Spatial Visualization Ability and Laparoscopic Skills in Novice Learners: Evaluating Stereoscopic Versus Monoscopic Visualizations

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Elevated spatial visualization ability (Vz) is thought to influence surgical skill acquisition and performance. Current research suggests that stereo visualization technology and its association with skill performance may confer perceptual advantages. This is of particular interest in laparoscopic skill training, where stereo visualization may confer learning advantages to novices of variant Vz. This study explored laparoscopic skill performance scores in novices with variable spatial ability utilizing stereoscopic and traditional monoscopic visualization paradigms. Utilizing the McGill Inanimate System for Teaching and Evaluating Laparoscopic Skills (MISTELS) scoring protocol it was hypothesized that individuals with high spatial visualization ability (HVz) would achieve higher overall and individual MISTELS task scores as compared to low spatial visualization ability (LVz) counterparts. Further, we also hypothesized that a difference would exist between HVz and LVz individual scores based on the viewing modality employed. No significant difference was observed between HVz and LVz individuals for MISTELS tasks scores, overall or individually under both viewing modalities, despite higher average MISTELS scores for HVz individuals. The lack of difference between scores obtained under the stereo modality suggested that the additional depth that is conferred by the stereoscopic visualization may act to enhance performance for individuals with LVz, potentially equilibrating their performance with their HVz peers. Further experimentation is required to better ascertain the effects of stereo visualization in individuals of high and low Vz, though it appears stereoscopic visualizations could serve as a prosthetic to enhance skill performance. Anat Sci Educ 00: 000–000. © 2013 American Association of Anatomists.

Key words: spatial visualization ability; Vz; stereo; surgical skills; visualization; laparoscopy; MISTELS

INTRODUCTION

Background and Rationale

Trends in surgical education have begun to supplant traditional methods of teaching in favor of more technologically modern, and potentially more cost-effective techniques, such as video gaming consoles, and simulations (Schlickum et al., 2009; Lynch et al., 2010; Adams et al., 2012; Giannotti, et al., 2013). This is likely the result of decreasing residency hours, increasing cost of operating room hours, and the ever present ethical debate pertaining to the use of patients for surgical skills practice (Feldman et al., 2003; Fried, 2004). The deviation from the traditional apprenticeship training method, ("see one, do one, teach one"), has led to further exploration of simulation and stand-alone box trainers for resident training (Rodriguez-Paz et al., 2009). One box trainer protocol that has been developed is the McGill Inanimate System for Teaching and Evaluation of Laparoscopic Skills (MISTELS) (Fraser et al., 2003; Vassiliou et al., 2006) to evaluate basic skills of laparoscopic surgery. The validated and standardized MISTELS tasks enables trainees to learn,

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quantify, and hone their laparoscopic skills in a safe, low-stress and low-cost environment, which translates easily to the real-world operating suite (Vassiliou et al., 2006). The MISTELS task battery has also been proven quantitatively to be an effective metric for the evaluation of laparoscopic skill performance (Fried et al., 2004).

The MISTELS test battery evaluated the speed and quality of completion for five individual skills pertaining to manipulation of laparoscopic tools. These skills included: pattern cutting, intracorporeal knot tying, extracorporeal knot tying, placement of a ligating loop, and peg-board transfers (Fraser et al., 2003; Vassiliou et al., 2006). Interestingly, little research has explored the effect of stereoscopic viewing environments or spatial visualization ability (Vz) on the performance of skills like those sampled in the MISTELS tasks.

At present, knowledge supporting stereoscopic visualizations for laparoscopic surgical procedures is growing (Hanna et al., 1998; Kong et al., 2010; McLachlan, 2011; Storz et al., 2012). This is likely due to the ability to interpret critical intrinsic structures of the human body during the stereoscopic visualization previously impossible with monoscopic visualization of minimally invasive procedures. With increased ability to interpret depth cues accurately, the objective performance of simulated surgical tasks may be enhanced, which has theoretical implications on surgical outcomes (Durrani and Preminger, 1995; Chan et al., 1997; Hanna et al., 1998; Falk et al., 2001; Grober et al., 2003; Huber et al., 2004; Byrn et al., 2007; Kong et al., 2010; Roach et al., 2012). Annually, millions of minimally invasive surgeries are performed using primitive monoscopic technology on complex three-dimensional anatomical structures such as the joint cavities (Mack, 2001). Could the lack of depth provided by traditional viewing modalities pose a significant conceptual roadblock for novice surgeons?

