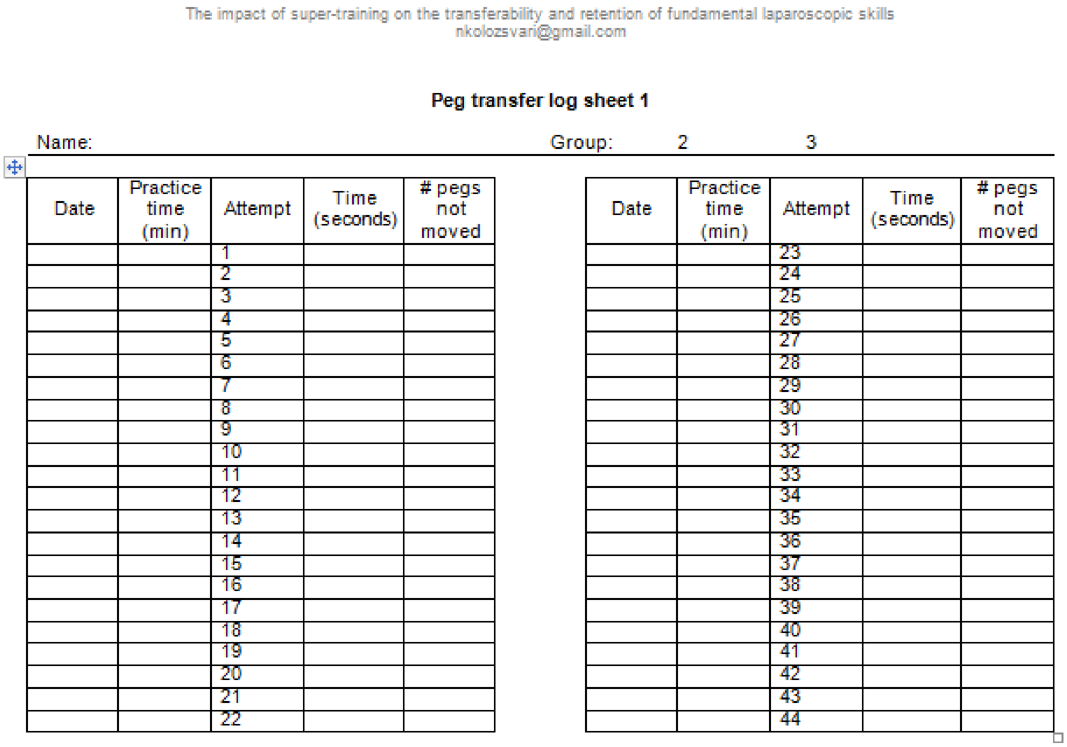
Group:

1. Academic year:	Undergrad 1 2 3	MS1	MS2	MS3
2. Gender:	Male	Female		
3. Handedness:	Right	Left		
4. My interest in surgery:	Low	Medium	High	
5. My exposure to surgery:	I've never been to the OR	I've been to the OR a few times	I've been to the OR frequently	
6. I am comfortable tying a one handed knot:		Yes	No	
7. I am comfortable tying a two handed knot:		Yes	No	
8. I am comfortable doing an instrument tie:		Yes	No	
9. My experience playing video games:		Low	Medium	High
10. I play/used to play a musical instrument:		Yes	No	
11. I do/used to do carpentry:		Yes	No	
12. I do/used to do sewing:		Yes	No	
13. I play/used to play competitive sports:		Yes	No	

Date of baseline testing:

	Time	Pegs not moved				
First peg						
	Time	R	L	K	A	gap
First ICK						

APPENDIX II: RESEARCH INSTRUMENTS – PRACTICE LOG SHEETS



The impact of super-training on the transferability and retention of fundamental laparoscopic skills
nkolozsvari@gmail.com

Peg transfer log sheet 1

Name: Group: 2 3

Date	Practice time (min)	Attempt	Time (seconds)	# pegs not moved
		1		
		2		
		3		
		4		
		5		
		6		
		7		
		8		
		9		
		10		
		11		
		12		
		13		
		14		
		15		
		16		
		17		
		18		
		19		
		20		
		21		
		22		

