Validation of the VBLaST Peg Transfer Task: A First Step toward an Alternate Training Standard

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ABSTRACT

Background: The FLS trainer lacks objective and automated assessments of laparoscopic performance and requires a large supply of relatively expensive consumables. Virtual reality simulation has a great potential as a training and assessment tool of laparoscopic skills and can overcome some limitations of the FLS trainer. This study was carried out to assess the value of our Virtual Basic Laparoscopic Surgical Trainer (VBLaST©) in the peg transfer task compared to the FLS trainer and its ability to differentiate performance between novice, intermediate and expert groups.

Methods: Thirty subjects were divided into three groups: novices (PGY1-2, n = 10), intermediates (PGY3-4, n=10), and experts (PGY5, surgical fellows and attendings, n = 10). All subjects performed ten trials of the peg transfer task on each simulator. Assessment of laparoscopic performance was based on FLS scoring while a questionnaire was used for subjective evaluation.

Results: The performance scores in the two simulators were correlated, though subjects performed significantly better in the FLS trainer. Experts performed better than novices only on the FLS trainer while no significant differences were observed between the other groups. Moreover, a significant learning effect was found on both trainers, with a greater improvement of performance on the VBLaST©. Finally, 82.6% of the subjects preferred the FLS over the VBLaST© for surgical training which could be attributed to the novelty of the VR technology and existing deficiencies of the user interface for the VBLaST©.

Conclusion: This study demonstrated that the VBLaST© reproduced faithfully some aspects of the FLS peg transfer task (such as color, size and shape of the peg board, etc.) while other aspects require additional development. Future improvement of the user interface and haptic feedback will enhance the value of the system as an alternative to the FLS as the standard training tool for laparoscopic surgery skills.

Keywords: Surgical training, virtual reality (VR), Virtual Basic Laparoscopic Surgical Trainer (VBLaST), Fundamentals of Laparoscopic Skills (FLS), force feedback

INTRODUCTION

The laparoscopic approach has become the standard of care for a wide variety of surgical procedures and is appealing from the patients' perspective because it is less traumatic, allows for reduced scarring and a quicker recovery compared to open surgery [1, 2]. This technique is more demanding for surgeons than open surgery and requires extensive training. This is due to the increased sensorimotor challenges associated with this technique [3, 4, 5].

As a result, laparoscopic surgery trainees must undergo a substantial amount of preparation using simulators prior to performing live operations. In the last decade, simulation-based training has become an important part of the laparoscopic surgery training curricula at many institutions [6]. For instance, the Society of American Gastrointestinal and Endoscopic Surgeons (SAGES), the American College of Surgeons (ACS) and the American Board of Surgery (ABS) have adopted the Fundamentals of Laparoscopic Surgery (FLS) curriculum as the standard method for assessing the proficiency of laparoscopic surgical skills [7]. The FLS trainer is a physical box-trainer based on the McGill Inanimate System for Training and Evaluation of Laparoscopic Skills (MISTELS) [8]. This validated trainer was developed to teach and measure basic laparoscopic skills [9].

Even though the FLS box-trainers are low-tech in nature, they are relatively expensive (around 2000 USD per unit), they lack automated and objective performance assessment methods [10], and are resource intensive as they require a large supply of consumables (e.g., gauze, endoloops, sutures, etc.) that increases the training costs.

To overcome these issues, virtual reality (VR)-based simulators can be used to replace physical models. Compared to physical trainers, VR simulators enable objective and automated assessment of performance, in real-time, and without the need for proctors [11]. Moreover, they permit unlimited training without the expense of consumables. They can also provide haptic feedback, which has already been shown to be an essential component of minimally invasive surgery simulations [12, 13, 14, 15, 16, 17]. VR-based simulators have already been shown to transfer effective technical skills to the operating room environment [16, 18, 19]. Existing commercial VR simulators that incorporated tasks similar to FLS trainers include LAP Mentor (Simbionix USA, Cleveland, OH) [20], Lap-X (Epona Medical, Rotterdam, The Netherlands) [21] and LapVR (Immersion Medical, Gaithersburg, MD) [22]. However, most of these systems lack realistic haptic feedback, are expensive, or have not been validated for training of laparoscopic skills.

