Investigation of Laparoscopic Skills in Veterinary Students using Simulation Technology

by

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A Thesis
presented to
The University of Guelph

In partial fulfilment of requirements
for the degree of
Master of Science
in
Clinical Studies

Guelph, Ontario, Canada

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ABSTRACT

INVESTIGATION OF LAPAROSCOPIC SKILLS IN VETERINARY STUDENTS USING SIMULATION TECHNOLOGY

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University of Guelph, 2016

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Laparoscopic surgery is gaining popularity in veterinary medicine for the patient-associated benefits, and enhanced visualization provided by the laparoscope. When compared to conventional open surgery, a laparoscopic surgeon must develop a unique technical skill-set to contend with new challenges and operating room distractions. It remains to be determined whether prior experiences that improve manual dexterity, bimanual coordination, and visuospatial perception enhance the baseline performance of laparoscopic technical skills. This thesis investigates the relationship between prior open surgical and non-surgical experiences on the performance of baseline laparoscopic skills in veterinary students. This thesis further explores the impact of operating room distraction on the performance of a simulator-based laparoscopic exercise in novices. We found that prior craft experience was the only significant predictor of baseline laparoscopic skill performance in a simulator in veterinary students, and the introduction of cognitive distraction significantly reduces the performance of a simulator-based laparoscopic exercise in novices.
In loving memory of my Grandma and number one fan.
Acknowledgements

I would like to thank my advisor Dr. Ameet Singh for his guidance and support over the last two amazing years. It is precisely because of his guidance that my research ran so smoothly and timely. At times graduate work is especially challenging and tedious, but Dr. Singh has an amazing way of motivating people. His positivity, enthusiasm, and passion for surgery is infectious, and inspires everyone that crosses his path. More importantly, Dr. Singh is truly one of the most kind, humble, and generous people I know. I am grateful to him for making this Masters experience both enjoyable and rewarding.

I would also like to thank Dr. Deep Khosa and Dr. Carolyn Kerr for being a part of my advisory committee, and for offering their continued support and expertise along the way. I really appreciate the time they took out of their busy schedules to attend committee meetings, review manuscripts, and meet with me on various occasions. Their feedback is extremely valuable.

Thank you to William Sears for all of his statistical help, and thank you to all of the veterinary students that volunteered their time to participate in this research!

Finally, thank you to my family and friends for their continued support!
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<th>Definition</th>
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<tr>
<td>2D:</td>
<td>Two-dimensional</td>
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<tr>
<td>3D:</td>
<td>Three-dimensional</td>
</tr>
<tr>
<td>ABS:</td>
<td>American Board of Surgery</td>
</tr>
<tr>
<td>ACS:</td>
<td>American College of Surgeons</td>
</tr>
<tr>
<td>ACVS:</td>
<td>American College of Veterinary Surgeons</td>
</tr>
<tr>
<td>CLS:</td>
<td>Canine Laparoscopic Simulator</td>
</tr>
<tr>
<td>CT:</td>
<td>Computerized Tomography</td>
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<tr>
<td>DVM:</td>
<td>Doctor of Veterinary Medicine</td>
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<tr>
<td>FOV:</td>
<td>Field of View</td>
</tr>
<tr>
<td>FLS:</td>
<td>Fundamentals of Laparoscopic Surgery</td>
</tr>
<tr>
<td>IQR:</td>
<td>Interquartile Range</td>
</tr>
<tr>
<td>GOALS:</td>
<td>Global Operative Assessment of Laparoscopic Skills</td>
</tr>
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<td>MIS:</td>
<td>Minimally Invasive Surgery</td>
</tr>
<tr>
<td>MISTELS:</td>
<td>McGill Inanimate System for Training and Evaluation of Laparoscopic Skills</td>
</tr>
<tr>
<td>NOTES:</td>
<td>Natural Orifice Translumenal Endoscopic Surgery</td>
</tr>
<tr>
<td>OR:</td>
<td>Operating Room</td>
</tr>
<tr>
<td>OSATS:</td>
<td>Objective Structured Assessment of Technical Skills</td>
</tr>
<tr>
<td>OVC:</td>
<td>Ontario Veterinary College</td>
</tr>
<tr>
<td>OVE:</td>
<td>Ovariectomy</td>
</tr>
<tr>
<td>OVH:</td>
<td>Ovariohysterectomy</td>
</tr>
<tr>
<td>SAGES:</td>
<td>Society of American Gastrointestinal and Endoscopic Surgeons</td>
</tr>
<tr>
<td>SSI:</td>
<td>Surgical Site Infection</td>
</tr>
<tr>
<td>VG:</td>
<td>Videogame</td>
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<tr>
<td>VR:</td>
<td>Virtual Reality</td>
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1.1 - Minimally Invasive Surgery

Minimally invasive surgery (MIS), minimal access surgery, keyhole surgery, endosurgery, endoscopic surgery, and videosurgery are all synonymous terms used to describe diagnostic and therapeutic techniques that are accomplished via small, millimeter incisions or portals in the body wall\(^1\). One subcategory of MIS is laparoscopy, which applies minimally invasive techniques to the abdomen of human and veterinary patients alike\(^1-3\). Abdominal access is typically achieved through three incisions in the ventral body wall of a patient positioned in dorsal recumbency. Although portal placement ultimately depends on the nature of the procedure and surgeon preference, the initial sub-umbilical incision is commonly reserved for the laparoscope. Ideally, the two subsequent instrument portals are positioned at equal distances and angles on either side of the laparoscope to preserve depth perception. This set up tends to resemble a baseball diamond where the laparoscope is positioned at the hypothetical home plate, the lesion at second base, and laparoscopic instruments at first and third base (Figure 1)\(^4\).

![Figure 1: Position of instruments and camera in the formation of a baseball diamond to preserve depth perception during laparoscopic surgery.\(^4\)](image)

The laparoscope transmits an image of the surgical field to a monitor screen that is positioned directly in front of the surgeon for visualization. In order to create sufficient working space for the surgeon inside the abdominal cavity, and to prevent iatrogenic damage to internal viscera during instrument insertion, a pneumoperitoneum is commonly established by inflating the abdomen with carbon dioxide\(^2\).
Care must be taken to achieve initial abdominal access through the closed “Veress needle” approach, the open “Hasson” approach, or a variation on one of these two classical methods, since ~50% of all laparoscopic complications are entry-related. In the closed “Veress needle” approach, a sharp needle is directed at an angle through a small millimeter incision for quick and direct access to the abdomen. In order to protect internal organs and vasculature from inadvertent damage by the needle on entry, a protective sheath springs forward immediately after the initial skin resistance is overcome. Thereafter, the abdomen is inflated with carbon dioxide, and the Veress needle is replaced with the first trocar-cannula assembly. Conveniently, the snug fit of the cannula forms a seal that prevents gas leakage from the pneumoperitoneum. On the contrary, there is a high risk of visceral and vascular complications due to the nature of this blind entry.

