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Is Three-Dimensional Videography the Cutting Edge of Surgical Skill Acquisition?

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The process of learning new surgical technical skills is vital to the career of a surgeon. The acquisition of these new skills is influenced greatly by visual-spatial ability (VSA) and may be difficult for some learners to rapidly assimilate. In many cases, the role of VSA on the acquisition of a novel technical skill has been explored; however, none have probed the impact of a three-dimensional (3D) video learning module on the acquisition of new surgical skills. The first aim of this study is to capture spatially complex surgical translational flaps using 3D videography and incorporate the footage into a self-contained e-learning module designed in line with the principles of cognitive load theory. The second aim is to assess the efficacy of 3D video as a medium to support the acquisition of complex surgical skills in novice surgeons as evaluated using a global ratings scale. It is hypothesized that the addition of depth in 3D viewing will augment the learner's innate visual spatial abilities, thereby enhancing skill acquisition compared to two-dimensional viewing of the same procedure. Despite growing literature suggesting that 3D correlates directly to enhanced skill acquisition, this study did not differentiate significant results contributing to increased surgical performance. This topic will continue to be explored using more sensitive scales of measurement and more complex "open procedures" capitalizing on the importance of depth perception in surgical manipulation. Anat Sci Educ 00: 000-000. © 2012 American Association of Anatomists.

Key words: surgical education; skill acquisition; e-learning; 3D; 3D videography; visual spatial ability; global rating scale

INTRODUCTION

There is growing support for the educational potential of three-dimensional (3D) modeling environments in the transfer of knowledge, as the 3D environment has been shown to provide a level of visual realism containing depth cues such as perspective, shading, and stereopsis, that are consistent with the real world (Dalgarno, 2002). It is also suggested that information obtained in 3D visualizations is more readily recalled and applied in the corresponding real world environment than identical two-dimensional (2D) visualizations due to the novelty of the experience (Dalgarno, 2002; de Jong et al., 2005; Dickey, 2005; Jones and Bronack, 2007; Qian, 2008).

Duranni and Preminger correlated the improved visualization to enhancement of the surgeon's ability to perform delicate endoscopic dissection and suturing. They suggest improvements in 3D technology could be developed to train novice surgeons, better preparing them for the operating room. This correlation asserts the necessity for cultivation, evaluation, and optimization of educational surgical tools to capitalize on technology and assist in the establishment of basic surgical skills and knowledge translation (Durrani and Preminger, 1994, 1995).

The described potential of 3D as a visualization tool is likely an interaction with the visual-spatial ability (VSA) of

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the user. VSA, the ability to visualize and mentally manipulate an object in three dimensions, has been proven to assist in initial learning of a technical skill (Brandt and Davies, 2006). This relationship is supported by scores on the mental rotation test (MRT) developed by Vandenberg and Kuse (1978), which show strong correlations between innate VSA and initial technical skill acquisition, particularly in the cases of end-point visualization where the participant must envision a complex series of steps unfolding to realize the end product (Brown et al., 1989; Anastakis et al., 2000; Matsumoto et al., 2002; Wanzel et al., 2002; Wanzel et al., 2003; Brandt and Davies, 2006; Glicksman et al., 2009).

The VSA of individuals appears to be enhanced by exposure to computer-based, self-directed learning, or “e-learning” using 3D tutorials (Dalgarno, 2002). This is the case particularly when several design strategies are adhered to in the construction of the method of delivery. One such strategy, which has been adopted by this study, is Mayer’s cognitive load theory of multimedia learning (Mayer and Moreno, 2003).

This theory suggests the existence of separate pathways for visual and auditory information (Paivio, 1990; Baddeley, 1997; Mayer, 2009). Thus, primary information should be presented to a single stream, while additional supplementary information reinforcing the primary information, is presented to the other stream. That is, if material is largely visual, the visual stream is occupied and the auditory stream is unoccupied and primed to accept additional information. Further, the theory also suggests that the pathways can be overloaded, thus the design strategy places great emphasis on organization of information into readily digestible packets, or “chunks”, making it simpler for learners to interpret and process at their own rate. (Cohen and Sekuler, 2010; Sargent et al., 2010) These principles are of particular importance to module creation, via the incorporation of narration rather than text, video speed controls, and custom playback to revisit difficult concepts.