The Virtual Basic Laparoscopic Surgical Trainer (VBLaST©) is being developed as the VR version of the FLS trainer [23]. The VBLaST© provides haptic feedback to aid learning, objective and automated measurements of performance, and repeated training with no need to replenish materials. VBLaST-PT© [24], the system used for this study, is a subset of the VBLaST© simulator that simulates the peg transfer task of the FLS system, which has undergone face and convergent validation [25, 26].

The purpose of this study was to assess the value of the current VR technology used in the peg transfer task of the VBLaST©, based on the subjective preference of surgeons, and their objective performance on the simulator and to investigate the ability of the VBLaST-PT© to differentiate between novice, intermediate and expert groups. It was hypothesized that subjects' performance would be similar on both simulators, regardless of their preference for the simulators (H1). Furthermore, subjects with more training or experience would perform better than those with less training or experience, and better than those with no training at all, when using either the FLS or the VBLaST-PT© (H2). Finally, subjects' performance was expected to improve with training on both the FLS and the VBLaST-PT© (H3).

METHODS

Participants

Thirty (30) subjects (25-55 years old; 19 males, 11 females) with varied experience in surgery were recruited in this Institutional Review Board (IRB) approved study from different teaching hospitals in the Boston Area. Two of the subjects were left-handed, and 28 subjects were right-handed. The subjects were categorized into three groups – novices, intermediates and experts, based on their experience level with 10 subjects in each group. The minimum number of subjects (10 per group) was calculated using G*power [27] for a mixed design ANOVA, using the following parameters: *Significance criterion*= 0.05, *Effect size*=0.4 (medium), *Desired power*=0.95 (high).

The "novices" consisted of general surgery interns in their first or second year of residency (PGY1 and PGY2). The "intermediates" consisted of third and fourth year general surgery residents (PGY3 and PGY4). The "experts" consisted of fifth year general surgery residents (PGY5), surgery fellows and attendings. Interns and second year surgical residents were selected as novices because they have limited laparoscopic training due to time in the residency program. Third and fourth year surgical residents were grouped into the intermediate group. Fifth year residents, fellows and practicing surgeons were selected into the expert category due to their advanced laparoscopic training.

Apparatus

The FLS and the VBLaST-PT© (Figure 1) were used to perform the peg transfer task. A peg board is placed in the center of the FLS box trainer with 12 pegs and six rings. The six rings are on the left side of the peg board at the start of each trial. The VBLaST-PT© simulator consists of computational software to simulate the FLS pegs and rings, and a physical user interface to connect two laparoscopic graspers to two PHANTOM Omni haptic devices

(Geomagic Inc., Boston, MA, USA). These tools allow force feedback to be transmitted to the users. A digital video capture device (AVerMedia, Milpitas, CA, USA) was used to record subjects’ performance inside the task space for the FLS trainer. The video was used to extract task completion time and errors for data analysis. The performance measures for the VBLaST-PT© were automatically recorded by the system.

Figure 1: The peg transfer simulators, left the FLS, right the VBLaST-PT©

Task

The peg transfer task, the first of five standard psychomotor tasks in the FLS, was used in this study. Using two graspers (one in each hand), subjects picked up the rings (one at a time) with the left hand, transferred them to the right hand, and placed them on the opposite side of the peg board. Once all the rings were transferred, the process was repeated to transfer the rings back to the other side of the peg board to complete one trial.