Alternatively, the more popular open “Hasson” technique involves the creation of a mini-laparotomy and the placement of two sutures on opposite ends of the facial incision. The sutures allow the surgeon to elevate the ventral abdomen for safe advancement of a cannula and blunt-tipped trocar. Tubing is then attached to the cannula for carbon dioxide insufflation. Creation of a pneumoperitoneum via the “Hasson” technique is associated with fewer complications compared to the closed technique because it allows for direct visualization during abdominal entry.

One incision per instrument is a widely accepted MIS approach; however, there is ongoing research to reduce both the number and size of portals to make laparoscopic surgery even less invasive, and a potentially scar less procedure. These techniques include single incision laparoscopic surgery (SILS), natural orifice transluminal endoscopic surgery (NOTES),
needlescopc surgery, and robotic surgery. MIS is frequently contrasted with conventional open surgery, which requires longer incisions for a more invasive approach.

1.1.1 - Technical Challenges of Laparoscopic Surgery

A minimally invasive surgeon must learn to perceive cues from an image displayed on a 2D monitor screen, and apply them to a 3D working field inside the abdomen. This challenges depth perception and eliminates peripheral vision, as the scope is limited in its ability to capture images outside of the direct surgical field. Despite drastic improvements in image quality, resolution and detail of the image on screen, eye strain is a frequent complaint among minimally invasive surgeons. Moreover, a restricted field of view combined with physical restraints imposed upon the surgeon by the size of the abdominal cavity, minimizes available working space compared to open surgery. This underscores the importance of precise and smooth instrument movements during laparoscopic procedures.

Furthermore, access to the abdomen is achieved with long instruments that act as extensions of the surgeon’s hands. As such, tactile feedback, an important source of sensory information during conventional open surgery, is limited in laparoscopic surgery. Moreover, laparoscopic instrument manipulation requires a lot of muscular strength in order to transmit forces applied at the handle through the length of the instrument to the tip. In fact, 6 times the amount of force must be applied to a laparoscopic instrument compared to the same instrument designed for open procedures, to achieve the equivalent outcome. A further consequence of operating through fixed access sites in the abdominal wall is the fulcrum effect that produces counterintuitive instrument movements. In other words, the direction of a surgeon’s hands must oppose the direction of instrument movements on screen to achieve the desired effect. At the
same time, multiple long instruments tend to clash within the abdominal cavity and accentuate hand tremor\textsuperscript{16,20}.

Laparoscopic surgery is currently the “gold standard” approach in human medicine\textsuperscript{21}. In comparison, the field of veterinary medicine has been slower to adopt laparoscopic techniques as a result of high equipment costs, technical challenges, the need for surgical assistants, and longer operating times associated with MIS\textsuperscript{8,22–25}. Despite these challenges, laparoscopic surgery continues to gain acceptance among veterinarians, as increasing evidence supports the use of this novel surgical technique over conventional laparotomy for patient-derived benefits, and enhanced visualization provided by the laparoscope\textsuperscript{26,18,27}. This thesis will discuss the impact of non-surgical experiences, innate abilities, and OR distractions on the ability of human and veterinary surgeons to acquire the basic technical skills of laparoscopic surgery. Past and present methods for laparoscopic skills training will be included in this discussion, with an emphasis on simulation.

1.2 - Laparoscopy versus Conventional Open Surgery

1.2.1 – Post-operative Pain

Reduced post-operative pain is a cited advantage of laparoscopic and laparoscopic-assisted techniques in veterinary medicine\textsuperscript{8,23,28} presumably because of smaller incision sizes that limit soft tissue and muscular trauma and minimize direct tissue handling by the surgeon compared to laparotomy\textsuperscript{25}. Laparoscopic-assisted procedures combine the characteristically small incisions of laparoscopy with extracorporeal maneuvers to minimize the complexity of a completely laparoscopic approach\textsuperscript{23}.

Devitt et al.\textsuperscript{23} reported significantly reduced post-operative pain in female dogs (>10kg) randomized to receive open ovariohysterectomy (OVH) compared to laparoscopic-assisted OVH.
Pain measured via heart rate, respiratory rate, arterial pressure, subjective behavioural
assessment, and wound palpation 1, 2, 4, 6, 12, and 24 hours post-operatively identified 9 of 10
dogs in the open OVH group that required additional morphine. However, individuals assigned
to assess pain in this study were not blinded to the treatment status of each dog, which introduced
a potential source of bias. Furthermore, long term post-operative complications were not
evaluated in either group of dogs.

In a similar study, subjective measures of painful behavior combined with objective pain
measurements such as heart rate, respiration rate, and the University of Melbourne Pain Scale
revealed significantly reduced post-operative pain in female dogs (2.4kg -31kg) that received
laparoscopic OVH versus open OVH. However, more dogs in the laparoscopic OVH group
experienced intra-operative complications, which included splenic laceration, pedicle and
vaginal hemorrhagic discharge, and suture reaction.

Consistent reports of reduced post-operative pain in female dogs (10kg-12kg)
randomized to receive laparoscopic OVH versus open OVH were documented by Hancock et
al. after applying the University of Melbourne Pain Scale and measuring tolerance of
abdominal palpation pressure (mmHg) in both groups at 0, 2, 6, 12, 24, 48, and 72 hours post-
operatively. Plasma cortisol levels were also significantly elevated 2 hours post-operatively in
the open OVH group; however, a conclusion on surgical stress could not be made based on this
parameter alone. Dogs in this study likely experienced multiple sources of stress, including the
housing environment where they were kept for the duration of the study. Therefore, the amount
of stress attributed to the surgical technique itself was unknown. Alternatively, physiological
measurements of pain such as temperature, heart rate and respiration rate did not differ between
groups. The authors proposed that human interaction during data collection excited the dogs and influenced these parameters.

In a similar splenectomy study, the only statistically significant differences between dogs that received an open versus laparoscopic technique in terms of post-operative pain were increased scores on the University of Melbourne Pain Scale and tissue trauma (elevated C-reactive protein levels) measured 2, 6, 12, 24, and 72 hours post-operatively in the open group\textsuperscript{10}. Interestingly, creatine kinase, an indicator of muscle trauma, and alkaline phosphatase, an indicator of inflammation, were significantly higher in the laparoscopic group. The authors of this study did not offer an explanation for either observation, but concluded that the increased levels of creatine kinase in the laparoscopic group were not clinically relevant since they did not exceed 10.000U/L or exceed $\geq2.000U/L$ for a prolonged period of time. Although not explicitly stated, perhaps distension of the abdomen and muscular layer during carbon dioxide insufflation influenced these values to some extent, but this hypothesis would require further research. Other blood parameters measured to assess pain and stress levels such as white blood cell count, alanine aminotransferase, blood glucose and blood cortisol levels did not differ between groups\textsuperscript{10}.