This study designed and evaluated 3D videographic e-learning modules utilizing the aforementioned cognitive load theory. Each learning module presents spatially complex translational skin flap procedures (rhombic flap and double z-plasty procedures) along with instructional narration as a means of teaching novel surgical skills to novice surgeons. Both procedures involved simple technical skills, but demanded strong visual-spatial skills, thus posing a challenge to novice surgeons and making them ideal for study (Wanzel et al., 2003). The aim of this study was to capture surgical skin flap procedures using 3D video and incorporate the footage into e-learning modules. Secondarily, the study aimed to determine the impact of learner visual spatial ability on the learning and subsequent performance of a novel surgical technical skill. Finally, this investigation sought to assess the benefit of 3D e-learning modules on the learning of surgical skills by novice trainees. It was hypothesized that surgical procedures could be captured in 3D and incorporated into comprehensive e-learning modules. Following this, it was also hypothesized that students with inherently higher visual spatial ability (as assessed by the Vandenburg and Kuse MRT) would score higher on the global rating scale (GRS) for surgical skill performance than their low Visual Spatial Ability counterparts. Furthermore, it was hypothesized that students using the 3D e-learning modules would perform the depicted surgical skills more effectively than those students instructed in 2D, as evaluated by blinded expert observers on the GRS.

MATERIALS AND METHODS

Participants

All participants were volunteers from various undergraduate programs in the allied health sciences with Ethical Approval from the University of Western Ontario Research Ethics Board, Protocol #17348E. These include medicine, dentistry, kinesiology, occupational therapy and physiotherapy (n = 43). All participants were tested for visual spatial ability (VSA) via the standardized MRT, and exposed to two randomized e-learning modules (the rhombic flap procedure and the double z-plasty procedure); viewing one procedure in 2D and the other in 3D (Peters et al., 1995). All students of the allied health sciences enrolled at The University of Western Ontario were eligible for voluntary participation; however, participants were excluded if they had previous experience with suturing techniques or if they had previously completed the MRT.

Study Protocol

The study was carried out according to a randomized cross-over design. Each student was assigned a random numeric label for the duration of the study, allowing for a link between a students performance on the MRT, and their surgical performance across the various surgical tasks. Following the completion of the MRT, participants were randomly assorted to one of four groups (Fig. 1) and then given 15 minutes to view an 8 minute long video randomly demonstrating one of four potential surgical modules—2D rhombic flap, 3D rhombic flap, 2D double z-plasty, 3D double z-plasty. Students were instructed to view the footage as many times as possible during the allotted time frame, and encouraged to revisit conceptually challenging segments, paying attention to detail and surgical nuances. Following viewing of the surgical video, participants were asked to perform the surgical skill they had just viewed. Students were allocated 15 minutes to perform the surgical skill and were provided with all the equipment utilized in the video. Each participant’s performance was captured using 2D video. Only the operative field and the randomly assigned student label were captured, thus ensuring participant anonymity. Following expiration of the allocated 15 minutes, or successful performance of the task, participants were removed from the laboratory and shown a second randomized surgical video. The duration of

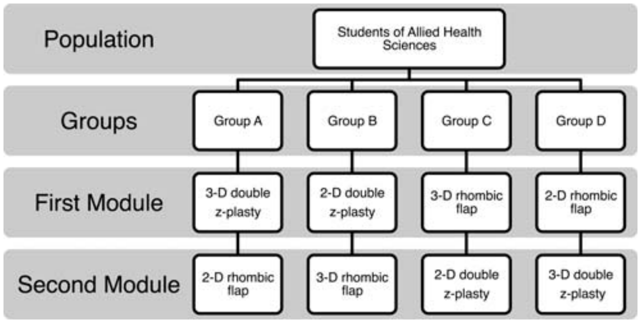

Figure 1.

Participant group breakdown.

the second surgical video was also 15 minutes, again with the same instruction to view the module attentively, revisiting the challenging segments and paying attention to surgical nuances, and was again, followed by a 15 minutes period of procedure performance via the protocol described. At the culmination of the study, participants were asked to complete a survey inquiring into their qualitative opinion of their experience (Table 1).