Procedure

Before the start of the experimental session, subjects were asked to fill out a questionnaire detailing the demographics and their previous laparoscopic surgery and laparoscopic simulators experience. The subjects were then shown an instructional video describing the peg transfer task, accompanied by a verbal explanation. Subjects were given one practice trial to become familiar with the procedure and each of the systems. They were then asked to perform ten trials of the peg transfer task in one trainer and then ten trials in the other trainer. To control the effect of simulators' order on the performance, the presentation order of the simulators (FLS vs VBLaST) was counterbalanced. The first two trials on the FLS for one subject (intermediate group) were not recorded due to a technical issue.

At the end of the session, the subjects completed a questionnaire to evaluate the features of the VBLaST-PT© relative to the FLS trainer and real laparoscopic surgery, using a 5-point Likert scale (from (1) representing very poor/ not satisfactory to (5) representing very good/very satisfactory). The questions were related to visual appearance, haptic feedback, 3D perception, tools movement and overall quality and reliability of the system as a training and assessment tool.

Dependent measures

For the FLS trainer, the dependent measure (obtained from video analysis) consisted of a total raw score (ranging from 0 to 300) calculated using undisclosed metric for the FLS [8] obtained from the SAGES FLS committee. The raw score is calculated using a combination of the task completion time and the number of rings dropped outside of the board. These raw scores were then divided by a normalization factor that was calculated using the best expert FLS score obtained in the FLS condition. The FLS normalized scores ranged from 0 to 100. For the VBLaST-PT© simulator, the raw score was automatically calculated by the system using the same formula. These raw scores were then divided by a normalization factor calculated using the best expert score obtained from the VBLaST-PT© condition in the experiment. The VBLaST© normalized scores also ranged from 0 to 100.

Data analysis

Since the data were not normally distributed (tested using the Shapiro-Wilk test), non-parametric statistical tests were used to analyze the data. The Spearman correlation test, the Wilcoxon signed rank sum test, the Kruskal Wallis test, the Mann-Whitney's U test, or the Friedman rank sum test were used, where appropriate, with an alpha value of 0.05. Descriptive statistics were used to analyze the questionnaire data by calculating the average subjective ratings and their standard errors. All analyses were performed using "R", a free and open-source statistical analysis software.

RESULTS

Correlation test

The Spearman correlation test showed that the FLS and VBLaST-PT© mean normalized scores had a correlation of 0.51 ($r(28) = 0.51$, $t= 3.18$, $p = 0.003$).

The effect of simulator

The Wilcoxon signed rank sum test showed that participants performed significantly better in FLS than in the VBLaST-PT© ($Z=4.76$, $p = 0.0001$, Figure 2).

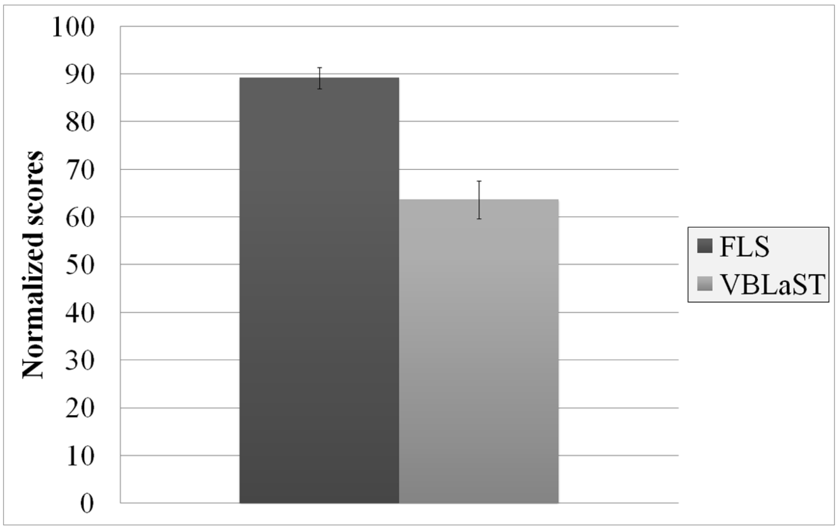

Figure 2: The comparison of the FLS and VBLaST mean normalized scores (error bars represent the standard error)

The effects of experience levels and simulators order

The Kruskal Wallis test was used to examine the effect of experience levels (novices, intermediates, and experts) on the performance scores (Figure 3).