Culp et al.\textsuperscript{27} used accelerometers to measure post-operative activity levels in dogs (<10kg) randomized to either laparoscopic or open ovariectomy (OVE). Dogs in the open OVE group experienced a significant decline in activity levels from baseline to 12 and 24 hours post-operatively. In contrast, the reduction in post-operative activity levels experienced by the laparoscopic OVE group did not reach statistical significance. Overall, the percent reduction in pre- to post-surgical activity counts were significantly greater for the open OVE group of dogs, suggesting that the open group of dogs experienced more post-operative pain. Dogs in this study
were not video taped and therefore the specific pre- and post-operative activities that each dog engaged in were not elucidated.

Despite reports of lower post-operative pain in laparoscopic versus open surgical candidates, the aforementioned studies concentrate solely dogs that are otherwise healthy. It remains to be determined whether the same benefits of laparoscopy can be observed in more advanced surgical procedures, in a more physically compromised subset of individuals, and across different species of animals. In cats, for example, single incision laparoscopic surgery via an extracorporeal or cautery technique versus open surgery for OVE, did not produce measureable differences in pain scores between groups after being thoroughly assessed by two blinded raters using a validated visual analog scale, descriptive pain scale, and an automated von Frey meter\textsuperscript{13}. However, it was acknowledged that differences in pain scores between groups could have reached statistical significance had it been a higher powered study. Furthermore, in order to conclude that pain is attributed solely to the surgical technique and not carbon dioxide insufflation or use of cautery, the inclusion of control groups without surgical intervention is required\textsuperscript{25}.

In addition to reduced post-operative pain, reports of significantly reduced hospitalization time, reduced surgical site infection (SSI), faster return to normal function, lower incision complications, reduced blood loss, reduced length of incision, and reduced stress are benefits of laparoscopy cited in the veterinary literature (Table 1)\textsuperscript{2,8,10,16,25,27,29–31}. 
Table 1: Reported benefits associated with the performance of laparoscopic versus open surgical procedures in small animals

<table>
<thead>
<tr>
<th>Benefits of Laparoscopy</th>
<th>Reference</th>
</tr>
</thead>
<tbody>
<tr>
<td>Reduced hospitalization time</td>
<td>Mayhew et al.\textsuperscript{32}</td>
</tr>
<tr>
<td>Reduced SSI</td>
<td>Mayhew et al.\textsuperscript{33}</td>
</tr>
<tr>
<td>Faster return to normal function</td>
<td>Culp et al.\textsuperscript{27}</td>
</tr>
</tbody>
</table>
| Lower incision complications            | Davidson et al.\textsuperscript{8}  
Stedile et al.\textsuperscript{10} |
| Reduced post-operative pain             | Arulpragasam et al.\textsuperscript{28}  
Davidson et al.\textsuperscript{8}  
Devitt et al.\textsuperscript{23}  
Stedile et al.\textsuperscript{10} |
| Reduced blood loss                      | Shariati et al.\textsuperscript{29}  
Stedile et al.\textsuperscript{10}  
Arulpragasam et al.\textsuperscript{28} |
| Reduced length of incision              | Shariati et al.\textsuperscript{29}  
Stedile et al.\textsuperscript{10} |
| Reduced surgical stress                 | Devitt et al.\textsuperscript{23}  
Hancock et al.\textsuperscript{25}  
Stedile et al.\textsuperscript{10} |

1.2.2 – Surgery and Anesthesia Times

Theoretically, a reduction in the size of laparoscopic incisions could reduce wound closure times and translate into reductions in overall procedural times compared to laparotomy\textsuperscript{10}. Researchers are interested in reducing the length of laparoscopic procedures to minimize the undesirable and potentially fatal effects of carbon dioxide insufflation and prolonged surgery and anesthesia times, which include increased risk of hypothermia and systemic vascular resistance\textsuperscript{9}, and decreased respiratory compliance and stroke volume\textsuperscript{34}.

To date, veterinary studies that compare procedural times between open and laparoscopic surgery have yielded mixed results\textsuperscript{8,10,23,27,28,31,33,35}. For example, one study reported a significantly reduced median surgical time of 21 minutes for open OVE compared to 30 minutes for laparoscopic OVE in canine patients\textsuperscript{27}. Likewise, a median of 69 minutes was significantly
less than a median of 120 minutes required to perform OVH in dogs through an open versus laparoscopic approach, respectively. A related study of laparoscopic-assisted versus open OVH in dogs revealed shorter mean surgery and anesthesia times in the open group, however these results did not reach statistical significance. In cats, open OVE took a median of 17 minutes, whereas single incision laparoscopic surgery using an extracorporeal suturing method took significantly longer (median of 70 minutes) due to the complexity of the technique which led to technical difficulties for the surgeon. In line with these findings, laparoscopic splenectomy (mean 115.4±13.6 minutes) produced significantly longer surgical times compared to open splenectomy (mean 51.5±5.5 minutes) in dogs. Furthermore, it took a mean procedural time of 143 minutes to perform laparoscopic-assisted cystotomy in dogs as compared to 86 minutes for open cystotomy.

In comparison, Singh et al. found no statistically significant difference in surgical times between open and laparoscopic–assisted techniques for the removal of cystic calculi in dogs that did not receive concurrent surgical procedures. In another study, Mayhew et al. reported a median surgical time of 90 minutes for laparoscopic adrenalectomy versus a significantly higher median surgical time of 120 minutes for open adrenalectomy in a group of client-owned dogs. Another retrospective study by the same group compared a variety of minimally invasive procedures (n=179) with a number of open procedures (n=379) in dogs and cats to identify differences in the incidence of SSI between groups. Although cases were not matched on breed, procedure type, technique, weight, age, year of surgery and institution where surgery was performed, the combined mean operating time for the minimally invasive group was significantly shorter (75 minutes) than those reported for the open group (105 minutes).
Potential discrepancies in surgery and anesthesia times reported in the literature may be explained by differences in laparoscopic techniques. For example, the use of vessel sealing devices instead of intracorporeal suturing or clip application to occlude vessels is suggested as a strategy to reduce operating times. Furthermore, the complexity of a surgical procedure and surgeon experience influences surgery times. It is postulated that as one gains familiarity with laparoscopic instruments and becomes more comfortable in the performance of laparoscopic techniques, procedural times for laparoscopy and open surgery will be equivalent or in favor of laparoscopy.

1.2.3 – Diagnostic Benefits

Enhanced visualization provided by the laparoscope is especially helpful in the staging of cancer and other disease processes, or in the identification of small lesions and malignancies that would otherwise go unnoticed by the unaided eye at the time of open laparotomy. For example, pseudorecurrence of uroliths is a major concern following open cystotomy because microscopic uroliths are difficult to identify and thus, are easily left behind. However, the magnification provided by a laparoscope increases the likelihood that small stones or stone fragments are recognized and removed during the initial surgery, minimizing the need for subsequent procedures.