Spatial Visualization Ability

Vz can be broadly defined as the ability to mentally manipulate structures in three-dimensional space (Thurstone, 1950), and as such, is of importance in anatomical and medical sciences due to the high prevalence of spatially complex structures and relationships (McGee, 1979). It is thought that Vz is linked intimately to the acquisition of technical skills, spatial reasoning, and knowledge transfer, and as such, may contribute innately to the burden that cognitive load places on mental processing in individuals (Piaget and Inhelder, 1971; Lohman, 1988; Pellegrino and Hunt, 1991; Carroll, 1993; Allen, 1999; Miyake et al., 2001; Hegarty and Waller, 2005; Velez et al., 2005; Yilmaz, 2009; Nguyen et al., 2012) Vz, though conceptually abstract (Lohman, 1988; Carroll, 1993), may be quantified through the completion of spatial tests, including but not limited to, the mental rotations test (MRT) (Guilford and Lacey, 1947; Zimmerman, 1954; Ekstrom et al., 1976; Vandenberg and Kuse, 1978; Pellegrino and Hunt, 1991; Carroll, 1993; Colom et al., 2003; Yilmaz, 2009).

The MRT is a "paper and pencil" spatial test employed to assess Vz (Shepard and Metzler, 1971; Vandenberg and Kuse, 1978). The MRT is composed of questions that require the participant to identify a pair of identical but uniquely rotated block formations from a pair of distractors accurately and efficiently using spatial cues. This test served to divide participants according to a bi-phasic distribution of high (HVz) and low (LVz) spatial visualization ability.

Objectives and Aims

This study aimed to evaluate differences resulting from variable levels of Vz on performances of validated laparoscopic tasks. More specifically, we aimed to assess how individuals of high and low spatial ability differed in terms of scoring on the validated MISTELS tasks. Additionally, we also aimed to assess the impact of viewing modality (Traditional monoscopic 2D or stereoscopic 3D), on task performance by both HVz and LVz individuals.

Hypothesis

We asserted that a difference would exist between levels of Vz and laparoscopic skill performance as measured by the MISTELS scoring protocol.

It was hypothesized that individuals with HVz would achieve higher overall MISTELS task scores as compared to their LVz counterparts. Further, we also postulated that this difference would exist between HVz and LVz individual scores according to the viewing modality, mono- or stereoscopic viewing. It was hypothesized that individuals with LVz would garner advantages from stereoscopic visualization, and thus, match their HVz counterparts on tasks presented in this modality.

MATERIALS AND METHODS

Participants

The sample used in this study consisted of first and second year medical students from the Schulich School of Medicine and Dentistry, who volunteered as participants in this pilot study due to their interest in learning complex surgical skills, and unfamiliarity with the laparoscopic skills in question ($n = 20$). All procedures were approved by the University's ethical review board.

Exclusion Criteria

Participants lacking stereovision (three individuals), and demonstrating average spatial ability were excluded from the study. Participants' ability to interpret visual stereoscopic stimuli was demonstrated by performance on the Graded Circles and Random Dot Stereo Butterfly Test Battery (Stereo Optical Company, Chicago, IL). Participant spatial ability was then assessed using a spatial ability test. Participants with a spatial ability score residing outside of the norm, or middle third of scores [a score of $\pm$1SD from the average, or less than 10 or in excess of 14 on the Vandenberg and Kuse MRT (Vandenberg and Kuse, 1978)] were excluded to allow for a distinct separation between HVz and LVz (ten individuals).

Study Protocol I: Pretesting

Prior to laparoscopic skill testing, participants completed a short battery of pretests to ensure adherence to the exclusion criteria. The pretest was composed of four levels; completion of an informed consent document, a demographic questionnaire pertaining to education level and handedness, the Stereo Butterfly Test (Stereo Optical Company, Chicago, IL) and Graded Circle Test (Kavita) to ensure adequate stereopsis, and an electronic adaptation of the Vandenburg and Kuse MRT to assess Vz (Vandenberg and Kuse, 1978).

