

Using a dynamic training environment to acquire laparoscopic surgery skill

A. K. Bell · M. Zhou · S. D. Schwaitzberg ·
C. G. L. Cao

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Abstract

Background Current physical laparoscopic surgical simulators provide training only for static tasks, which do not develop the more advanced hand–eye coordination skills needed to navigate the dynamic surgical environment. A novel dynamic minimally invasive training environment (DynaMITE) was developed to address this need. This study aimed to evaluate further the utility of the system as a training and skill assessment tool. Two studies were performed with a second-generation design. The authors hypothesized that the dynamic task environment would be challenging to novices and would differentiate experienced surgeons from the inexperienced by emphasising the dynamic skills gained through surgical experience.

Methods The participants in the first study were 42 novice and experienced surgeons attending the Society of American Gastrointestinal and Endoscopic Surgeons (SAGES) 2007 Learning Center, whereas the second controlled laboratory study had 16 participants (5 novices and 11 experienced surgeons). The participants performed two tasks: an aiming task and an object manipulation task. Both tasks were positioned on a dynamic platform that moved in five different trajectories.

Results The subjective feedback from the surgeons at the SAGES Learning Center was positive. The results from the controlled study showed significant performance deterioration in the fast diagonal task compared with the task of aiming and manipulating in the static environment for both experience groups but no performance differences between the groups.

Conclusions Dynamic tasks are challenging, and surgeons need to be trained specifically for these tasks. The DynaMITE system can provide training benefits for dynamic skill development, even for expert surgeons who may have had no opportunity to gain these skills through their surgical practice.

Keywords Dynamic skills · Laparoscopic surgery · Training

The benefits of laparoscopic surgery such as reduced scarring, shorter hospital stays, reduced pain, a quicker return to work, and lower hospital costs are well established [1, 2]. Despite its many benefits for patients, however, laparoscopic surgery has proved to be a challenging technique for surgeons to learn and master, sometimes resulting in unintended surgical errors. For example, a comparison of laparoscopic and open cholecystectomy showed that laparoscopic procedures resulted in more bile duct injury [3], a serious complication of the procedure that is potentially lethal. The source of these errors lies in sensory challenges for surgeons that are not present in open surgery. These challenges include reduced depth perception, a lack of shadows in the surgical environment, limited tool motion due to restriction from trocars, and reduced or distorted tactile and force feedback [1, 4–7].

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A. K. Bell · M. Zhou · C. G. L. Cao (✉)
Department of Mechanical Engineering, Tufts University,
200 College Avenue, Medford, MA 02155, USA
e-mail: caroline.cao@tufts.edu

A. K. Bell
e-mail: audreykbell@gmail.com

S. D. Schwaitzberg
Cambridge Health Alliance, Cambridge, MA, USA

Because of these challenges and their consequences, it is very important for a laparoscopic surgeon to undergo an effective training program before operating on a patient. Studies have shown that practicing on laparoscopic trainers is effective for teaching basic laparoscopic skill to novices [8–10]. In addition, using more challenging exercises during training can enhance the development of higher skill levels [11]. Therefore, existing physical box trainers that contain only tasks allowing trainees to interact with stationary objects (e.g., transferring pegs, suturing, and tying a knot in a Penrose drain) may not be adequate. Given the complexity of the surgical site in laparoscopic surgery, these simple static training tasks do not train surgeons to cope with more challenging operating conditions.

As the surgeon's view of the remote surgical site is restricted and magnified in laparoscopic surgery, any movement of the target tissue during fine surgical motions (e.g., vessel anastomosis) becomes magnified and can affect performance outcome. Because remote manipulation in a dynamic environment is extremely challenging, especially if the movement of the target is unpredictable in direction and speed, surgeons take great care to immobilize dynamically moving parts of the anatomy before acting on them. This can extend the total time of the procedure, increasing the fatigue effect on the surgeon. It is possible that a simulator offering experience with dynamically moving target objects may develop the type of dynamic skills surgeons need for operating in situations that do not allow complete immobilization of the anatomy.