In one study, laparoscopic-assisted cystotomy in dogs and cats reportedly offered excellent visualization of the bladder and urethra, which aided in the complete clearance of uroliths from 9 of the 10 dogs that received post-operative imaging. Alternatively in two different canine cystotomy studies, incomplete cystolith removal did not differ significantly between open and laparoscopic-assisted cystotomy techniques. However, the authors suggested that increased experience with laparoscopic and laparoscopic-assisted techniques
would likely favour a minimally invasive approach to cystolith removal in the future. In a different study of dogs, enhanced visualization of the ovaries in laparoscopic ovariectomy patients contributed to reduced rates of ovarian remnant syndrome compared to dogs that received open ovariectomy. The successful removal of ovarian tissue in the laparoscopic group was attributed to the use of a laparoscope for a more thorough examination of the ovaries. Furthermore, laparoscopy for the management of ovarian remnant syndrome has been previously described and successfully performed in dogs and cats as an alternative to open laparotomy. The ability to closely and precisely examine the ovarian pedicles was cited as one of the main advantages of the laparoscopic technique. In a similar study, few complications were reported in dogs and cats that received laparoscopic cryptorchidectomy, suggestive of enhanced visualization of reproductive anatomy provided by the scope. The combination of results support the use of laparoscopy as a safe alternative to conventional laparotomy in veterinary medicine, which can be strengthened by more prospective, adequately powered, randomized trials.

1.3 - Laparoscopic Surgery Skills

1.3.1 – Lesson from Laparoscopic Cholecystectomy

Historically, laparoscopic cholecystectomy was rapidly embraced as a minimally invasive alternative to conventional open laparotomy for gall bladder resection for the treatment of gallstones. Short, weekend-long training courses represented the only source of formal laparoscopic skills training in the 1980s because of an underlying assumption that prior open surgery experience would adequately prepare a surgeon for laparoscopy. Therefore, it was highly anticipated that skills would transfer from conventional surgery to laparoscopy, and by extension, experienced surgeons would easily adopt these novel techniques. However, the
increased rate of bile duct injuries observed when laparoscopic cholecystectomy was first introduced to human medicine served as direct evidence that prior open surgical experience did not facilitate the acquisition of laparoscopic skills. Since the early experience with laparoscopic cholecystectomy, a strong evidence-base has accumulated to support a lack of skill transfer from open to laparoscopic techniques.

In one study, it took a surgeon with an extensive background in open surgery a total of 200 laparoscopic cholecystectomy procedures to reach proficiency, as measured by operative time. In a similar study, the learning curve for laparoscopic cholecystectomy was no different between senior attending surgeons and chief residents, even though the senior surgeons had a much more extensive background in open surgery. Another study reported that practicing laparoscopic surgeons scored significantly higher on basic laparoscopic surgery exercises in a simulator than attending surgeons with only conventional open surgery experience. More specific evidence for a lack of skill transfer from open to laparoscopic surgery was in the ability of junior surgical residents to outperform senior surgeons, with extensive open surgery experience, on three laparoscopic intracorporeal suture exercises in a pelvi-trainer simulator. Together, these findings represent conclusive evidence that conventional and laparoscopic surgical techniques are separate entities, necessitating distinct skill-sets that require specific training.

1.3.2 - Innate Qualities

The recognition of a unique laparoscopic skill-set that differs markedly from open surgery has prompted researchers to investigate innate qualities or prior experiences that might enhance the learning process or predict one’s performance of technical skills in the OR. Uncovering particular qualities and prior experiences that promote rapid technical skills
acquisition could enhance laparoscopic surgical training, and make learning more effective\textsuperscript{52}. Once identified, individuals lacking these qualities and experiences could seek remedial skills training early in their education to keep pace with their peers, or to remain competitive candidates for surgical residency programs\textsuperscript{53}, in the event that technical skills testing becomes part of the selection criteria.

With respect to gender, it seems male medical students tend to achieve higher scores initially on virtual reality and box trainer surgical simulators compared to their female counterparts\textsuperscript{52}. However, this gender effect is removed in a more homogeneous group of surgical residents. The noted discrepancy in medical students might be explained by enhanced visuospatial abilities\textsuperscript{53}, arising from a culture where males are more likely to engage in sports and videogames (VG) growing up compared to females. Moreover, the male dominated discipline of surgery suggests that an interest in a surgical career might provide added motivation for male medical students to perform well in surgical simulators\textsuperscript{54,55}. That being said, female medical students overcome this initial discrepancy, and do so most effectively with one-on-one training and instructor feedback\textsuperscript{52}. Most importantly, there appears to be no difference in the quality of OR performance between males and females\textsuperscript{56}. To date, no studies directly investigate gender related differences in the performance of simulator-based laparoscopic skills in veterinary medicine.

Researchers are also interested in the relationship between VG play and laparoscopic surgery, given the parallels between each activity. For example, successful video gamers and laparoscopic surgeons demonstrate superior hand-eye coordination and reaction time compared to non-gamers and non-surgeons, respectively\textsuperscript{57}. Furthermore, both VG play and laparoscopic surgery require human interaction with a 2D computer interface\textsuperscript{58}. The assumption is that
familiarity with a 2D interface and refinement of the aforementioned skills associated with gaming will transfer to laparoscopic surgery. If this assumption is correct, commercially available VG consoles may serve as useful, inexpensive, and engaging laparoscopic training tools.

Research in the human literature on the relationship between laparoscopic surgery and VG play is extensive. Several human studies report a positive correlation between prior or current VG play and baseline performance in a laparoscopic surgery simulator, however, many are observational studies that rely on self-reported VG experience, rather than objective measures of VG performance. Furthermore, it is possible that individuals with enhanced dexterity and visuospatial skills have a tendency to play VGs, which adds a significant source of bias to correlation studies. Results are mixed in terms of the usefulness of VGs for laparoscopic skills training, and comparability between studies remains a challenge for a number of reasons. Namely, a vast array of VGs and game consoles are commercially available for training. To date, a standard definition of VGs does not exist, nor does a validated scale to measure VG experience or performance. A variety of study designs are used to investigate this topic, and few are randomized controlled trials. Finally, a number of different simulators/metrics are used to assess the performance of laparoscopic skills after VG training.

Few studies in veterinary medicine seek to identify a relationship between VG play and performance on laparoscopic simulators, since both laparoscopic surgery and simulation training are relatively recent areas of investigation in veterinary medicine. The results are mixed in the few studies that have been published. In one study of third year veterinary students (n=29), a positive association was reported between scores on three Nintendo Wii VGs and laparoscopic surgery skills performed on an inanimate box trainer. In contrast, self-reported VG experience
did not correlate with the performance of five laparoscopic technical skills tasks performed on an inanimate simulator in American College of Veterinary Surgeons (ACVS) board certified surgeons, American College of Veterinary Internal Medicine board-certified specialists, and veterinary residents in disciplines other than surgery\(^65\).