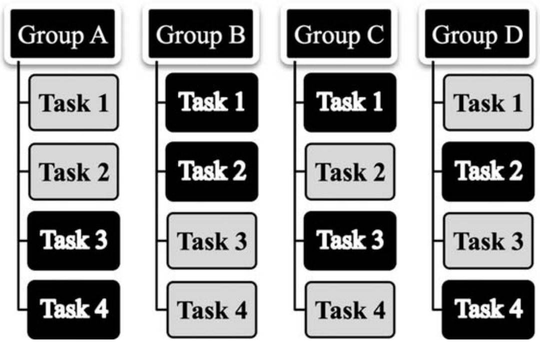

Figure 1.

Explanation of the testing paradigm breakdown in terms of visualization modality exposure. Gray shading represents monocular visualization, while black represents stereo visualization. The numbered tasks are: 1: peg transfer; 2: ligating loop placement; 3: extracorporeal suture; and 4: intracorporeal suture. All participants are assigned to 1 of the 4 groups randomly regardless of spatial visualization ability (Vz).

Study Protocol II: Introduction and Instruction

Participants of high and low Vz were randomly allocated to one of four laparoscopic viewing categories that dictated the modality viewing sequence for the MISTELS tasks (Fig. 1). Participants then viewed an instructional MISTELS companion video to gain familiarity with the laparoscopic tasks. During the viewing period, participants were allotted 10 minutes to view the 6 minute video, allowing for review and revisitation of challenging techniques.

Following completion of the required instructional viewing, participants were given a brief introduction to the laparoscopic tools required to complete the tasks, as well as time to familiarize themselves with the visualization technology and nuances of operating laparoscopically.

Study Protocol III: Task Trials and Evaluation

Each participant completed the each of the MISTELS tasks in the same order, with no repetition:

Precision circle cutting. Through the use of the laparoscopic scissors and grasper, the participant was required to cut along a predrawn circle from suspended gauze. The aim of this task was to cut as close to the predrawn line as possible.

Peg transfer. Through the use of two laparoscopic graspers, the participant was required to relocate each of six rubber rings from pegs located on the participant's nondominant side to corresponding pegs on their dominant side, transferring the rings between the graspers in the process. This process was then reversed from dominant to nondominant sides to see completion of the task.

Ligated loop placement. Through the use of an endoloop tool and a laparoscopic grasper, the participant was required to place the endoloop proximal to the demarcated section of the sponge prop and tighten the endoloop. The task was considered complete upon cutting of the accompanying suture.

Extracorporeal knot. Through the use of a laparoscopic needle driver and grasper, the participant was required to thread a suture through the indicated demarcations in a penrose drain. The task was considered complete upon successful completion of three throws of the knot outside of the box trainer and cutting of the suture.

Intracorporeal knot. Through the use of a laparoscopic needle driver and grasper, the participant was again required to thread a suture through the indicated demarcations in the Penrose drain. The task was considered complete when the participant successfully tied three knots inside the box trainer and cutting the suture. All scoring and MISTELS task parameters were conducted according to the methodology outlined in the work of Fraser and collaborators (Fraser et al., 2003).

Visualization Technology and Specifications

The MISTELS tasks were carried out on fundamentals of laparoscopy (FLS) box-trainers (VTI Medical, North Billerica, MA) using the accompanying standard camera for the monoscopic visualization modality. For the stereoscopic visualization modality, the accompanying default monoscopic camera was substituted with the 3D VisionSense VSII system (VisionSense, New York, NY) and accompanying stereo eyeglasses. Both systems employed a standard 32 inch display with 1080 pixel resolution, maintained at a height of 73 inches and were viewed from a distance of approximately 65 inches. In both circumstances, the cameras were held stationary and were not adjusted by the participants, as dictated by the MISTELS administration protocol.