We propose a novel approach to surgical skills training that uses a dynamic targeting system to increase the complexity of the simulated surgical environment. This enhancement is expected to improve surgeons' efficiency and accuracy in manipulating laparoscopic tools when faced with dynamically moving target objects. In addition, training in a dynamic environment may result in better performance of static tasks due to the overtraining.

To investigate this method of surgical training, a targeting system with controlled motorized motion was designed and fabricated. A pilot experiment then was conducted in which subjects with differing amounts of surgical experience completed a simple aiming task under varied dynamic conditions. The results of this initial evaluation indicated that the dynamic trainer had the potential to train the hand–eye coordination skills of even expert surgeons [12]. The promising results from the pilot experiment led to the design of a second-generation dynamic minimally invasive training environment (DynaMITE).

We present the findings of the two experiments to evaluate the dynamic system. It was hypothesized that subjects without experience in laparoscopic surgery would perform less efficiently and with more errors than subjects with laparoscopic training.

Materials and methods

The dynamic minimally invasive training environment

The dynamic minimally invasive training environment (DynaMITE) was designed to fit within any existing trainer box to facilitate an easy upgrade for current simulation training systems. In our two experiments, the DynaMITE was placed inside the torso of a ProMIS simulator (Haptica Inc., Dublin) (Fig. 1). This allowed the surgical tools to be tracked for performance evaluation.

The DynaMITE system consists of a $22.9 \times 22.9 \times 7.6$ -cm basin in which a $6.4 \times 6.4 \times 2.5$ -cm platform is housed. By riding along two cylindrical rails placed orthogonally within the basin, the platform can achieve controlled motion in two dimensions (Fig. 2). The device is programmed to allow the platform to follow any of four target trajectories: (1) static, in which the platform remains stationary; (2) horizontal, in which the platform moves in a left-to-right motion across the task space; (3) vertical, in which the platform moves in a front-to-back motion across the task space; and (4) hourglass, in which the target moves around the task space in a “figure eight” pattern.

Modular laparoscopic task fixtures may be placed on the platform to allow for training in a range of task difficulties. This study used two tasks of different difficulty levels: an aiming task and an object manipulation task.