Despite the fact that remedial skills training helps to narrow the performance gap between individuals, there is presumably a small proportion the population (~8.1\%) incapable of ever learning and executing the technical skills necessary to perform laparoscopic surgery safely\(^66\). After repetitive practice on surgical simulators, these individuals do not improve over time, and demonstrate no evidence of conceivable improvement on learning curve analysis. Consequently, it is suspected that these individuals do not possess the innate qualities that facilitate the acquisition of laparoscopic technical skills. For this reason, the use of technical skills assessment to screen surgical residency candidates may be warranted. Ultimately, the compilation of information regarding innate qualities, prior experiences, and capacity for improvement is important for the development of appropriate, effective, and efficient training programs aimed at teaching and improving upon the technical skills of laparoscopic surgery.

1.4 - Operating Room Distraction

To complicate technical skills training for laparoscopy, a surgeon must learn to overcome the aforementioned challenges (Section 1.2.3) in the wake of inevitable OR distraction. Furthermore, laparoscopy itself introduces a new dimension of technical distraction and ergonomic challenges, and is considered more stressful than open surgery for novice trainees to learn\(^67\). The unique technical challenges of laparoscopic surgery often mandate awkward limb movements and require that unnatural, uncomfortable body positions be assumed for extended
periods of time. These challenges may inflict mental and physical strain on the surgeon that could compromise surgical performance.

Indeed, one study used measures of skin conductance and eye-blink rate to demonstrate significantly increased stress levels and mental concentration in human surgeons during the performance of a laparoscopic knot-tying task compared to an equivalent open surgical suturing task in a box trainer. Furthermore, elevated levels of stress and mental concentration appeared to negatively impact performance, as the number of knots tied in 2 minutes was significantly less for the laparoscopic exercise. A similar study on veterinary laparoscopic surgeons found large discrepancies in muscle activity, hand movements, and wrist angle when four different laparoscopic tasks were performed in a box trainer. Precision cutting, suturing, and the use of ring handled instruments inflicted the highest amount of muscle strain on this experienced subset of individuals.

Investigation of ergonomics in the field of surgery is important to ensure that future ORs are designed with the challenges of laparoscopy in mind. Perhaps it would also be worth considering ergonomics in the design of surgical simulators given the repetitive demands of laparoscopic technical skills training and the aim to standardize training.

OR distractions and interruptions are events that divert the attention of the surgeon or OR personnel from the primary surgical task to a less urgent secondary task. OR distraction events may be classified as cognitive, technical, auditory, or visual in nature, and their impact on surgical performance depends on a multitude of factors, including surgeon experience level, and innate abilities. Frequent distractions encountered in the human and veterinary OR are presented in Table 2.
Table 2: Sources of distraction in the human and veterinary OR organized by nature of distraction event  

<table>
<thead>
<tr>
<th>Cognitive</th>
<th>Auditory</th>
</tr>
</thead>
<tbody>
<tr>
<td>• Questions about case at hand</td>
<td>• Cell phone ringing</td>
</tr>
<tr>
<td>• Question about prior or future case</td>
<td>• Anesthesia monitor beeping</td>
</tr>
<tr>
<td>• Question to surgeon about career choice</td>
<td>• Pager beeping</td>
</tr>
<tr>
<td>• Teaching students</td>
<td>• Background music</td>
</tr>
<tr>
<td>• Time pressure and stress</td>
<td>• Side conversation</td>
</tr>
<tr>
<td>• Intra-operative complications</td>
<td>• Dropped equipment</td>
</tr>
<tr>
<td>• Unusual anatomy</td>
<td>• Opening and closing of OR door</td>
</tr>
<tr>
<td>• Time pressure and stress</td>
<td>• Noise level</td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th>Technical</th>
<th>Visual</th>
</tr>
</thead>
<tbody>
<tr>
<td>• Laparoscope navigation</td>
<td>• Hemoabdomen or pyoabdomen</td>
</tr>
<tr>
<td>• Instrument coordination</td>
<td>• Fogged laparoscope lens</td>
</tr>
<tr>
<td>• Instrument clashing</td>
<td>• Observer reaches for an item within the field of view</td>
</tr>
<tr>
<td>• 2D monitor screen for visualization</td>
<td>• Entrance and exit of OR staff</td>
</tr>
<tr>
<td>• New equipment or technique</td>
<td>• Request for interpretation of diagnostic imaging</td>
</tr>
<tr>
<td>• OR design and ergonomic issues</td>
<td></td>
</tr>
</tbody>
</table>

Data published in the human literature suggest that distraction events are encountered as frequently as 10-20 times per surgical case, or once every 1.8 minutes. The entrance and exit of individuals from the OR and case-irrelevant communication were the most frequent distraction events observed in a cross-sectional study of 90 open and laparoscopic human surgical procedures. In the same study, technical difficulty due to incorrect or faulty surgical equipment was considered the most intense type of distraction because it demanded the attention of 2 or more surgical team members. Equipment problems and conversation not pertinent to the surgical procedure were also identified as the most frequent sources of distraction in a similar study of 78 endourological procedures. Interestingly, surgeons rather than residents were the largest source of case-irrelevant communication in this study. In line with the above findings, communication, including case relevant and irrelevant communication, was the greatest single
source of distraction in 19 elective urological procedures\textsuperscript{79}. Of the other non-communication distractions observed, issues with surgical equipment occurred most frequency\textsuperscript{79}.

Distractions in the OR are of grave concern because they increase surgeons’ mental workload\textsuperscript{81,83} and stress\textsuperscript{82}, and are thought to be responsible for ~40-50\% of hospital errors\textsuperscript{78}. In general, distraction events encountered in the OR during 90 open and laparoscopic surgical procedures were significantly correlated with increased mental workload, stress, and impaired teamwork as expressed by surgical scrub nurses, anesthesiologists and attending surgeons\textsuperscript{82}. However, correlation does not imply causation. Although these results cannot be used to draw conclusions about the impact of distraction on surgical performance or patient outcomes, distractions are concerning as they appear to negatively affect the functionality of the OR team.

Simulation offers an effective and ethical platform to quantify the impact of distraction on surgical performance. In one study, 14 medical students, residents, and surgical fellows performed a suturing exercise on a robotic surgical simulator in the presence of four different distraction conditions. Time to task completion significantly increased and overall speed decreased when math questions, a decision making task, and a memory task were posed concurrently to participants compared to performance in the non-distracted condition\textsuperscript{78}. Likewise, experienced first, second, and research year general surgery residents made significantly more errors during a simulated VR laparoscopic cholecystectomy procedure when distracted by realistic OR distractions (i.e. cell phone ringing and irrelevant conversation) compared to not\textsuperscript{69}.

