Application of Stereoscopic Visualization on Surgical Skill Acquisition in Novices

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OBJECTIVE: The use of stereoscopic imaging can provide additional depth cues that may increase trainee performance on surgical tasks, but it has yet to be evaluated using a validated surgical skill system. This study examines the influence of monoscopic vs stereoscopic visualization in novice trainees performing the McGill Inanimate System for Training and Evaluation of Laparoscopic Skill (MISTELS) tasks, a validated laparoscopic skill–evaluation system, predicting a difference in performance based on visualization modality.

DESIGN: A total of 31 first- and second-year medical students at the University of Western Ontario were selected, each performed the MISTELS battery of tasks (circle cutting, peg transfer, ligated loop Placement, intracorporeal knot tying, and extracorporeal knot tying) using either monoscopic or stereoscopic visualization displays. Performance was evaluated in accordance with the MISTELS protocol. Participant visual spatial ability and manual dexterity skills were also analyzed and compared with performance. p values less than 0.05 were considered significant.

RESULTS: For ligated loop placement, extracorporeal knot tying, and intracorporeal knot tying, no significant difference was found between monoscopic and stereoscopic visualization on task performance ($p > 0.05$). Monoscopic visualization was shown to produce significantly better performance in the peg transfer task alone ($p = 0.001$). Qualitatively, 57.1% of participants believed their performance was aided by stereoscopic visualization and 68.8% believed that future learners would benefit from its implementation into surgical education. Most participants rated the peg transfer task to be the least difficult task (60%) and rated the intracorporeal knot-tying task to be the most difficult (65.9%).

CONCLUSIONS: These results suggest that the intrinsic difficulty of the MISTELS tasks may exceed a novice user's skill. No benefit with additional 3-dimensional cues in naïve surgical trainees was found. Additional visual cues in stereoscopic visualization may only serve to increase cognitive load and potentially decrease skill acquisition and learning. (J Surg ■:■■■-■■■. © 2013 Association of Program Directors in Surgery. Published by Elsevier Inc. All rights reserved.)

KEY WORDS: stereoscopy, skill acquisition, MISTELS, 3D visualization, laparoscopy

COMPETENCIES: Practice-Based Learning and Improvement, Systems-Based Practice

INTRODUCTION

Traditionally, surgeons are trained by a system of didactic lectures paired with hands-on experience in the operating room. Surgical residencies are a system of increasing incremental responsibility, where volume of exposure has become more critical than quality of exposure.[1] However, with a modern trend toward decreased operating room time and decreased length of the residency work week, there is an ever-falling access to practical learning for surgeons.[1] Didactic instruction has proven ineffective[2] and thus there is a trend toward greater utilization of technology to find cost-efficient ways to maximize surgical training without expending resources and increasing operative risk.

Given a need for alternative surgical learning options, 3-dimensional (3D) (stereoscopic) imaging is now a reality owing to technological innovation. Stereoscopy is shown to improve surgical performance of trainees during a procedure[3-6] as well as increase anatomical spatial awareness via

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learning modules.[7] Stereoscopic imaging is provided via 2 different lenses within the same camera body simulating the left and the right eye. These images are then overlaid with the appropriate convergence and presented as a single stereoscopic image. Despite its drawbacks, most medical imaging is presented in 2D (monoscopically), yet the third dimension and stereoscopic vision have the ability to offer greater visual acuity,[8] additional depth cues, and anatomical awareness—essential information for a novice surgeon when attempting fine motor tasks.[9] Interestingly, Luursema et al. demonstrated that a 3D computerized self-learning module aimed at teaching abdominal vascular anatomy is superior to the same 2D learning module for all participants.[7,10] An even greater benefit for trainees with lower initial Visual Spatial Ability (VSA), a metric that positively correlates with better skill performance[11,12] is demonstrated.[7,10] Three-dimensional visualization of the surgical field is associated with better surgical results with decreased procedure time and decreased medical errors, laproscopically,[4,6] endoscopically,[13] and even when remotely controlling the da Vinci robotic system.[14] Additionally, expert surgeons, who have grown accustomed to 2D imaging, express a favorable stance on the implementation of 3D imaging citing better differentiation of the tissue layers and increased depth of field.[6,14] A primary application of stereoscopic technology in the surgical field is the implementation of 3D imaging in real time by the use of binocular scopes.[6] These scopes, if applied to training, allow learners to assimilate information about anatomy with depth cues in real time, and translate it immediately to action. This can not only increase learning beyond simple identification, but assimilation between motor coordination and physical surgical skill as well.