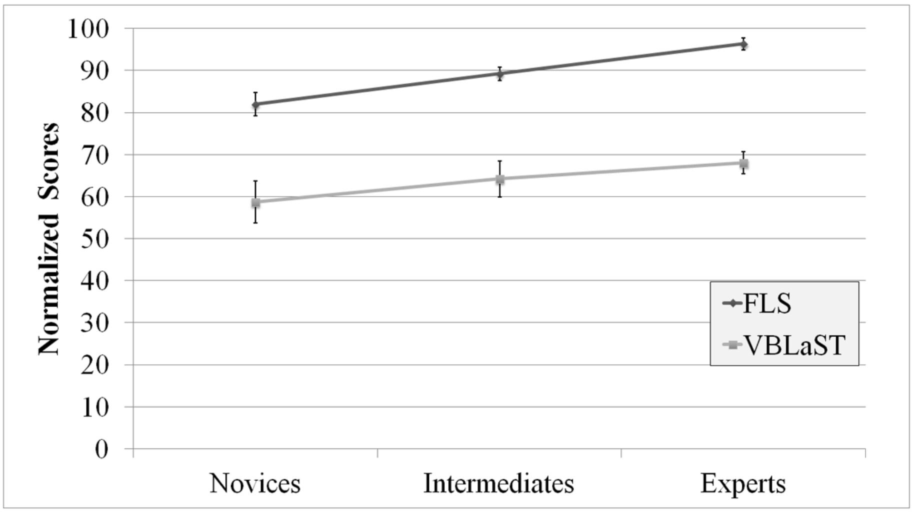

Figure 3: The effect of experience level on the mean normalized scores (error bars represent the standard error)

The test revealed no significant effect of experience level on the VBLaST-PT© performance scores (H= 0.44, p>0.05). On the other hand, a significant effect of experience level on the FLS normalized scores **(**H= 6.39, p=0.04**)** was found. The Mann-Whitney's U test was then used to evaluate the difference between the groups. The results showed that the FLS scores were higher in the expert group than in the novice group **(**U = 81, Z = -2.31, p = 0.02, r=0.51). There were no significant differences, neither between the novices and intermediates (U = 63, Z = -0.94, p > 0.05), nor between the intermediates and experts (U = 73, Z = -1.7, p > 0.05). Finally, the Mann Whitney U-test showed no significant effect of the order of simulators neither on the FLS scores nor on VBLaST scores (U=96, Z=-0.68, p=0.49; U=110, Z=-0.10, p=0.91, respectively).

Learning effect

The Friedman rank sum test was used to examine the learning effect from trial #1 to trial #10 (Figure 4) The results showed a significant learning effect in both FLS and VBLaST-PT© systems ($\chi^2(9)$=39.82, p = 0.01; $\chi^2(9)$= 56.50, p = 0.01, respectively).

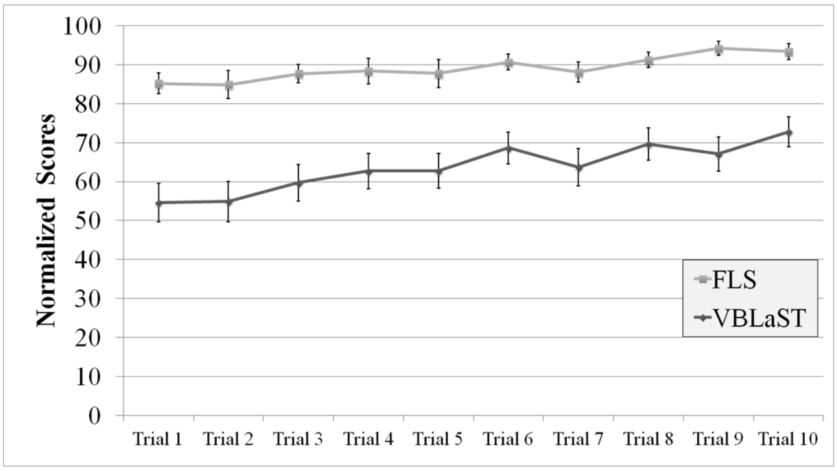

Figure 4: Effect of trials order on performance (error bars represent the standard error)