Task Performance and Data Acquisition

Participants first performed the circle cutting task as an introduction to laparoscopic tasks and to familiarize themselves with the tools and viewing conditions. The modality of performance for this task was dictated according to the participant's group assignment; the viewing modality mirrored the modality of their first task to be evaluated. This task was not evaluated and presented as "practice." Following successful completion, the participant then completed each of the four remaining MISTELS tasks under evaluation by a trained observer in accord with the validated MISTELS scoring system. Neither the task scores nor the overall MISTEL score was revealed to the participants. Participants were permitted only one attempt at each task; no repetitions were accommodated, regardless of individual participant performance.

Post-Test Survey

Following trial completion, participants remarked on their experience with both viewing modalities and answered questions pertaining to their opinion of stereoscopic visualizations during the MISTEL task completion and their thought on its incorporation into surgical education. This took the form of a short, electronic survey employing Likert and open-ended questions for qualitative analysis.

RESULTS

Quantitative Results

Following exclusion of individuals without stereoscopic vision, and those with average Vz, 20 individuals (10 of HVz and 10 of LVz, 13 Male and 7 Female, mean age: 23.4) remained ($n = 20$). Individuals in these two groups, HVz and LVz, each demonstrated significantly different scores on the

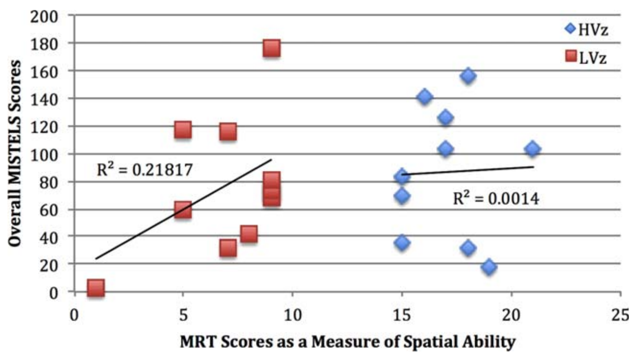

Figure 2.

Relationship between spatial ability and MISTELS task performance. A regression analysis graph illustrating the relationship between different levels of spatial visualization ability and overall MISTELS scores ($n = 20$).

MRT, thus validating their assignment to either high or low spatial visualization groups, F(2.19) = 246.84 ($P < 0.001$).

Overall Scores and Spatial Visualization Ability

Individually normalized MISTELS scores for all participants on each task were calculated according to the MISTELS scoring parameters, and combined to yield an overall MISTELS score. The average total score for all participants was 81.68 ± 46.59.

Average total MISTELS scores were segregated according to participant Vz to illustrate differences between task performances. HVz individuals demonstrated a tendency to score higher (86.68 ± 15.14), though not significantly, than their LVz counterparts (76.67 ± 15.73) overall, $F(1,19) = 0.211$ ($P = 0.652 > 0.05$).

To further illustrate a potential relationship between Vz and MISTELS tasks score, a multiple regression analysis was performed comparing participant MRT score to their MISTELS score (Fig. 2). No statistically significant correlations were observed, but a greater correlation was exhibited between degrees of LVz and task performance ($R^2 = 0.21$, $P = 0.174$), than between degrees of HVz ability ($R^2 = 0.0014$, $P = 0.918$).

Individual Task Scores and Spatial Visualization Ability

The mean MISTELS scores for both Vz groups were subdivided according to individual tasks to illustrate any deviations. No statistically significant differences were found between individuals of HVz and LVz on any of the individual tasks, $F(1,19) = 0.046$, 0.262, 4.048, and 3.873 on the peg board transfer, ligated loop placement, extracorporeal suture, and intracorporeal suture, respectively, ($P > 0.05$), despite a pattern where HVz individuals tended to score higher on all tasks, excluding task 3: Extracorporeal Knot Tying, where the LVz individuals scored higher (Fig. 3A).

Individual Task Scores, Viewing Modality, and Spatial Ability

Scores were further subdivided according to viewing modality; stereoscopic and monoscopic. No significant differences were found in overall MISTELS scores for individuals of different Vz based on viewing modality.

Total MISTELS scores were subdivided by task to further illustrate any differences between HVz and LVz for the different viewing modalities. A single difference was noted on Task 1 (peg transfer) according to viewing modality for both the HVz and LVz individuals. Here, under the monoscopic viewing modality, both LVz and HVz scored higher than during the stereoscopic modality $F(1.19) = 9.61$, $P < 0.05$. All other differences between viewing modality and individual MISTELS task scores were found to be statistically similar ($P > 0.05$) despite a tendency towards elevated HVz scores (Fig. 3A).