Although the aforementioned studies provide evidence of decreased surgical performance in the midst of distraction, one common limitation remains that a skills lab environment does not completely replicate the complexity of the OR environment itself or the advanced surgical
procedures that surgeons perform. Perhaps stress levels are also higher when performing surgery on a live patient versus a simulated one and this variable could also affect performance. Recognizing that a team of OR personnel are responsible for a successful or failed procedure, the impact of distraction on all members of the surgical team could be a future consideration.

That being said, OR “distractions” such as anesthesia and patient monitors are mandatory, as they permit the surgeon and surgical team to continuously monitor the patient throughout the course of a procedure. These devices also alert the OR staff immediately in the event of a problem. In addition to monitors, patient-related communication among members of the surgical team is important to ensure that everyone is aware of their role in the procedure and knows what to do in the event of a complication. Furthermore, communication among OR personnel establishes a positive, collaborative working environment that helps keep team members on task and focused\textsuperscript{75,83}.

Undoubtedly, effective communication between members of the surgical team is important to enhance patient safety in the OR. However, background music and noise is considered by some researchers a barrier to communication in the OR since it contributes to volumes of 55dB-120dB in a typical OR setting\textsuperscript{84}. At these high noise levels it is not only a challenge for the OR staff to hear and understand one another, but it becomes difficult to distinguish essential sounds\textsuperscript{85} like anesthesia monitor alarms or the beep from a LigaSure device that indicates a blood vessel has been effectively sealed.

One observational study of 20 laparoscopic and open surgical procedures at two different institutions noted that the surgeon had to repeat their request or instruction (i.e. ask a surgical nurse to pass a certain instrument) five times more when music was played in the OR compared to not\textsuperscript{86}. Video records of each procedure revealed body language that was suggestive of
frustrated surgical team members that could not hear the initial request made by the surgeon as a result of the high OR noise level. In one case scenario, the anesthesiologist could not distinguish the patient’s heart beat from the beat of the bass in a song.

In another study, auditory processing was significantly impaired in the presence of pre-recorded background noise compared to a quiet simulated OR setting in 15 human surgeons with 6 years of prior OR experience. The decline in auditory processing was amplified further by the addition of background music to the pre-recorded OR noise when the surgeons had to perform a concurrent peg transfer task in an inanimate box trainer. Considering the negative implications of background noise and music on auditory processing during a simple peg transfer task, it seems logical to expect that music could have detrimental effects on auditory processing in an OR environment where multiple stimuli exist, and where more complex surgical procedures are performed. Perhaps deficits in auditory processing would be even more problematic in hearing impaired or non-English speaking surgeons, but this warrants further research. Additionally, many individual factors should be considered when investigating the impact of background music on OR functionality. For example, the innate response to different genres of music, sensitivity to noise level, the complexity of the primary task being performed, and the experience level of the individual.

Background noise that contributes to communication breakdown in the OR is a concern if it compromises surgical performance and patient safety. In one study, noise significantly impaired performance and increased cognitive errors in a group of post-graduate year 1 human surgical residents during the concurrent performance of a simulator-based ring transfer exercise. In fact, auditory rather than vibratory or visual noise distractions was the most detrimental with respect to cognitive errors. In a similar randomized trial of third year medical
students, communication in the form of verbal questions about a previously studied case scenario were asked to participants in the intervention group as they simultaneously performed exercises on an endurological VR simulator\textsuperscript{73}. Task performance in the distracted group, as measured inherently by the simulator, was significantly worse than in the non-distracted control group\textsuperscript{73}. A decline in technical skill performance and increased cognitive errors could translate to compromised patient safety in the OR as has been suggested elsewhere. Indeed, Sevdalis et al.\textsuperscript{79} reported that fewer patient safety checklists were completed as the frequency of communication distractions during urological procedures increased. Furthermore, case-irrelevant communication between surgical team members at the time of wound closure significantly increased the odds of SSI by 1.29 in 167 different human open surgical cases\textsuperscript{87}.

In contrast, background OR noise played at 50-80dB did not significantly increase time or economy of motion metrics, and did not significantly decrease the speed with which medical students, residents, and fellows performed a suturing task on a robotic surgical simulator when compared to quiet conditions\textsuperscript{78}. Likewise, in a more experienced group of surgeons, performance of a laparoscopic suturing task in a pelvi-trainer remained unaltered in the presence of classical music and pre-recorded OR noise\textsuperscript{88}. Moreover, the majority of OR personnel interviewed stated that background music played at low to moderate levels actually enhances communication and reduces stress levels in the OR during a surgical procedure\textsuperscript{73,89}. These opinions are somewhat concerning if case-irrelevant communication, background music, and high noise levels truly have a negative impact on surgical performance, but staff do not recognize them as burdensome\textsuperscript{73}. This could imply that self-assessment of performance in the OR is unreliable.

Granted that distractions and interruptions are a natural part of the OR environment, research is currently focused on identifying the major sources of distraction in order to limit
these unsafe events from the OR. Alternatively, it is not feasible or appropriate to eliminate all sources of distraction from the OR, as some are necessary for patient monitoring or are inherent to complex surgical techniques such as laparoscopy. As a result, a more reasonable approach to training laparoscopic surgery might involve teaching novices to manage predictable OR distractions. To date, there are two schools of thought in terms of designing training programs to effectively manage OR distraction. The first is to expose trainees to relevant OR distractions simultaneously while they acquire a basic laparoscopic skill set\textsuperscript{75}. This approach assumes that training in the presence of distraction will better prepare an individual for the multi-task demands of the OR\textsuperscript{75}. The second school of thought takes the approach that regardless of training environment, repetitive pre-training exercises solidify a basic technical skill-set which frees up cognitive resources to effectively manage distraction events in the OR\textsuperscript{70}. However, further research is warranted to determine the effectiveness of each training program and to deduce whether or not one program is superior to the other.

1.5: Laparoscopic Learning Curve

The combination of a unique skill-set and an OR plagued with distraction contributes to the complex learning curve associated with laparoscopy\textsuperscript{18}. The learning curve begins as a steep line to reflect a period of rapid improvement in performance over time\textsuperscript{90}. Inexperienced surgeons in the initial stage of the learning curve typically have higher rates of conversion to open surgery, experience higher intra- and post-operative complication rates, and take longer to complete a procedure than their more experienced counterparts\textsuperscript{91}. In the second stage of the learning curve the line becomes moderately sloped, which implies that performance continues to improve gradually over time. Eventually the line will plateau in the final stage of the learning curve where any additional improvement is undetectable\textsuperscript{90}. 