Moreover, the Mann-Whitney's U test was used to evaluate the difference in the average gain in scores between the first trial and the last trial for the two simulators (Figure 5). The results showed a greater improvement of performance in VBLaST-PT© compared to FLS (the mean ranks of FLS gain in scores and VBLaST-PT© gain in scores were 24.2 and 36.8, respectively; U = 640, Z = -2.8, p = 0.005, r = 0.36).

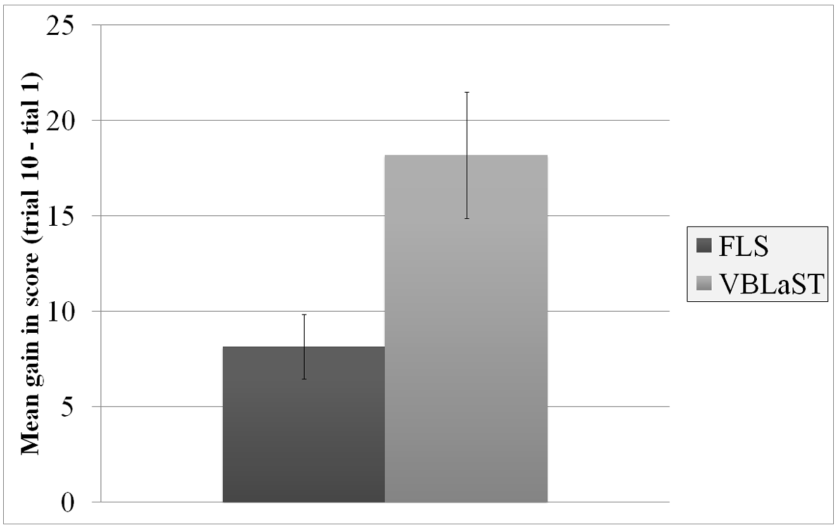

Figure 5: Effect of simulator on the average gain in scores between the first trial and the last trial (error bars represent the standard error)

Subjective evaluation

The subjective ratings of the VBLaST-PT© features are shown in Table 1. The average rating for Questions 5 (usefulness of force feedback) was the highest (3.96). Realism in rendering, usefulness for learning hand-eye coordination skills, and usefulness for learning ambidexterity skills were rated second highest. Questions 2 (realism of instrument handling), and 9 (trustworthiness in quantifying performance measures) had the lowest ratings. Only 13.6% of subjects preferred using the VBLaST-PT© over the FLS for training laparoscopic surgery skills, 82.6% of them preferred the FLS trainer, while one subject did not show any preference.

Table 1: Subjects' ratings of the VBLaST-PT© system on a 5-point scale (from (1) representing very poor/ not satisfactory to (5) representing very good/very satisfactory)

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		Mean rating	Standard error
1	Realism in rendering	3.74	0.24
2	Realism of instruments handling	2.90	0.16
3	Overall realism compared to FLS	3.17	0.18
4	Quality of force feedback	3.04	0.26
5	Usefulness of force feedback in task completion	3.96	0.28
6	Usefulness for hand-eye coordination skills compared to FLS	3.43	0.23
7	Usefulness for ambidexterity skills compared to FLS	3.48	0.25
8	Overall usefulness in training for FLS skill set	3.171	0.22
9	Trustworthiness in quantifying performance	2.96	0.26