In stereoscopic visualization situations, HVz individuals did exhibit increased scores on the first two tasks (peg board transfer and ligated loop placement) while the LVz individuals achieved higher scores on the latter two tasks (extra and intracorporeal knot tying, respectively) (Fig. 3B). Under the monoscopic visualization, HVz individuals exhibited elevated scores on all tasks, with the exclusion of Task 3

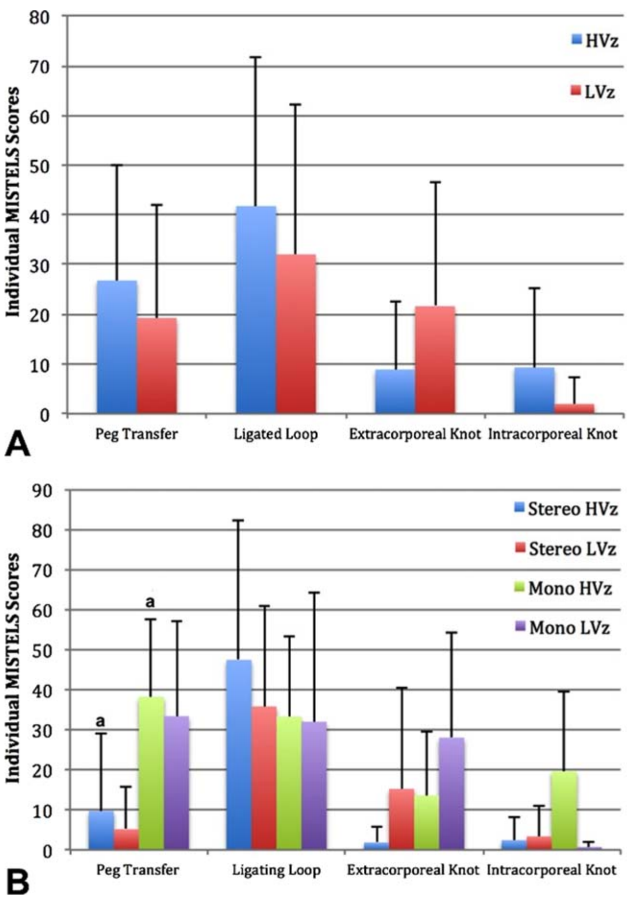

Figure 3.

Individual MISTELS task performance scores for high spatial visualization ability (HVz) and low spatial visualization ability (LVz) individuals. **A**, Mean MISTELS task scores for HVz and LVz individuals, under both viewing modalities ($n = 20$); **B**, Mean MISTELS task scores for HVz and LVz individuals divided according to both viewing modalities ($n = 20$). [a]A significant difference was noted on the first task (peg transfer), where individuals viewing the procedure using the monoscopic modality outperformed their stereoscopic counterparts significantly; F(1.19) = 9.68, $P = 0.008$.

(extracorporeal knot); in which LVz individuals performed markedly (though not significantly) better than their HVz counterparts (Fig. 3B).

Qualitative Results

Overall, participants of both HVz and LVz levels perceived the stereoscopic viewing modality positively. Of the participants tested, 78% of the HVz individuals and 50% of the LVz individuals assumed that stereo visualizations improved their MISTELs performance. Additionally, 88% of LVz individuals indicated that compared to their stereoscopic visualization tasks, traditional monoscopic visualization paradigms stymied their ability to perceive depth and thus reduced task performance. Conversely, their HVz counterparts indicated that the monocular paradigm did not inhibit their depth perception and performance (56%).

With regard to potential discomfort associated with stereoscopic glasses, and sensations of movement/jarring, participants rated their discomfort low at 1.43 on the 5-point Likert scale (0 = no discomfort; 5 = constant, copious discomfort). Overall, free comments regarding the experiment were overwhelmingly favorable towards stereoscopic laparoscopic visualization and its use in surgical skills training.