Date	Practice time (min)	Attempt	Time (seconds)	# pegs not moved
		23		
		24		
		25		
		26		
		27		
		28		
		29		
		30		
		31		
		32		
		33		
		34		
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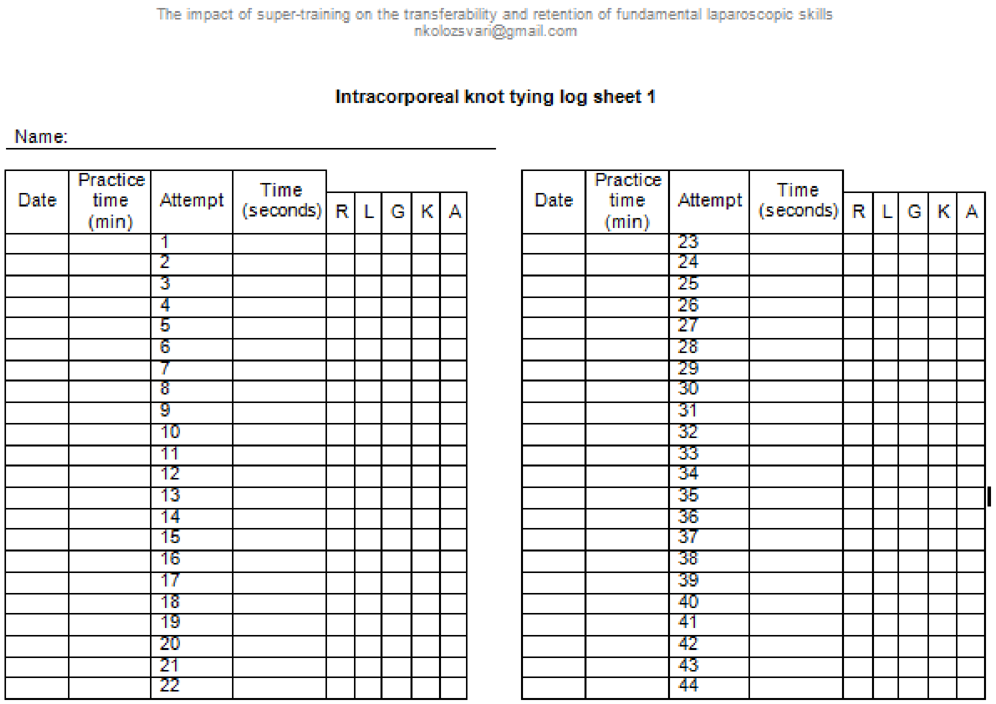
		44		



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nkolozsvari@gmail.com

Intracorporeal knot tying log sheet 1

Name:

Date	Practice time (min)	Attempt	Time (seconds)	R	L	G	K	A
		1						
		2						
		3						
		4						
		5						
		6						
		7						
		8						
		9						
		10						
		11						
		12						
		13						
		14						
		15						
		16						
		17						
		18						
		19						
		20						
		21						
		22						

Date	Practice time (min)	Attempt	Time (seconds)	R	L	G	K	A
		23						
		24						
		25						
		26						
		27						
		28						
		29						
		30						
		31						
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		44						

APPENDIX III: LEARNING CURVE ANALYSIS

We felt this thesis warranted a more in-depth description of our choice for learning curve analysis than the manuscript length allowed.

Traditionally, learning curves were analyzed by data splitting, namely splitting groups in arbitrary levels of experience. This however is not ideal as knowing an individual's performance on, for example, the first and last ten repetitions of a task tells us nothing about where on their learning curve they are or what level that performance may ultimately achieve. Furthermore, studies reporting the number of trials to reaching a passing score are flawed in that individuals often fail after an initial pass. We are now able to provide a much richer description of learning using a curve fitting technique.

There are three parameters of interest in describing the learning curve: the starting point, which is the level where performance begins; the learning plateau, which is the level at which performance flattens, representing the theoretical best score a subject could achieve with infinite practice; and learning rate, the number of trials necessary to achieve 95% of the learning plateau, which represents the speed with which a subject learns the task. Curve fitting can be used to identify a learning curve effect and obtain mathematical estimates of the asymptote and rate of learning [87] and has already been applied to characterizing the learning curve of a fundamental laparoscopic task [63]. Our lab's previous work highlighted the opportunity to use the curve fitting learning curve as an outcome for surgical educational effectiveness studies [63], which made it the method of choice for our current study.

Data from each performance of a simulator task were plotted to produce a learning curve for each subject. Nonlinear regression was used to fit a variety of curve shapes to each individual's curve (Matlab 7.8, Matlab Inc., Natick, MA), as shown in Figure 4a, and the Akaike Information Criterion (AIC) values for each curve were calculated. The AIC essentially assesses the fit between a data set and a curve model. The curve yielding the smallest AIC value is considered the one with the maximum likelihood of being the correct fit for the data and have the largest estimated predictive accuracy [88]. As seen in Table 4, the inverse function yielded the lowest total AIC. We therefore used the inverse curve to estimate an asymptote and rate parameter for each curve [63, 72]. These estimates were then used to define two of the previously described parameters of interest for each learning curve: the learning plateau, or asymptote, and the learning rate (Figure 4b).

This curve fitting technique for describing the learning curve thus provides us with a much more complete and clinically relevant description of learning than the traditional data splitting and is particularly useful when comparing performance between groups, as we did in our study.

APPENDIX IV: PILOT STUDY

A pilot study was undertaken to assess the feasibility of the design. Seven simulator-naïve subjects were included. Non linear regression was used to estimate the learning plateau and rate for ICS performance after the subjects were randomized to the three PT training groups. Data are presented Table 3 as mean (SD) and suggest that the peg-trained subjects had better initial performance, higher learning plateau and faster rate of learning for the ICS. Furthermore, the overtraining proficiency target seemed to provide an additional advantage compared to standard training.