DISCUSSION

The FLS box trainer has already been validated as a tool for training basic laparoscopic skills. The objective of this study was to assess the value of the VBLaST© simulator with haptic feedback compared to the FLS trainer box, using only the peg-transfer task. The VBLaST© is expected to serve the same training objectives of the FLS while avoiding its drawbacks. We hypothesized that subject performance, over a range of surgical experience, would be similar on both simulators. The results showed that the subjects' overall performance score for the peg-transfer task on the VBLaST© was significantly lower than on the FLS. This finding may be attributed to the newness of the VBLaST-PT© system. In fact, the participants may have required an adaptation period before being able to correctly perform the task in the VR environment. This was supported by the analysis of the learning effect over 10 trials on both simulators. The results showed that the participants did improve their performance in both systems, and this improvement of performance was significantly higher in VBLaST-PT©. One may surmise that some adaptation to the virtual environment was needed, after which the participants improved their performance with practice (Figure 4).

Nevertheless, the subjects' performance in VBLaST© remained lower than their performance in the FLS trainer even at the end of the experiment. Moreover, the results showed a significant correlation between the VBLaST-PT© performance scores and the FLS performance scores although the correlation coefficient was of medium strength. This suggests a medium relationship between the VBLaST and the FLS scores and the existence of other factors that affected the performance.

In fact, factors related to the interaction in the VR environment may have contributed to the poor performance in the VBLaST-PT©. One possible factor can be differences in the quality of the user interface. In this context, the subjective evaluation and the participants' comments provided valuable information regarding the usability of the user interface. Although they were very satisfied by the quality of the graphical user interface, the subjects' rating of the realism of instrument handling was low. This suggests that they had difficulty adapting to the use of real instruments to manipulate the virtual objects which altered their performance in the visuomotor task. Moreover, the subjects rated the quality of the system's force feedback low even though they acknowledged the usefulness of haptic feedback, suggesting that the displayed haptic feedback was not appropriate. In fact, haptic feedback has been shown to be an important component for laparoscopic skill training [12, 13, 14, 15, 16, 17]. The quality of the system's haptic feedback may have altered the users' performance in the peg transfer task. Although the users agreed on the usefulness of VR technology for training laparoscopic skills, most of them preferred to use the FLS trainer in which they performed better. Hence, improvements in the manipulation of the tools and the realism of haptic feedback will be necessary to improve the user's performance in the VBLaST-PT© or any other VR system in the future.

Finally, the results showed that the VBLaST-PT© could not differentiate the three experience groups while the FLS was able to differentiate only between the experts and the novices. Again, this may be attributable to the novelty of the system and the quality of the user interface. These factors may have contributed to lower the users' performance, especially during the initial trials.

FUTURE WORK

Our design approach for the VBLaST© system consists of including the end users in different stages of the design cycle. The current study permitted the evaluation of the VBLaST© by users with different expertise levels in laparoscopic surgery. Although the results show that the peg transfer task in VBLaST© offers a good alternative to overcoming important drawbacks of physical trainers, this study pointed out some limitations of the current VBLaST© trainer, mainly related to the usability of the user interface. These limitations do not permit validation of the current version of the VBLaST-PT© system. Future development will include improvement of the user interface as well as the haptic feedback to enhance the users' interaction when using the system for training purposes. Lessons learned here will be applied in the development of the four remaining psychomotor tasks of the FLS curriculum in the VBLaST© system. Validation studies will be conducted before offering the VBLaST© as an alternate training standard for laparoscopic surgery.

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DISCLOSURE

Dr. Steven, D. Schwaitzberg is a consultant for Stryker and Olympus and member of the advisory board for NeatStitch, AcuityBio, MITI, Cambridge Endo and Surgiquest. Dr. Daniel B. Jones is a consultant for Allurion. Likun Zhang, Venkata S. Arikatla and Drs. Amine Chellali, Ganesh Sankaranarayanan, Woojin Ahn, Alexandre Derevianko, Marc DeMoya and Caroline, G.L. Cao have no conflicts of interest or financial ties to disclose.

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