DISCUSSION

This study set out to examine differences in laparoscopic task performance scores derived from novice individuals of differing Vz. More specifically, we sought to assess how individuals of HVz and LVz differed in terms of scoring on the validated MISTELS tasks. Additionally, we also assessed the impact of viewing modality (monoscopic or stereoscopic), on novel task performances in individuals of different Vz.

Spatial Visualization Ability and Task Performance

In terms of the evaluation of variant levels of Vz on laparoscopic task performance, HVz individuals did exhibit a tendency to outscore (86.68 ± 15.14) their LVz counterparts (76.67 ± 15.73); however, this difference was found to be statistically insignificant (Fig. 3). This finding aligns with previous trends pertaining to elevated Vz and aptitudes for surgical skill performance (Anastakis et al., 2000; Wanzel et al., 2002a,b, 2003; Brandt and Davies, 2006; Roach et al., 2012).

Laparoscopic performances were further subdivided into individual MISTELS task scores to expose any differences relating to performance resulting from Vz. However, no statistically significant differences were noted for any individual MISTELS tasks based on Vz ($P > 0.05$) (Fig. 3A) when no differentiation according to viewing modality is considered.

These findings lend to the concept that individuals with elevated Vz may acquire technical skills more readily than their LVz counterparts, and may be supported by the patterns presented in the linear regression conducted in this study, which related spatial ability to overall MISTELS scores.

It was noted that Vz was much more tightly linked to performance in individuals of LVz when compared to their HVz peers. This suggests that as Vz approaches a critical point (at approximately "average" spatial ability; MRT = 10–14) that task performance increases proportionately; but upon surpassing said threshold, MISTELs scores may become independent of Vz. This trend could potentially serve as evidence to suggest that the Vz of LVz individuals can be trained to garner improved technical skill acquisition; though further exploration is required to substantiate this claim.

Spatial Visualization Ability and Modality

Secondarily, we also asserted that a difference would exist between HVz and LVz individual scores based on the viewing modality employed. It was thought that individuals with LVz would benefit from stereoscopic visualization; due to the additional depth and dimensionality that stereo confers on the LVz individual, which is innate in the HVz individual (Anastakis et al., 2000). With this advantage, LVz individuals could, in theory, equal their HVz counterparts on tasks presented in this modality. This hypothesis was supported by a lack of a statistically significant difference between individual MISTELS scores based on variable levels of Vz (Fig. 3A). In effect, this finding suggests that the additional depth provided by the stereoscopic modality may act as a prosthetic for spatial interpretation in individuals with diminished Vz (Luursema et al., 2006). In fact, the LVz group actually outperformed their HVz peers on two of the four MISTELS tasks under the stereo paradigm (Fig. 3B), suggesting that the stereoscopic visualization may not confer the same perceptual advantage in individuals of HVz (Nguyen et al., 2012).

Additionally, it was also postulated that individuals with HVz would possess an innate advantage over their LVz counterparts in terms of skill performance, and this would be reflected in elevated HVz scores under the monoscopic viewing modality. This hypothesis was not supported by the results of this study; despite a tendency in the HVz group to achieve higher average task performance scores under this modality, as compared to their LVz counterparts (Fig. 3B). This suggests that the monoscopic viewing modality confers no advantage to either group, and demonstrates the aptitude of the HVz group to interpret complex spatial structures in skill performance; an aptitude that is diminished in individuals of LVz.

In further exploration of this hypothesis, two interesting findings emerged in the subdivision of the individual MISTELS tasks. The first being the statistically significant difference of MISTELS Task 1 scores for both HVz and LVz individuals based on viewing modality (Fig. 3B); surprisingly, scores were significantly higher under the monoscopic visualization than the stereoscopic alternative. This difference, though contrary to literature, may be attributed to the order of the performance of tasks; in that Task 1 was always performed at the outset of the study. Thus, the evaluation of this particular task may have taken place prior to participant acclimatization with the unconventional visualization modality, despite the built-in pattern-cutting task to familiarize participants with laparoscopic visualization protocols. Additionally, as participants were still becoming acquainted with the technology during the completion of the first task, and due to the nature of the MISTELS testing parameters, many participants exceeded the allotted time period dedicated to perform this task (1 student exceeded the time allotment under the monoscopic visualization, while 5 exceeded under the stereoscopic visualization); which may have resulted in the abnormal dichotomy of scores in this instance.