Table 1.

Qualitative Results of Post-Test Survey Instrument

Statement	Answer (%)
I felt that the 3D video was more helpful than the 2D video to learn the surgical procedures	Yes (27.8) No (22.2) Indifferent (50)
I found the 3D video to be visually jarring or unpleasant	Extremely jarring or unpleasant (0) Somewhat jarring or unpleasant (27.8) Not at all jarring or unpleasant (72.2)
I felt I performed better on the __________ procedure	2D Task (47.2) 3D Task (52.8)
The video controls were _____to command	Intuitive (100) Challenging (0) Impossible (0)
I found the addition of narration to be _______.	Very Helpful (52.8) Helpful (41.6) Ineffectual (2.8) Detrimental to my learning (0)
I would like to see this technology applied to other surgical procedures (i.e., open procedures, laparoscopic procedures, etc.)	No (0) Indifferent (31.1) Absolutely (63.9)
I found video based learning to be _______ for learning complex tasks	Very Helpful (36.1) Useful (58.3) Neither Useful nor Useless (5.6) Useless (0) Completely Useless (0)
Comment on your experience of 3D learning.	Open-ended

E-Module Creation

Both the rhombic flap and double z-plasty procedures (Figs. 2 and 3) were performed by the Royal College of Surgeons of Canada certified surgeons (M.G.B., C.C.M.) and recorded in 3D utilizing a 3D Panasonic AG-3DAU1 high-definition camcorder (Panasonic Corp., Osaka, Japan) and edited using "Final Cut Pro 7" editing suite (Apple Inc., Cupertino, CA) with the "Stereo 3D Toolbox" plug-in (Dashwood Studios, Toronto, ON). The edited videos were paired with stepwise surgical narration to form a comprehensive learning module, designed with attention paid to cognitive load theory of multimedia learning (Mayer and Moreno, 2003). Both modules were designed as visually streamlined, self-guided videos with pertinent surgical narration highlighting important sections of video footage, viewer controls to allow for self-pacing, playback speed controls, and visual review of challenging portions. Save for the addition of the color polarized 3D anaglyph effect that required the use of blue/amber glasses to view the footage, the pair of videos was identical. Both e-modules were 8 minutes in length and viewable on standard personal computers using QuickTime 7 (Apple Inc., Cupertino, CA).

Surgical Model Selection

The rhombic flap (Lister and Gibson, 1972) and double z-plasty procedures (Furlow, 1986, 1995) were selected as surgical technical skills to be evaluated (Figs. 2 and 3) based on their innate spatial complexity (Wanzel et al., 2002a,b). Two different procedures were selected in effort to limit the experience bias while still maintaining the comparison between 2D and 3D learning modalities intact. The ventral surface of the porcine abdominal wall was selected as media for suturing due to its reasonable visual and tactile approximations of human skin. Before evaluation, the porcine abdominal walls were warmed and surgically draped to expose an appropriate surface area akin to what was seen in the e-module video. This practise was repeated in each evaluation instance in an identical fashion to ensure continuity between the video modules and the participant's point of view.

Skill Evaluation: GRS and Qualitative Survey

The GRS for surgical performance was utilized in this study to evaluate participant skill. This scale of measure was selected due to its high reliability and validity, and ease of administration (Martin et al., 1997; Goff et al., 2000; Swift and Carter, 2006; Doyle et al., 2007). It is commonly used in the evaluation of skill performance in otolaryngology—head and neck surgery, making it ideal for the evaluation of the selected surgical procedures. Originally designed by Martin and the research team at the University of Toronto Skills Centre in effort to objectify surgical skills, the GRS was originally created as a subcomponent of the larger objective structured assessment of technical skills in 1997. This standardized tool uses a five-point Likert scale including levels such as dexterity, respect for tissue, instrument control, time and progressive thought (Martin et al., 1997).