Although promising, the validity of stereoscopic technologies in training, in the context of surgical trainees, has yet to be analyzed using a validated surgical skill–evaluation system. Currently, the McGill Inanimate System for Training and Evaluation of Laparoscopic Skill (MISTELS) is an essential component of the Fundamentals of Laparoscopic Surgery (FLS) program used to evaluate surgical residents to certify proficiency in laparoscopic skill. It is a set of 5 tasks requiring manipulation of laparoscopic tools in skills such as cutting, knot tying, object movement/transfer, and coordinated object placement. The MISTELS battery of tasks has been validated to be an accurate measure of laparoscopic competency.[15] This system is designed for trainees, allowing them to improve upon their skill set in a safe and cost-effective environment, and provides an ideal backdrop for implementation of stereoscopic visualization in surgical skill education and skill acquisition. This study aims to evaluate differences in laparoscopic skill performance between monoscopic and stereoscopic visualization in novice medical trainees performing MISTELS tasks. We hypothesize that the added visual cues of stereoscopic visualization would enhance trainee performance.

METHODS

Participants

A total of 35 first- and second-year medical students, 19 males and 16 females, participated in this study. Participants had received no surgical specific training prior to testing, and the majority had no laparoscopic experience and minimal recreational engagement in video games (less than 5 h per week).

Pretesting

Each participant first completed a simple demographic questionnaire documenting education level, surgical experience, and handedness, followed by testing of stereovision, VSA, and manual dexterity (MD). To experience the benefit of 3D scoping, a participant must possess stereovision: the ability to merge left and right images from your eyes into a single 3D image. Fine and gross stereovision were assessed using a combined Schmetterlings Test and Graded Circle Test (Kavita). VSA was evaluated using an electronic adaptation of the Vandenberg and Kuse Mental Rotations Test[16] and scores were recorded. Finally, the Purdue Pegboard Test (Lafayette) was used to quantify MD in each participant.

Treatment Groups and Tasks

Participants were then randomly assigned to 1 of 4 laparoscopic viewing categories that determined their viewing modality and order for each MISTELS task (Fig. 1). Participants were shown an instructional video, outlining each of the tasks before commencing. The MISTELS skills and order are as outlined (Table 1).

Equipment and Setup

MISTELS tasks were performed on FLS protocol box trainers (VTi medical) with accompanying default 2D camera. Display size was standardized at 32 in, 1080p resolution at a height of 73 in, with participants situated approximately 65 in from the display. A 3D stereoscopic

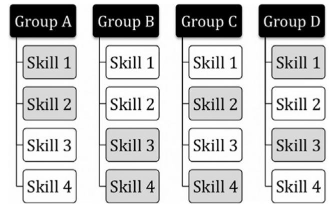

FIGURE 1. Explanation of the testing paradigm randomization in terms of visualization modality exposure. Gray shading represents monocular visualization, whereas white boxes represent stereo visualization. The numbered skills are: 1: peg transfer 2: ligating loop placement 3: extracorporeal suture 4: intracorporeal suture. All participants are assigned to 1 of the 4 groups randomly.