In laparoscopic surgery, this plateau suggests that a surgeon has reached a level of proficiency in performance and often corresponds to a defined number of procedures or time period. The construction of a learning curve for laparoscopic surgery in human medicine presents a challenge, as it typically varies by experience level, procedure type, technique used, and proficiency measurement used (i.e. time, number of conversions, etc.). Furthermore, a consensus on the number of procedures required to achieve proficiency in human laparoscopic surgery is difficult because the current literature does not use a standard definition of proficiency. Consequently, some studies prematurely report that proficiency has been achieved when in fact surgical performance continues to improve subsequently. As such, there is a large discrepancy in the number of cases required to reach proficiency in a variety of laparoscopic procedures. Table 3 summarizes the results of a systematic review that attempts to quantify the learning curve for common laparoscopic procedures in human medicine.

**Table 3:** The learning curve for common laparoscopic procedures in human medicine presented as mean (range)

<table>
<thead>
<tr>
<th>Procedure Type</th>
<th>Procedures to Reach Proficiency</th>
</tr>
</thead>
<tbody>
<tr>
<td>Cholecystectomy</td>
<td>30 (8-200)</td>
</tr>
<tr>
<td>Fundoplication</td>
<td>28 (20-60)</td>
</tr>
<tr>
<td>Colectomy</td>
<td>40 (13-70)</td>
</tr>
<tr>
<td>Splenectomy</td>
<td>20 (16-20)</td>
</tr>
</tbody>
</table>

One study published in the veterinary literature on the learning curve for a 3-port laparoscopic ovariectomy in novice surgeons suggested that ~80 canine laparoscopic procedures were required to achieve proficiency, as measured by reduced complication rates. However, it is possible that not all minor intraoperative complications were reported given the retrospective...
nature of the study. Additionally, concurrent diseases and body composition, which challenge laparoscopic procedures and increase the risk of complications\(^9\), were not documented in this study\(^{38}\). In another study, ~8 canine laparoendoscopic single-site ovariectomy procedures were required for a board-certified veterinary surgeon to reach proficiency, as measured by operative time\(^92\). In line with human medicine, different techniques and individual qualities influence the laparoscopic learning curve in veterinary medicine.

The construction of a learning curve can be used to estimate the number of procedures one must perform to reach proficiency in a particular laparoscopic technique, and can help predict when training would be most effective to mitigate potential OR complications\(^92\). If properly defined, the learning curve serves as an important construct for the development of effective training programs, and the establishment of minimum caseload requirements for novice surgeons. The purpose of minimum caseload requirements is to provide novice surgeons with mandatory guidelines to ensure that all patients can expect to receive a minimum standard of care\(^{26}\).

### 1.6 - Minimum Caseload Requirements

#### 1.6.1 – American College of Veterinary Surgeons

Recently, the American College of Veterinary Surgeons (ACVS) modified the minimum MIS caseload requirements for small animal surgical residents to reflect more specific guidelines in terms of the type of MIS cases performed. In 2009, a minimum 20 MIS cases were mandatory over the course of a small animal surgical residency program\(^{26}\). These cases included either, or all, laparoscopic, arthroscopic, and thoracoscopic cases. However, recent modifications published in 2015 specify that at least 5 laparoscopic/thoracoscopic cases must be performed under supervision, in addition to a minimum of 15 arthroscopic cases\(^{93}\). Although more specific
in terms of the type of MIS cases, minimum caseload requirements for MIS have not increased since 2009 even though >50% of ACVS diplomats and residents surveyed in 2010 felt that the number of cases should be expanded\textsuperscript{26}. In comparison, the European College of Veterinary Surgeons (ECVS) requires surgical residents to complete a minimum of 30 arthroscopic procedures, but has not published minimum standards for laparoscopy or thoracoscopy\textsuperscript{94}.

1.6.2 - Apprenticeship Model

The minimum caseload requirements set by ACVS represent the only source of formal guidance available for MIS training in small animal surgical residency programs in North America, and all of this training occurs in the OR under the apprenticeship model of teaching, “see one, do one, teach one”\textsuperscript{18,95}. This training approach involves an expert laparoscopic surgeon or mentor who shares and demonstrates their knowledge and experience with a resident in training to facilitate learning in the OR. As the surgical trainee displays improved competence over time, the mentor gradually assigns them increased responsibility. Resident training evolves from a strictly observational role, to a more active assistant role, until the resident is capable of assuming the position of primary surgeon\textsuperscript{21}.

In this system, evaluation of a resident is highly subjective, as it is the responsibility of the mentor to judge surgical competence\textsuperscript{96}. The availability of board certified veterinary surgeons with experience and an interest in laparoscopic surgery at any one institution presents a perceivable challenge to resident training under the current apprenticeship model\textsuperscript{21}. Additional considerations such as the type of residency\textsuperscript{26} (private practice or teaching hospital) and the location of the residency program (urban vs. rural setting) further impact the quality of resident training opportunities in MIS under the apprenticeship model.
There is consensus in both the veterinary and human medical communities that the OR does not serve as the most effective training platform for novices to acquire the unique technical skill-set of laparoscopic surgery. Frequent distractions and multiple stimuli intrinsic to the OR, overwhelms the cognitive capacity of a novice trainee and hinders learning. In addition, it is no longer feasible or efficient to train novices in the OR under the apprenticeship model given the financial considerations and the high value placed upon OR time.

The nature of technical skills training complicates matters further because unlike non-technical skills that can be obtained through textbook readings or observation in the OR, the acquisition of technical skills requires frequent, repetitive, and deliberate hands on training. Unfortunately, the unpredictable and limited caseload that is inherent to a clinical setting is not conducive to these requirements.

Furthermore, it is considered unethical to practice new skills and techniques on live patients in the OR. In human medicine, a surgical trainee that enters the OR is expected to have previously trained in a setting removed from the OR where they have proven competency in the execution of basic laparoscopic skills. However, this requirement has yet to be established in veterinary medicine.

1.7 - Alternative Training Platforms

1.7.1 – Simulation Technology

In human medicine, surgical simulators were developed in an effort to address patient safety concerns and challenges associated with the apprenticeship, or Halstedian model of training. A surgical simulator is a constructed reality that combines trainable elements of the OR in an educational tool for the purpose of individual or team training. As with any training or performance measure a simulator must undergo a series of validity and reliability tests.
to verify that the time and financial resources necessary for development are warranted (Table 4). Validity tests confirm that a training/assessment device measures what it intends to measure (i.e. technical skills of laparoscopy), and reliability tests verify the reproducibility and precision of the educational tool\textsuperscript{97,104}.