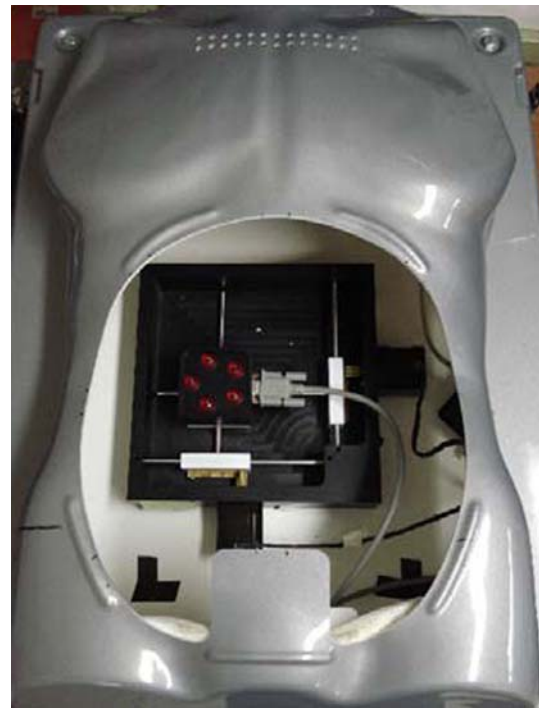


Fig. 1 Experimental setup

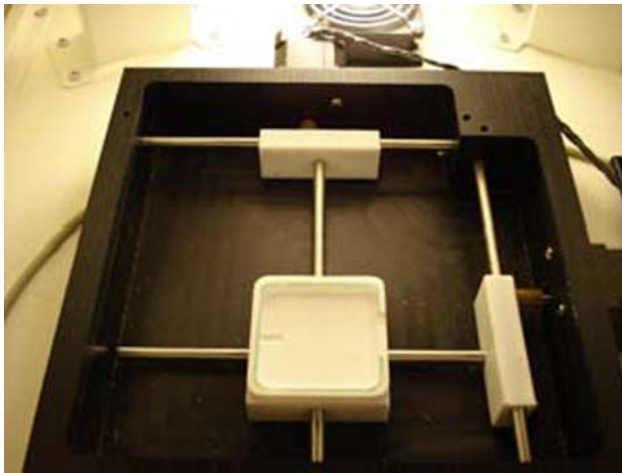


Fig. 2 DynaMITE apparatus with a dynamic platform

Task 1: aiming

The aiming task comprised an array of five vertical posts, each sitting atop an indicator light (Fig. 3). The subjects were required to use laparoscopic graspers to make contact with the top of each post according to which indicator light was illuminated in a random fashion. When successful contact was made with the illuminated post, the light was extinguished and another light was lit. If successful contact with the target post was not achieved within 15 s, the window of opportunity to make contact with that post expired, and the next peg was illuminated. This pattern continued until all five posts had been illuminated.

Task 2: object manipulation

The object manipulation task consisted of a platform holding three geometric objects: a cylinder, a triangular prism, and an asymmetric shape (Fig. 4). The subjects were

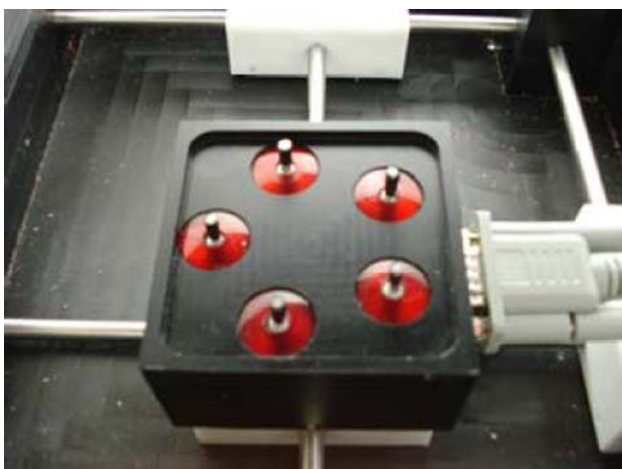


Fig. 3 Aiming task

required to acquire the objects from one side of the platform and reorient them to fit into holders on the opposite side. Illuminated arrows indicated which of the three objects was to be manipulated. Once the indicated transfer had been completed, the illuminated arrow was extinguished, and the next arrow was illuminated. If successful transfer of the target shape was not completed within 15 s, the window of opportunity to transfer that object expired, and the next object was indicated. The task continued until all three objects had been transferred successfully or until the specified time limit for each object had expired.

Dependent measures

A computer interface was developed that allowed performance to be scored automatically. The dependent performance variables included the number of errors (inability to make contact with a target peg or complete the transfer of a geometric object in the specified time) and time to task completion. In addition, the ProMIS simulator in which the DynaMITE was housed can track the surgical tool path length (total length of the tool trajectory) and smoothness (number of direction changes undergone by the tools during each trial). These additional dependent measures were collected during the controlled laboratory study.

Experiment 1: 2007 SAGES Learning Center

Subjects

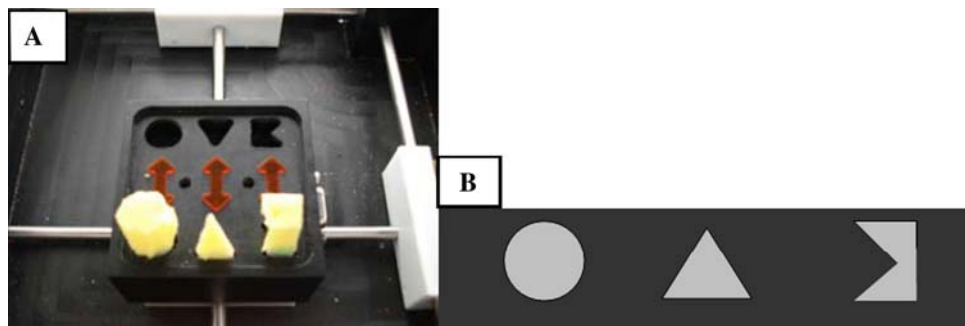
The first experiment had 42 participants ranging in age from 28 to 66 years. The subjects were attendees of the 2007 meeting of the Society of American Gastrointestinal and Endoscopic Surgeons (SAGES). They ranged from those who had no experience (had performed no laparoscopic procedures) to those who were very experienced (had performed more than 2,500 laparoscopic procedures). The subject group included both men and women who were right-handed, left-handed, or ambidextrous.