TABLE 1. MISTELS Tasks and Battery Order

Warm Up	Precision circle cutting	Using laparoscopic scissors and a grasper, trainee must cut a predrawn circle out of suspended gauze. The aim is to cut as close to the predrawn line as possible.
Skill 1	Peg transfer	Using 2 laparoscopic drivers, trainees must, one by one, pick up each of the 6 rings with the grasper in their nondominant hand, transfer it to the grasper in their dominant hand and place on a peg on the alternate side of the board. This is then repeated with direction reversal from dominant to nondominant.
Skill 2	Ligated loop placement	Aim is to tie the ligated loop as close to a premarked band as possible. Once the knot is tightened, trainees must cut the suture.
Skill 3	Extracorporeal knot	Trainees must thread a suture as close to premarked points as possible. The 3 throws of the knot are then made outside of the box. The task is completed by cutting of the suture.
Skill 4	Intracorporeal knot	Trainees must thread a suture as close to premarked points as possible. Three throws of the knot are made inside of the box. The task is completed by cutting of the suture.

VisionSense VSII rig was used for stereoscopic image acquisition. Three-dimensional laparoscope and stereoscopic display monitor (VisionSense) were positioned using the same parameters. Cameras were held stable and were not adjusted by participants as mandated by MISTELS protocol. VisionSense 3D glasses were worn for all tasks completed in 3D.

Trials

To familiarize themselves with the equipment, participants performed the circle-cutting task using the visual modality of their first evaluated task as per their treatment group. The circle-cutting task was not evaluated. Participants then completed each of the 4 remaining MISTELS tasks with viewing modality for each task in accordance with their assigned treatment group. Tasks were timed and scored by a trained observer according to the MISTELS-validated evaluation criteria.

Posttest

Participants ended their trials by completing a posttest targeted at experience with the 2 viewing modalities and opinion of stereoscopic laparoscopy and applications to surgical education.

Statistical Analysis

Data tabulation was performed using the MISTELS scoring system, which calculates and normalizes the trainee's raw score on each task to produce a final overall normalized performance score. Statistical analysis was performed using SPSS software package, version 20 (IBM, Armonk, NY), with an alpha level of 0.05 and a power level of 0.80.

RESULTS

Four participants did not possess stereovision and were discounted from data analysis, $n = 31$.

Quantitative Findings

Scores were normalized according to MISTELS scoring guidelines and final scores were calculated. Average score for all participants was 84.92 (±49.74) (Fig. 2). Average final scores across the 4 treatment groups were compared using multivariate analysis of variance and were found not to be significantly different from one another ($p = 0.190$) (Fig. 3). Multivariate analysis of variance was used to analyze performance in individual MISTELS tasks based on visualization. Scores were not found to be significantly different for stereoscopic and monoscopic visualization for ligated loop placement ($p = 0.547$), extracorporeal knot tying ($p = 0.284$), or intracorporeal knot tying ($p = 0.795$). Performance on peg transfer was significantly greater when visualized monoscopically ($p = 0.001$) (Fig. 4). For individual tasks, participants exceeded the MISTELS time limit in 12.9% (8 of 62 attempts) of the tasks performed with monoscopic visualization and 37.1% (23 of 62 attempts) of the tasks performed with stereoscopic visualization (Table 2).

Correlation analysis comparing pretest scores for MD and VSA to normalized final scores found VSA to be weakly positively correlated ($r = 0.012$) to MISTELS performance, and MD to be negatively correlated ($r = -0.032$) to MISTELS performance. Neither result was found to be significant (VSA $p = 0.252$, MD $p = 0.812$) (Fig. 5).

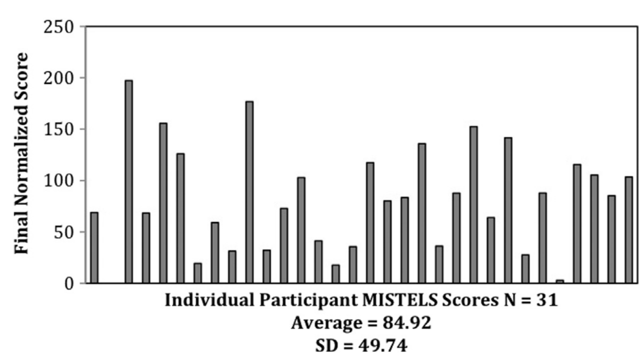

FIGURE 2. Distribution of normalized final MISTELS scores for all participants (n = 31).