Of additional interest is the fact that HVz individuals outperformed their LVz counterparts on all but one task; the extracorporeal knot tying task. This fact may be attributed to the high variability of scores obtained on this particular task, or in the fact that a portion of the task actually occurs outside the laparoscopic skill box (i.e., outside the view of the scope—effectively bringing the visualization into normal stereoscopic view), which may have influenced the performance of the LVz individuals by conferring the depth associated with normal stereoscopic vision.

Qualitative Results

In general terms, the experimental stereoscopic viewing modality was well received by participants of all spatial visualization abilities; with 76% and 50% (HVz: LVz) suggesting that the stereoscopic modality improved their task completion. Interestingly, 88% of participants with LVz felt that the monoscopic modality greatly reduced their ability to perceive depth, thus reducing their ability to complete the task, contributing to the trend noted in the results wherein the stereo modality might serve as a prosthetic to Vz.

Overall, when prompted to discuss the experiment, protocols and viewing modalities freely, participants were overwhelmingly favorable towards stereoscopic laparoscopic visualization and its continued evaluation for use in surgical skills training.

Limitations

This study was conducted using evaluations of task performance in a small group of convenience, consisting of novice volunteers (medium effect size: 0.25, Power = 0.18), who were completely naive to the procedures being evaluated. This posed a significant challenge in evaluation, as MISTELS scoring protocol places emphasis on speed and efficiency (Fraser et al., 2003). In observation of the participants during the tasks, many individuals demonstrated passable skills, but exceeded the time limit set by MISTELS parameters. Unfortunately, when an individual failed to complete the task in the allotted time, a score value of zero was recorded (Fraser et al., 2003). This phenomenon occurred a total of 31 times during the course of the trial; 13 times for the HVz group, and 18 times for the LVz group. The most common task on which participants "zeroed-out" was the intracorporeal knot (12 occurrences: 5 HVz and 7 LVz), followed by the extracorporeal knot (9 occurrences: 5 HVz and 4 LVz), the peg-board transfer (6 occurrences: 2 HVz and 4 LVz), and the endoloop placement (4 occurrences: 1 HVz and 3 LVz). This system of scoring resulted in a substantial variability in the recorded scores, and likely reduced the effect of the different visualization modalities on the individuals' performances. Of additional note is the structural design of the study; in that to achieve consistency with the monoscopic apparatus, the stereoscopic monitor was viewed from a position slightly outside the ideal viewing range. Given that the 3D VisionSense II System has an interpupillary distance of 0.8 mm, a closer vantage point could have enhanced the effect of the stereoscopic visualization by encompassing a great area of the subjects' field of view.

Future Directions

Given the limitation brought forth in the use of novices for evaluation, additional studies are planned to evaluate individuals with additional laparoscopic skill experience (residents, practicing laparoscopists, etc.) who would have a familiarity performing the laparoscopic tasks involved with speed and efficiency. This would, in theory, reduce the high level of variability in scores, and give a better representation of the effect of both viewing modality and level of Vz effects on MISTEL task outcomes.

CONCLUSIONS

This work contributes to anatomical, medical, and surgical education realms through the lens of Vz, and its role in the acquisition of technical skills, and understanding of complex structural relationships (Anastakis et al., 2000; Wanzel et al., 2002a; Brandt and Davies, 2006; Nguyen et al., 2012; Roach et al., 2012; Mistry et al., 2013). Through exploration of the impact of stereopsis as an adjunct to Vz, we suggest potential sectors in which stereoscopic visualization as a training protocol may be best applied. In the paradigm of novel task acquisition in laparoscopy, it appears as though individuals of LVz are most benefited by the addition of stereoscopic learning environments at the novice level, as the additional depth conferred may assist these individuals in perceiving depth-associated nuances. Similarly, additional benefits may be noted according to the learner's experience, and familiarity with the skills taught, thus hearkening to a temporal window in which stereoscopic visualization may be most effective (Wilson et al., 2010). Though further research is merited, this finding could extend beyond anatomical, medical, and surgical sciences, to all varieties of technical skills, and potentially dictate how, and to whom, technical skills are taught.

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