Participants were filmed performing the procedure, and were later evaluated by two blinded Royal College of Surgeons of Canada certified surgeons who viewed the footage on a single screen simultaneously. At no point in time were the surgeons made aware of the treatment group of the participant. Ratings were performed for all like surgical procedures (i.e., double z-plasty, rhombic flap) before rating the second surgical procedure. To initiate the rating process and establish a baseline for global ratings, the surgeons viewed three student's performances sequentially with no evaluations taking place before rating the performances of each of the procedures. The evaluators individually rated each student's performance using the GRS and at no time were scores shared amongst the two expert

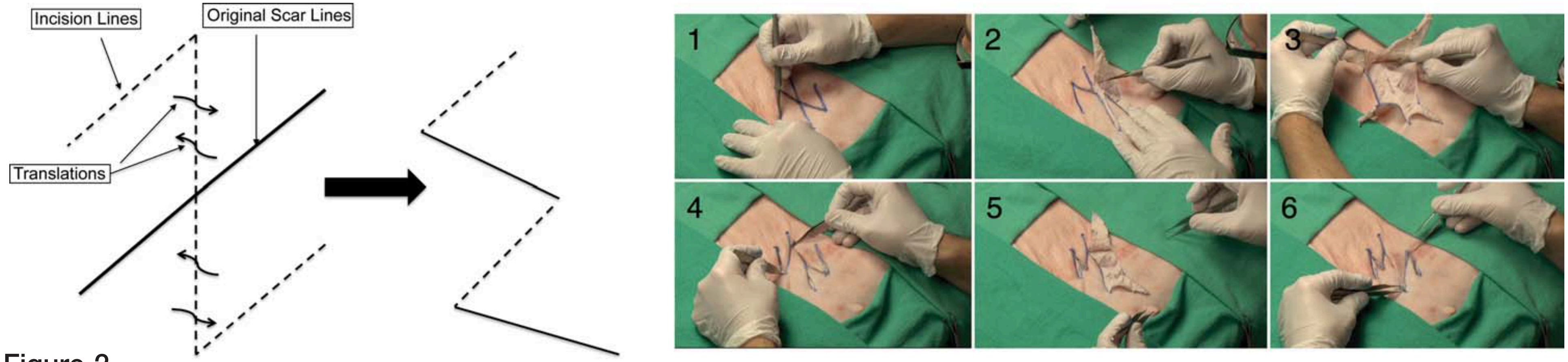

Figure 2.

Step-wise diagrams of the double z-plasty: A side-by-side comparison of traditional instructional methods with e-module screen shots illustrating the procedure. You may notice the conceptually challenging illustration of the double z-plasty commonly used by residents (left), and how the step-by-step screen shot sequence of the double z-plasty e-module addresses this challenge (right).

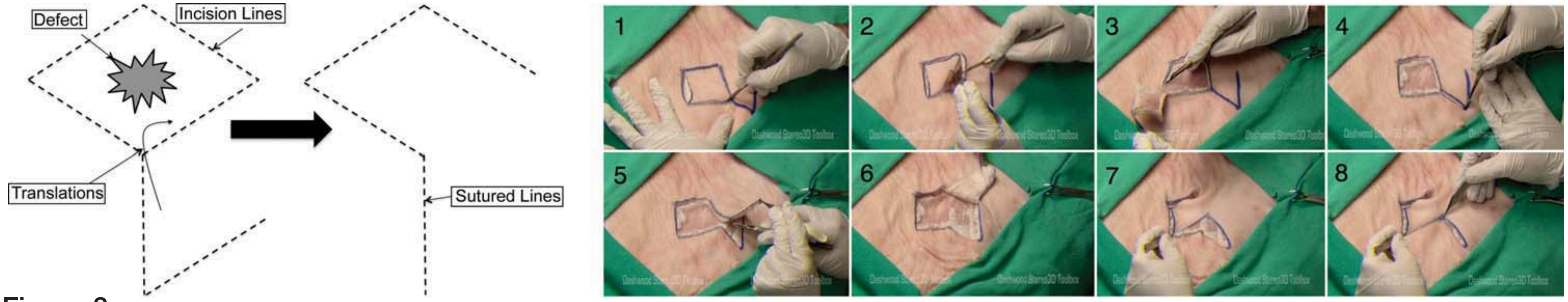

Figure 3.