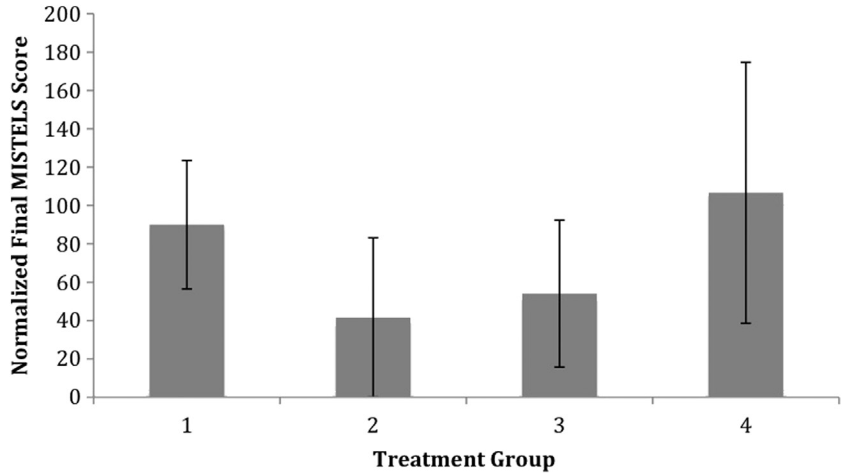

FIGURE 3. MISTELS performance by treatment group. Mean normalized final MISTELS scores were not found to be significantly different between treatment groups ($p = 0.190$). Error bars indicate ±SD. SD, standard deviation.

Qualitative Findings

Overall, participants viewed stereoscopic visualization modality positively, as 57.1% believed it aided their skill performance and 68.8% believed that learners would benefit from its implementation in skill-acquisition training. In regard to potential discomfort associated with 3D glasses and sensations of movement/jarring, participants rated the discomfort at 1.43 out of a potential 5 (0 = no discomfort, 5 = constant, copious discomfort). When questioned about perceived task difficulty, most participants indicated that they believed peg transfer to be the easiest task (60%) and intracorporeal knot tying to be the most difficult task (65.9%) (Table 3). Overall, free comments regarding the experiment were overwhelmingly favorable toward stereoscopic laparoscopic visualization and its use in surgical skills training, but noted adjustment to the visualization causing some discomfort.

DISCUSSION

Our testing focused on the implementation of stereoscopic visualization in surgical skill acquisition by analyzing the performance of novice medical trainees in MISTELS battery of tasks. The MISTELS tasks were chosen because they are validated and have been implemented as a performance-evaluation system in the FLS programs for surgical residents.[15] It should be noted that only 4 of the 5 MISTELS tasks were evaluated. This design provided the circle-cutting task as a warm-up to allow participants to familiarize themselves with the equipment and experimental protocol

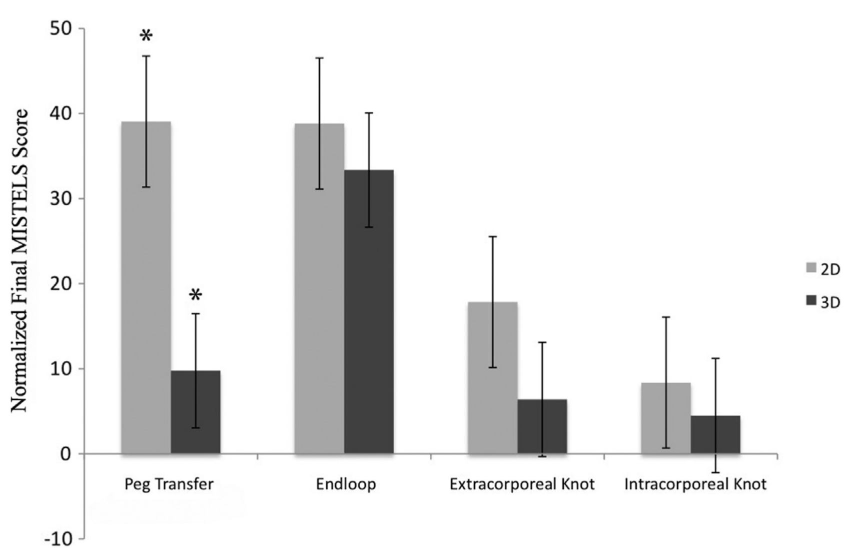

FIGURE 4. Performance on individual MISTELS tasks by visualization. Error bars indicate ±SE. SE, standard error.