Experimental design

The subjects were invited to complete the aiming task with three different movement trajectories: static, vertical, and fast vertical. The object manipulation task was completed under five different movement trajectories: static, vertical, fast vertical, hourglass, and fast hourglass. For each task, the task platform moved at 0 mm/s (static), 7.85 mm/s (vertical or hourglass), or 15.7 mm/s (fast).

Because this experiment took place in the Learning Center at the 2007 SAGES annual meeting, it was difficult to control for the order of task condition and the number of

Fig. 4 **A** Object manipulation task. **B** Geometric shapes



trials. The participation of the subjects ranged from one to six trials completed under each condition.

Data analysis

For the purposes of data analysis, the subjects were split into seven experience groups according to the number of laparoscopic procedures they had performed. These experience groups were defined as follows: group 1 (0–10 procedures performed), group 2 (11–100 procedures performed), group 3 (101–200 procedures performed), group 4 (201–500 procedures performed), group 5 (501–1,000 procedures performed), group 6 (1,001–2,500 procedures performed), and group 7 (more than 2,500 procedures performed). Data then were analyzed using two-factor analysis of variance (ANOVA) and the post hoc Tukey test.

Experiment 1 results

Aiming task: time to task completion

Analysis showed significant main effects both in experience groups ($p = 0.02$) and in task trajectories ($p < 0.001$) on time to task completion. The post hoc Tukey tests showed that the subjects in experience group 6 were significantly more efficient than the subjects in group 1 ($p = 0.02$) but that none of the other groups were statistically significant from one another. Similarly, the subjects were significantly slower in completing the fast-moving dynamic tasks than in performing either the static or slow-moving tasks ($p < 0.001$) (Fig. 5). No interaction was found between experience and task trajectory.

Aiming task: error

The data analysis showed a significant main effect of task movement trajectories on error committed ($p = 0.005$). A post hoc Tukey test showed that the subjects made significantly more errors in the fast tasks than in the static and slow tasks ($p < 0.001$). No significant performance differences were found between experience groups, and no interaction was found between experience and task trajectory.

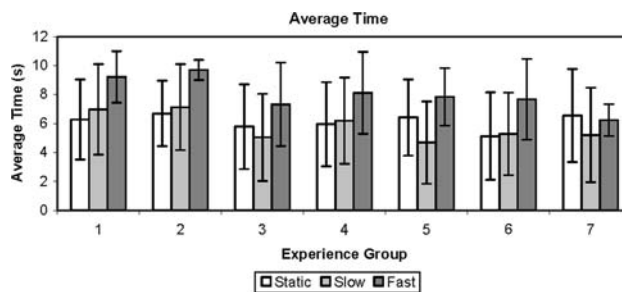


Fig. 5 Average time for the aiming task

Object manipulation task: time to task completion

A two-factor ANOVA test comparing the time taken across subject groups to transfer each of the three geometric shapes indicated a significant main effect among both experience groups ($p = 0.01$) and shapes ($p < 0.001$) (Fig. 6). Post hoc Tukey tests showed that it took significantly more time to transfer the triangle and asymmetric shapes than to transfer the circle ($p < 0.001$). In addition, subject group 1 was significantly slower overall than either group 2 ($p = 0.01$) or group 7 ($p = 0.03$).

Experiment 2: controlled laboratory study

Subjects

The second study had 16 subjects (5 novice subjects and 11 experienced subjects with at least 18 h of laparoscopic

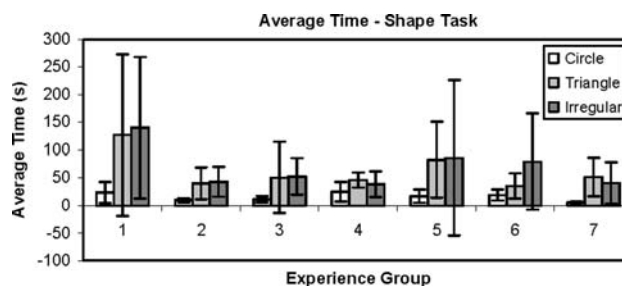


Fig. 6 Average time per shape in the object manipulation task

training). These 11 men and 5 women ranged in age from 22 to 49 years.