Step-wise diagrams of the rhombic flap procedure. A side-by-side comparison of traditional instructional methods with e-module screen shots illustrating the procedure. You may notice the conceptually challenging illustration of the rhombic flap procedure traditionally used by residents (left), and how the step-by-step screen shot sequence of the rhombic flap procedure addresses this challenge (right).

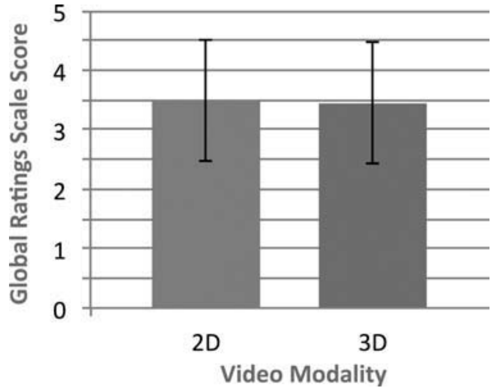

Figure 4.

Video modality versus GRS scores for 2D and 3D treatments illustrating no significant different between video treatments.

observers. Scores were then averaged for each student to yield an overall GRS score.

Following their second surgical procedure attempt, participants completed a survey describing their experience with the pair of e-modules qualitatively. Both structured multiple choice and open-ended questions posed in the survey can be found in Table 1.

Statistical Analysis

A linear regression model was used to compare the average MRT scores of the participants in each group to their overall global rating scores for each procedure for each instruction type. In addition, multiple one-way ANOVAs were conducted to determine the impact of 2D and 3D treatments on the GRS of the participants. Statistical analysis and data tabulation 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

Video Module Production

Following 3D video production, the footage was incorporated into stand-alone 3D video learning modules. These modules were viewed with standard blue-amber analglyph 3D glasses that are inexpensive and effective, without significant compromise in the color of the footage. Images are depicted from screen shots from the pair of 3D modules; including the double z-plasty (Fig. 2) and rhombic flap (Fig. 3). The entire video can be witnessed in 2D at the laboratory website (CRIPT, 2011).

Data Obtained from Pre-Test Measures

All MRT scores obtained were normally distributed with a mean score of 11.21 ± 4.31. There was no significant difference in performance between the sexes as determined by a one-way ANOVA ($P > 0.05$). Of the recruited participants, the mean age exhibited was 23.3 ± 2.26 years. The ratio of male to female participants was 25 to18 (M/F), inclusive of medical, dentistry, kinesiology, and anatomy students. The approximate representations by faculty of study, are inclined toward medical students (accounting for 50.00% of the sample population), followed by anatomy students representing 21.40%, kinesiology students representative of 16.70% and dentistry students representing the final 11.90%.

Global Ratings Scores

No significant difference was detected between surgical procedure type or video modality for any level of the GRS ($P > 0.05$). That is, there was no difference between overall GRS score for 2D or 3D e-learning modules for either of the skin flap procedures (Fig. 4).

There was a strong correlation observed between MRT and GRS score, $R^2 = 0.18$ $F(1,41) = 9.16$ ($P < 0.05$) (Fig. 5). Students with higher VSA performed better on each task irrespective of whether they observed a 3D or 2D video demonstration before task completion.

The qualitative survey demonstrated a preference for 3D visualization (Table 1). The survey not only revealed that more students preferred the 3D modality to the 2D modality, most students (52.8%) felt that they performed better on the 3D instructed skill than on the 2D instructed skill. The 3D technology was very well received and the majority of students found 3D to be a valuable tool for learning complex tasks (94.4%) and 63% agreed that 3D technology should be applied to other surgical techniques.