TABLE 2. Occurrence of Time Limit Expiry by Task and Visualization

	Task 1 2D	Task 1 3D	Task 2 2D	Task 2 3D	Task 3 2D	Task 3 3D	Task 4 2D	Task 4 3D
No. of trials exceeding time limit	1	6	1	3	1	6	5	8
Total no. of trials	18	13	15	16	16	15	13	18

and what was to be expected of them throughout the testing process. Students were given the opportunity to use each of the tools to familiarize themselves with their function as well as perform the circle-cutting task to familiarize themselves with movements. Warm-up time was based on parallel studies.[6,17] Storz et al. commented that a second attempt at a task showed improvement, but no additional improvement was noted after that attempt.[17] Based on this data, we believe that the circle-cutting task provided adequate familiarization time. This was further reflected in our qualitative data as discomfort and frustration was deemed to be minimal. Circle-cutting task was chosen as the initial task owing to its uniplanar geometric design. We have shown in previous work that the effect of stereoscopic visualization is diminished in tasks that are highly planar in nature, such as the creation and suturing of skin flaps used in plastic surgery.[18] This qualified the circle-cutting task as the best suited to be removed from evaluation.

Upon evaluation of performance between the different experimental treatment groups, no significant difference was found between groups, signifying equality between the treatment groups ($p > 0.05$). Regarding visualization, stereoscopic imaging was not found to be more effective than monoscopic imaging for 3 of the 4 evaluated MISTELS tasks (ligated loop placement, extracorporeal knot tying, and intracorporeal knot tying) ($p > 0.05$). Interestingly, in the remaining peg-transfer task, monoscopic visualization was found to produce significantly better scores than stereoscopic visualization ($p = 0.001$). This fails to validate our original hypothesis that stereoscopic visualization would enhance performance. Additionally, these results are in partial contradiction to a study conducted by Storz et al., investigating 2D vs 3D visualization and performance in phantom surgical tasks. Sampling performances in both residents and medical students[17] they found that stereoscopy significantly enhanced performance in both groups. We suggest that the differences in our studies lies in the nature of the tasks used for evaluation. The phantoms tasks mimicked basic surgical skills, but were not a validated set of tasks. They appear to be innately less difficult than the MISTELS tasks, thus decreasing the cognitive load on the participant. The idea of cognitive load is significant when applying technological multimedia to education.

Mayer has devoted extensive time developing cognitive load theory for educational multimedia.[19,20] Cognitive load theory is not a new concept in technical education and was first described by Sweller et al. in 1988.[21] Mayer has adapted it to a level appropriate for technology of the current era into medical education. This theory is founded upon the components of learning: an input phase, a processing phase, and a memory storage phase.[19,20] The processing phase occurs when various external stimuli are interpreted, extraneous signals discarded, and relevant information retained for organized and structured memory storage. Mayer shows that the highest rate of retention in learn-and-recall modules and posttests are found when multimedia is designed in a specific fashion.[20] This is best achieved by splitting information