Experimental design

The subjects were required to complete each task under five movement trajectories: static, horizontal, vertical, diagonal, and fast diagonal. The task platform traveled at a speed of 0 mm/s in the static trajectory; 7.8 mm/s in the horizontal, vertical, and diagonal trajectories; and 15.7 mm/s in the fast diagonal trajectory.

Each subject completed three trials of the aiming task and two trials of the object manipulation task under each movement trajectory, for a total of 25 trials. To avoid a learning effect, the movement trajectory conditions were completely randomized within each task, whereas the order of the tasks was counterbalanced.

Data analysis

Similar to experiment 1, data were analyzed using ANOVA and a post hoc Tukey test.

Experiment 2 results

Aiming task: time to task completion

Data analysis showed a significant main effect among movement trajectories ($p < 0.001$). A post hoc Tukey test showed that the subjects took significantly longer to complete the tasks that moved in the fast diagonal trajectory than those that moved in any of the other four trajectories ($p < 0.001$) (Fig. 7). There were no differences between experience groups in time to task completion. No significant interaction between the two factors was found.

Aiming task: error

A significant main effect due to task movement trajectory was found ($p < 0.001$). A post hoc Tukey test showed that subjects committed significantly more errors in the fast

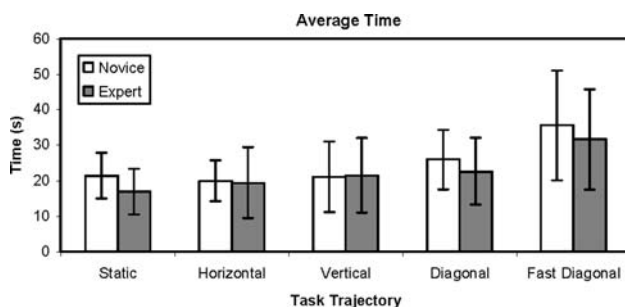


Fig. 7 Average time in the aiming task

diagonal condition ($p < 0.001$) than in any of the other four movement trajectories ($p = 0.001$) (Fig. 8). There were no significant differences between experience groups in the number of errors. No interaction between the two factors was found.

Aiming task: path length and smoothness

Analysis showed a significant main effect in task movement trajectories ($p = 0.006$). A post hoc Tukey test showed that tool path length was significantly longer in the fast diagonal trajectory ($p = 0.002$) than in the static and horizontal trajectories ($p = 0.02$) (Fig. 9). No other significant differences or interactions were found in path length analyses. A two-way ANOVA conducted to analyze the smoothness data identified no significant performance differences in subject groups or task trajectories.

Object manipulation task: time to task completion

The experts were significantly more efficient than the novices in completing the object manipulation task