DISCUSSION

The initial aim of this study lay in the 3D capture of surgical procedures and their subsequent incorporation into comprehensive e-learning modules to train novice surgeons. This aim was achieved through the design of the 3D double z-plasty and 3D rhombic flap modules. Second to this, it was hypothesized that learners trained using 3D would out-perform learners using 2D on the skills depicted in the modules as evaluated by expert observers on the GRS for skill performance. This hypothesis was not supported by the findings of this study, as there was no significant difference between the GRS scores of 3D and 2D learners. Finally, it was hypothesized that learners with higher innate visual spatial ability would exhibit higher GRS scores than their lower VSA

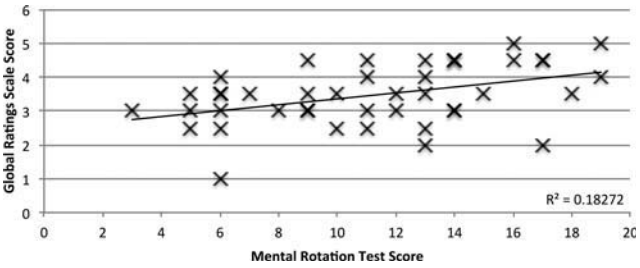

Figure 5.

Mental rotations test scores versus GRS scores illustrating the correlation between visual spatial ability and surgical skill performance.

counterparts. This hypothesis was confirmed by a significant correlation between GRS scores and MRT scores (Fig. 5).

The Benefit of 3D on Learning of Surgical Skills

The results of this study suggest that the incorporation of 3D video had no effect on enhancing surgical skill acquisition and performance. This finding, albeit contrary to research in support of 3D technology as a learning tool (Dalgarno, 2002; de Jong et al., 2005; Dickey, 2005; Jones and Bronack, 2007; Qian, 2008) may be explained in the choice of surgical procedures. The two procedures selected for evaluation were regarded as spatially complex procedures that possess a reputation of being conceptually difficult to most learners. However, as these procedures are both superficial skin flaps, they are essentially two dimensional in their design and performance, leaving their complexity to appear more conceptually geared rather than spatially, as suggested. This left the addition of 3D video as something of a "bonus" instead of vital learning component (Omale et al., 2009). In addition, there is also the possibility that the 2D video conferred enough visual information, such as monocular depth cues, innately to diminish any effect resultant from the additional dimension in the 3D learning modality.

Learner experience and opinions were surveyed following module exposure to gain insight into module design and preference. The survey revealed that more students preferred the 3D modality to the 2D modality and felt that they performed better on the 3D instructed skill than the 2D skill. The 3D technology was well received and the majority of learners perceived 3D to be a valuable tool for learning complex tasks and expressed interest in seeing this technology applied to other surgical techniques such as laparoscopic and vascular procedures.

In general, the overall opinion of the module in terms of design, layout, and construction was positive, in that 100% of students found it easy to control, and 94% found the addition of narration to be useful or very useful to their learning. This reaffirms the importance of the incorporation of the cognitive load theory in the design of multimedia learning tools in that dual stimulation along separate sensory streams (visual and auditory) is well received by the learner.

Through observing a substantial and enthusiastic interest in learner participation to experience learning in 3D, coupled with the general perception of enhanced personal performance, the role of 3D as a novelty must be raised. As an emerging and cutting-edge skill translation technique, it is possible that the inclusion of 3D in surgical education could raise academic performance simply due to its innate difference from traditional teaching methods. It has been exhibited anecdotally that individuals tend to study longer and perform better on evaluations when using learning strategies that are stimulating and enjoyable; thus enhancing academic performance by exposure. Those who enjoy the learning method are more inclined toward spending greater study time with the material, paying attention to detail and nuances that are vital in surgical techniques and are thus, more likely to perform better on examinations (Durrani and Preminger, 1995). In this study, learner opinion suggests a preference for 3D videos, supporting the idea that with time and exposure, learners will spend more time watching 3D videos than identical 2D videos. In this study, time spent on the e-learning modules was controlled; therefore the data cannot speak to potential effects of students spending differential time with 2D vs. 3D modules.

Visual Spatial Ability and Surgical Skill Acquisition

In line with previous literature, a significant correlation was found in terms of the relationship between MRT scores and GRS performance scores in the whole sample group (Anastakis et al., 2000; Wanzel et al., 2002; Wanzel et al., 2003; Brandt and Davies, 2006). This supported previous findings suggesting a correlation between innate visual spatial ability and the initial performance of a novel surgical skill as assessed by the GRS.