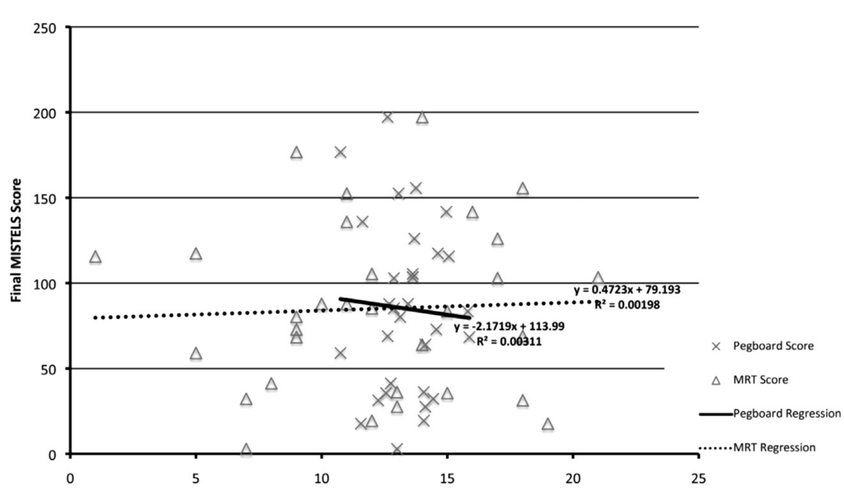

FIGURE 5. Linear regression correlation of: manual dexterity represented by Perdue Pegboard Test scores ($r = -0.032$), and visual spatial ability represented by Mental Rotation Test (MRT) ($r = 0.012$), to MISTELS performance.

TABLE 3. Summary of Qualitative Posttest Survey Responses

Statement	Answer (%)
Do you feel that the addition of 3-D visualization aided in your skill performance?	Yes (57.1) No (42.9)
Did you experience difficulty with depth cues in 2D?	Yes (74.3) No (24.7)
Did 3-D help?	Yes (54.3) No (45.7)
From a scale of 0 to 5, 0 being no discomfort, 5 being the worst discomfort you've ever experienced, how much visual discomfort, including spinning, blurring, straining, or a jarring sensation did you feel while using the 3-D visualization setup?	0 (40.0) 1 (11.4) 2 (22.8) 3 (20.0) 4 (2.9) 5 (2.9)
Which task did you find the most difficult?	Precision cutting (9.7) Peg transfer (2.5) Ligated loop placement (4.9) Intracorporeal knot tying (65.9) Extracorporeal knot tying (17.0)
Which task did you find the least difficult?	Precision cutting (5.8) Peg transfer (60.0) Ligated loop placement (34.2) Intracorporeal knot tying (0) Extracorporeal knot tying (0)
Do you think Laparoscopic learners would benefit from 3D?	Yes (68.8) No (31.2)

between visual and audio inputs, as well as by utilizing effective layouts of both text and visuals: the dual coding theory, originally described by Alan Paivio and incorporated by Baddeley in his description of working memory.[22] When there is additional extraneous information, further loading the visual sensory channel occurs and the resulting increase in cognitive load could equate to decreased learning.[20]

The MISTELS tasks are intrinsically difficult, as they incorporate the use of laparoscopic tools to perform a variety of complex geometric tasks. Although there is no audio component in the learning tasks presented here, the complex haptic feedback provided by the box trainers and the endoscopic tools provide a new dimension to cognitive load research as it pertains to technical skill acquisition. We suggest that the cognitive load of performing the tasks themselves is high, adding further pressure to the memory-encoding systems of naïve trainees, and potentially, deleterious effects on behavioral learning. We suggest that our results demonstrate the addition of the visual third dimension may over burden the naïve learner's visual system with extra depth cues, thereby exacerbating cognitive load, which may decrease learning in the short term. This idea is supported by our results showing a higher rate of participants exceeding task time limits in tasks visualized stereoscopically (37.1%), compared with only exceeding time limits 12.9% of the time when visualized monoscopically. This may represent added difficulty encountered by additional processing of visual cues in stereoscopic tasks. Stereoscopic visualization may not provide the learning advantage intended by the system in novice trainees. In the peg-transfer task, it was found that monoscopic visualization is favorable to stereoscopic visualization. This task was simple enough to generate differentiation between the 2 visualizations, without the intrinsic difficulty of the task itself compromising performance. Two-dimensional visualization provided adequate cues for task completion, but the addition of the third dimension overloaded the visual input and compromised performance. This is further reflected in the qualitative feedback provided by participants, as the greatest proportion of participants (60%) indicated that they believed the peg-transfer tasks to be the easiest. Additionally, peg-transfer task time limit was only exceeded 7 times, compared with extracorporeal knot tying, which was exceeded 14 times and rated to be the most difficult task (Tables 2 and 3). Both had equal number of attempts. Stereoscopic visualization may prove to be a better application in a higher-trained population such as surgical residents. These trainees have minimized cognitive load generated by the tasks themselves and may be better able to attend to the additional sensory feedback such as the augmented perception of depth provided by 3D visualizations.