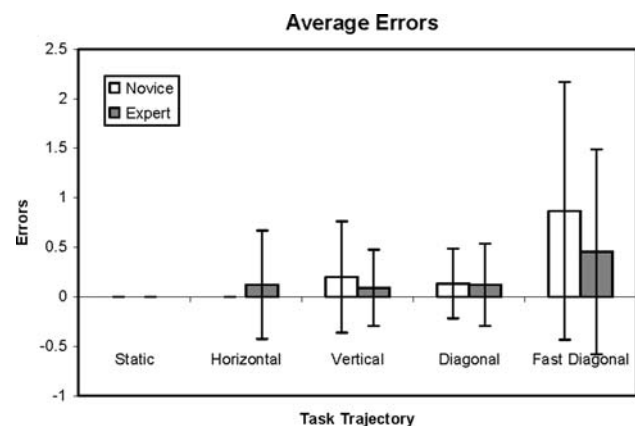


Fig. 8 Average errors in the aiming task

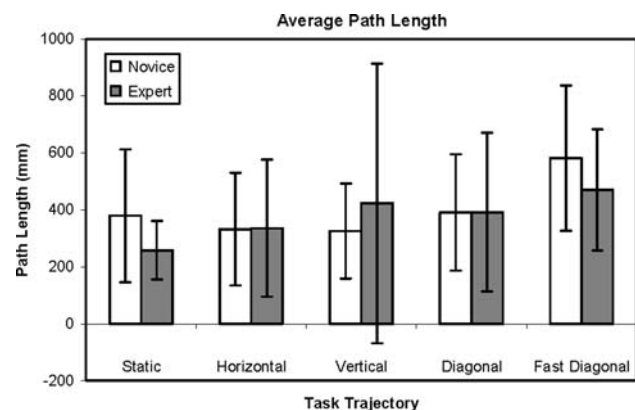


Fig. 9 Average path length in the aiming task

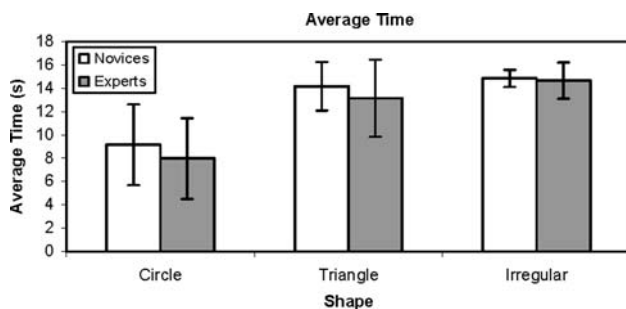


Fig. 10 Average time in the object manipulation task

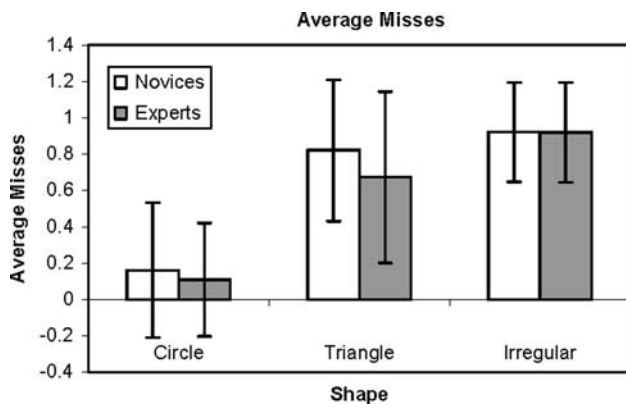


Fig. 11 Average misses in the object manipulation task

($p = 0.003$) (Fig. 10). In addition, significant performance differences were noted in the time it took to transfer each of the three differently shaped objects ($p < 0.001$). No significant differences among task trajectories were identified.

Object manipulation task: accuracy

A three-way ANOVA showed a significant difference in the number of errors made in transferring each of the three shapes, but no significant differences between subject groups or task trajectories ($p < 0.001$) (Fig. 11).

Object manipulation task: path length and smoothness

Analysis of the path length and smoothness data showed no significant performance differences between the subject groups or task trajectories.

Discussion

The results from the initial evaluation of the DynaMITE system indicated that experts may be more efficient and more accurate than novices in performing simulated laparoscopic tasks in a dynamic environment [12]. However,

the results from the Learning Center testing session were inconclusive. Few consistent trends in the data were observed. This is not surprising considering the uncontrolled nature of the Learning Center and the small number of trials performed by each participant.

In addition, the crowded and noisy Learning Center made for a testing environment with many distractions. It also should be noted that the subjects tested in the Learning Center were separated into experience groups based on the number of cases they reported having completed. It is possible that the number of completed procedures estimated by the subjects was not accurate and that the analysis based on experience grouping was therefore not meaningful.

Despite the inconsistent nature of the performance data collected at the Learning Center, useful subjective data were obtained, especially from the experienced surgeons who used the device. Whereas a small minority of the subjects thought the DynaMITE system would not add any useful skills to their repertoire, most indicated that they felt it would be a valuable training tool.