Limitations Faced By the Study

This study faced a number of challenges in design and implementation, inclusive of those pertaining to technology, testing supplies, and evaluation scale sensitivity. With regard to technological limitations, there are several worth noting, including the lack of the appropriate display units (3D compatible monitors) for visualization and evaluation of the modules. This lack of technology demanded that the modules be output using the "color polarization" (blue/amber glasses) method instead of the more suitable and 'side-by-side' output technique that is present in 3D movie theatres. This technology would keep color tone accurate, resulting in the footage appearing more "true-to-life," which is an important factor in student experience, making the procedure more realistic and the skills learned therein more transferable.

Further to this, additional limitations arose in the quality of the porcine abdominal walls. Because of innate variability in the toughness of the porcine abdominal walls, many participants expressed frustration at the force required to make incisions and drive the needle. This was reflected in the instrument control and respect for tissue scores; particularly as time progressed through the evaluation and material toughness was exacerbated as a result of tissue drying.

Finally, and perhaps most significant of the limitations facing this study are those pertaining to the selected scale of evaluation. In using the standardized GRS for surgical skill acquisition as the sole method of evaluation in this study, the dominant effects of 3D on learning may have been diminished or even completely hidden. This may be illustrated in the correlation between VSA and endpoint visualization, in that the reduced cognitive load burden presented in the 3D scenario should require less time to visualize and complete. Noting this, additional measures of evaluation, such as "time to begin" and "time to complete" measures likely would have shed more light on the true impact of 3D on surgical skill acquisition and leaning, and should be explored in future studies.

Future Directions

In consideration of the growing body of literature advocating for the inclusion of 3D as a learning tool, and the recent explosion and inundation of the educational sector with new 3D simulations and techniques lacking validation; one must remain selective in the acceptance of "all things 3D" until they are proven to be effective tools in medical education.

As found in this study, little effect was noted from the technology over simple, readily available methods in overall performance for simple translational flaps, but this result fails to rule out 3D videography as a viable surgical training tool. This is the case in that the application of 3D video, as applied to the translational flaps may have failed to capitalize on the full potential of the additional dimension; given that the procedures are planar in their complexity. Similarly, the evaluation method used may have failed to capture the benefit of 3D. Noting this, future research aims to explore the application of 3D videography to more complex and depth intensive procedures such as those found in laparoscopy or vascular surgery which would rely heavily on an awareness of tools and structures in 3D space (Durrani and Preminger, 1994, 1995; Anastakis et al., 2000; Matsumoto et al., 2002; Wanzel et al., 2002; Brandt and Davies, 2006).

In addition to this extension of the technology to more complex and appropriate procedures, future directions for research must also extend into the realms of visualization with regard to the output measures and sensitivity of the scales used to evaluate outcome. The technology used has the capacity to output video that relies on linear polarization and active shutter mechanisms to create 3D vision but was not evaluated in the demonstration process. In future studies, this same footage should be evaluated using side-by-side output technology, akin to that presented at large scale cinemas, which does not rely on color polarization to depict 3D.

CONCLUSIONS

It was hypothesized that surgical procedures could be captured using 3D video acquisition technology, and this was successfully achieved in the development of both the 3D double z-plasty and 3D rhombic flap e-learning modules. Following this, it was hypothesized that the addition of depth brought forward by 3D video would augment the student's acquisition of surgical skills and ability to manipulate depth cues in space. The findings of this study do not support this hypothesis, as there was no significant difference in average participant score across 2D and 3D modalities. These findings may be attributed to scale sensitivity, as the GRS does not take into account "time to begin" or "time to complete" measures. It is likely that such a measure could reveal the true effect of 3D, as with reduced mental processing demanded by the 3D image, the learner should require less time to acquire the skill. This assertion, plus the acceptance of the third hypothesis; that individuals with elevated VSA score higher on the GRS for skill performance than their lower VSA counterparts, suggests the need for further evaluations that take advantage of more spatially complex procedures and more sensitive scales. This investigation is the first to evaluate the role of 3D learning on the acquisition of novel surgical technical skills. Through the further evaluation of this niche area, it is predicted that the real potential of 3D videos as learning tools will be realized, solidifying their role in medical and surgical education.

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