Despite any significant increase in MISTELS performance, the overall attitude toward stereoscopic visualization was favorable among participants. Previously, Hu et al. evaluated the use of a stereoscopic laryngeal model in a didactic lecture describing the anatomy and clinical significance of these structures. Commensurate with results of the current study, they did not find any significant effects on student posttests but similar positive student perceptions of the technology's utility for their comprehension.[23] This reflects a general positive attitude toward technology, embraced by modern society. Discomfort was rated to be negligible, and interestingly, many indicated that they believed stereoscopy to be beneficial in their performance. Some participants were able to acknowledge that personally they may not have found stereoscopic visualization beneficial, but that it may have greater potential in the scheme of surgical education. These results may point to the potential of 3D visualizations in populations with greater amounts of training also known a prior knowledge in cognitive load fields.[20] Future studies should investigate the influence of visualization on performance of surgical residents and expert surgeons in a validated skill-evaluation battery. It would be beneficial to test trainees at all stages of training, with comparison between postgraduate year-1 (PGY-1) and PGY-2 residents, more established PGY-3, -4, -5, and -6 residents, and surgical fellows and expert surgeons. Each subset has a different degree of skill development and development of VSA.[7] As such, the benefit they may receive from additional visual cues offered by stereoscopy may differ between the subsets of surgical trainees. It would be valuable to curriculum designers to isolate if, where, and when stereoscopy has the most beneficial application in skill training so as to assess if it is practical to introduce the technology to training programs. This may enable medical education programs to best allocate their training resources, and potentially help residents and experienced surgeons to become proficient at new skills and techniques, if the technology is deemed beneficial. This study suggests that perhaps at the novice level, monoscopic skills training should be offered initially, before graduating students to more complex tasks and implementing stereoscopic technology.

A study by Kong et al. demonstrated that stereoscopic visualization provided no increase in speed of basic surgical task performance, but instead reduced error in novices and residents.[6] Again, the tasks in this study did not use validated tasks for evaluation, but it does raise a limitation in our study. The MISTELS tasks are scored in a combination of speed and accuracy, with a maximum time for each task. Participants who exceeded time limits for any task received an automatic score of zero for that task, regardless of accuracy or how long after the time limit they took to complete. This approach factors in the total score calculations. It also lends to the variability in our results, as total score is calculated with weighted contributions from each task, and a zero in one or more tasks can affect a large portion of your final score. The performance distribution across the time threshold is not correspondingly represented in the scores, generating increased variability. In a more experienced group of trainees, we predict this limitation would not be a factor, as that cohort's higher skill development and training would afford the ability to complete each task within the dictated MISTELS time limits.

Surgical education has been forced to adapt to produce educational systems that keep skills sharp, while balancing with decreased operating room time owing to mandatory caps on resident work hours. To ensure that the decreased live exposure do not translate into increased procedure error and complication rates by trainees, medical training institutions have invested in technological solutions for skill development of their budding surgeons. Our study informs clinical training centers in 2 ways. First, we demonstrate that 3D stereoscopic technology may not provide adequate return on surgical skill development in novice trainees. Secondly, novice learners are indeed open to the use of technological resources, thus the curriculum may be better at fostering skills at higher clinical skill levels only after the foundations are laid using lower-fidelity simulation environments where skills can be honed. Monoscopic visualization was shown to be the same or more advantageous than stereoscopic visualization at basic training levels utilizing the MISTELS standardized evaluation criteria.

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