The results from the second controlled experiment, although fairly consistent, did not support our hypothesis. The aiming task showed that both experience groups performed significantly worse in terms of efficiency (time to task completion), accuracy (error), and sometimes path length in the fast-moving dynamic tasks than in the slow-moving or static ones. In fact, no significant performance differences were found between the two experience groups. This suggests that the expert group was not any better equipped to handle the challenges of dynamic tracking than the novices. Indeed, the experts had not developed heightened dynamic tracking skills from their long experience performing laparoscopic surgery, as we had expected.

This finding emphasizes the importance of specificity of training and supports numerous findings that transfer of skill from one task to another is typically small, even when the two tasks are similar [13]. Lordahl and Archer [14] performed a study that asked three groups of subjects to practice a rotary pursuit task at one of three different speeds: 40, 60, or 80 rpm. During a second data collection session, all three groups were asked to complete the same task at 60 rpm. According to the results, the group that practiced the task at 60 rpm in the first session performed better in the second session than either of the other two groups. This indicates that although all three groups learned the same task, the groups that learned the tasks at 40 and 80 rpm developed skills that were not completely transferable to the completion of the task at 60 rpm [14].

Based on these observations, it is somewhat surprising that performance in the static and slow-moving tasks was not significantly different. It is likely, however, that the speed chosen for the slow-moving tasks was too slow to require a substantial change in technique. As in the study of

Lordahl and Archer [14], however, the increase in speed from the slow tasks to the fast tasks was a change great enough that the skills learned by training in static environments were not transferable to the same task at a much higher speed.

The object manipulation task showed a similar pattern in the time measure, with both experience groups performing significantly worse in the faster dynamic tasks than in any of the other tasks. In the accuracy measure, however, the expert group outperformed the novice group by a significant margin. This may be due to the fact that surgeons regularly use object manipulation skills in the course of their practice, even in static environments. It is possible that the more experienced surgeons were able to draw on their experience in static environments to aid them in the object orientation portion of this task. Indeed, a task analysis showed that the object manipulation task consists of three subtasks: aim and pick up object, orient object, aim and drop object. It is during the second subtask of object orientation that experienced surgeons showed an advantage in performance, allowing them to complete the task within the allotted time. In the aiming subtasks, the experts had no advantage over the novices.

The similarity in performance observed in the novice and expert groups during dynamic task completion may indicate that dynamic training is not necessary for the acquisition of expert-level laparoscopic skills. It is unclear, however, whether this is because the experts themselves do not possess the basic skill to perform dynamic tasks. That is, the experts have never been trained to perform dynamic tasks and have mostly avoided operating under dynamic conditions in their clinical practice, so their performance did not differ from that of the novices. Perhaps dynamic skills are not relevant for expert-level performance in laparoscopic surgery given that surgeons often put forth great effort to stabilize the anatomy before interacting with the surgical site.

Future work should include a learning curve study to determine whether extended practice with dynamic tasks can benefit the learning of tool manipulation skills for static tasks or shorten the amount of training time it takes to reach general proficiency. The study of Lordahl and Archer [14], in which practice at a higher speed did not result in higher task performance at a lower speed, suggests that this study may not produce favorable results. However, it should be noted that Lordahl and Archer's subjects were trained with a single data collection session. It is possible that this was not enough time for them to retain the skill being learned. If that is true, then we expect that given a substantial amount of time to reach proficiency with a difficult task, skills will transfer to simpler tasks.

Additional future work will require subjects to complete tasks under different trajectory movement conditions. The

tasks presented to the subjects in the current experiments had motion with a constant speed and a predictable trajectory. Target motion that is more random to mimic more closely the type of motion that might be encountered during surgery would be appropriate.

Conclusions

The results from these experiments indicate that fast dynamic tracking tasks are more difficult to perform than static or slow-moving dynamic tasks for people of all experience levels. The fact that expert surgeons were not any better than novices in dynamic tracking suggests that this skill is missing from the surgical training curriculum. If it is desirable for laparoscopic surgeons to add this skill to their repertoire, then it is necessary for them to be exposed to a dynamic training environment such as the DynaMITE. Even if the dynamic tracking skill proves to be an infrequent necessity in actual surgery, it may be useful for surgeons to be “overtrained” such that static tasks are easy by comparison. A transfer of learning study should be conducted to determine the utility of a dynamic simulator in developing skills that are valuable in a static surgical setting.

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