**Table 4:** Levels of reliability and validity testing\textsuperscript{97}

<table>
<thead>
<tr>
<th>Validity Measures</th>
<th>Definition</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>Subjective</strong></td>
<td></td>
</tr>
<tr>
<td>Face</td>
<td>The clinical applicability of skills attained on a simulator as judged by experts.</td>
</tr>
<tr>
<td>Content</td>
<td>The appropriateness of a simulator on its ability to incorporate all relevant clinical domains.</td>
</tr>
<tr>
<td><strong>Objective</strong></td>
<td></td>
</tr>
<tr>
<td>Construct</td>
<td>The degree of correlation between performance on a simulator with another construct (i.e. level of expertise) that claims to measure the same attribute.</td>
</tr>
<tr>
<td>Concurrent</td>
<td>Degree of correlation between performance on a simulator and performance measured by an existing “gold standard”.</td>
</tr>
<tr>
<td>Predictive</td>
<td>Performance on the simulator predicts current or future performance in the clinical setting.</td>
</tr>
<tr>
<td>External</td>
<td>The extension, or generalizability of results to other individuals, institutions or situations.</td>
</tr>
<tr>
<td><strong>Reliability Measures</strong></td>
<td><strong>Definition</strong></td>
</tr>
<tr>
<td>Inter-rater</td>
<td>The level of agreement between two raters that measure the same performance.</td>
</tr>
<tr>
<td>Intra-rater</td>
<td>The level of agreement between performances measured at two different time points by the same rater.</td>
</tr>
<tr>
<td>Central tendency</td>
<td>The level of correlation between overall performance and performance on each individual task that comprises a simulator.</td>
</tr>
</tbody>
</table>

Surgical simulation training typically takes place in a designated simulation lab within a teaching hospital or training facility. Simulation labs are highly controlled environments,
designed to reduce the stress and cognitive burden imposed upon a trainee as they learn new skills and techniques\textsuperscript{98}. Simulation labs are ideally suited to objectively train the technical skills of laparoscopic surgery because they facilitate repetitive and deliberate, goal-directed practice\textsuperscript{95}. Moreover, a trainee has the opportunity to practice techniques and procedures that are infrequently encountered in the OR without risking patient safety. Skills trained in this manner eventually become automatic and no longer require conscious thought or the recruitment of substantial cognitive resources\textsuperscript{70}. Subsequent training in the OR is therefore more constructive, as the trainee can shift their attention elsewhere, perhaps to the complex steps of an operation or to the closer examination of patient anatomy\textsuperscript{95}. Unlike the OR, laparoscopic surgical simulators offer consistent and standardized practice because training is independent of surgical caseload\textsuperscript{105}. Moreover, a large portion of the learning curve is overcome in a simulator, which reduces the likelihood of intra-operative complications arising from surgeon inexperience\textsuperscript{106}.

The successful application of simulators in other high-stakes disciplines such as aviation, military operations, and anesthesia offers insight and promise for surgery\textsuperscript{105}. In aviation, training and certification on high fidelity flight simulators is a prerequisite to flying a plane. This practice dates back to 1955 as a solution to address multiple plane crashes that resulted from human error\textsuperscript{107}. The complexity of flight simulators has progressed to such an extent that 1 hour of training on the simulator is equivalent to half-an-hour training in an airplane\textsuperscript{108}.

1.7.2 - Laparoscopic Surgical Simulators

There is no substitute for OR experience; however, it is no longer feasible or ethically acceptable to train surgeons in the OR\textsuperscript{105,101}. Consequently, efforts have focused on the development of valid and reliable surgical simulators to serve as surrogates for OR training. Simulator classification is based on their ability to incorporate aspects of the actual OR
environment in their design, namely fidelity. Thus, the closer a simulator replicates OR conditions the higher its fidelity\textsuperscript{109}. A variety of commercially available surgical simulators exist ranging from low fidelity inanimate box trainers to high fidelity animal models or virtual-reality (VR) systems\textsuperscript{105}. A large body of evidence supports the transfer of skills acquired in a surgical simulator to the OR in human medicine\textsuperscript{99,100}.

Live animal models and cadavers provide trainees with the opportunity to practice laparoscopic skills on specimens that bear similar anatomic and tissue properties to veterinary patients in the OR. Despite their high fidelity, live animal models and cadavers are difficult to obtain, and present a challenge in terms of storage and disposal\textsuperscript{45,18}. Furthermore, these specimens are generally single use and therefore do not lend themselves well to laparoscopic technical skills training, which demands repetitive practice. The same ethical concerns related to training on live animals in the OR extend to live animals and cadavers used for the sole purpose of training in wet labs\textsuperscript{105,101}.

Virtual Reality (VR) simulators offer a high fidelity, more ethical alternative to live animal and cadaveric models that are especially suitable for laparoscopy because they allow for repetitive practice of basic skills, part-tasks, and full procedures with realistic complications such as bleeding\textsuperscript{21,108,110,111}. Laparoscopic VR simulators force the user to interact within the confines of a computer-generated abdomen through a 2D visual system, which replicates clinical conditions. The simulator generates inherent performance metrics and provides immediate feedback to facilitate improvement without the need for an observer. Unfortunately, the high cost associated with the initial purchase price ($45 000 to $120 000 USD)\textsuperscript{108,56} and subsequent software updates, combined with the fact that these systems are based on the principles of human anatomy, limits their usefulness in veterinary medicine\textsuperscript{18}. 
Although lower in fidelity, inanimate box trainers are equal, and perhaps more effective than VR systems for the training of basic laparoscopic skills in novice human surgeons\(^{108,112,113}\). When asked to decide between a VR system and inanimate box trainer in terms of effectiveness and user satisfaction, pre-clinical medical students chose the latter\(^{114}\). Perhaps the lack of clinical exposure and laparoscopic experience among participants led to higher scores achieved on the lower fidelity box trainer compared to the MIST-VR trainer, which could have influenced opinions in favour of the box trainer. However, a correlation between user satisfaction and simulator performance was not possible as scores on either simulator were not recorded. In one study, a group of medical students, resident medical officers, interns, registrars, and experienced human surgeons demonstrated transfer of basic skills in one direction, from an inanimate box trainer to a VR simulator. Interestingly, camera navigation skills were transferred, despite the fact that camera navigation was not a part of the box training program\(^{112}\). Thus, box trainers may confer additional advantages to participants outside of learning to manipulate authentic laparoscopic instruments, while contending with the fulcrum effect. A similar study reported that a validated inanimate box trainer was superior to the Minimally Invasive Surgical Trainer - Virtual Reality (MIST-VR) in its ability to distinguish between medical professionals with varying amounts of laparoscopic surgery experience\(^{113}\). Furthermore, novice surgeons trained on a box trainer performed significantly better on a simulated laparoscopic cut and clip task, as measured by economy of motion metrics compared to untrained controls\(^{108}\). In the same study, novices that trained on a VR simulator (LapSim) did not perform any better than the box trainer group or the untrained controls on the same simulated laparoscopic cut and clip task.

Box trainers provide a platform to learn basic hand eye coordination, depth perception, and ambidexterity\(^{65,103}\), as opposed to full or part procedures. These fundamental skills enhance the
performance of grasping, cutting, clipping, and suturing tasks that are applicable to a wide range of laparoscopic procedures\textsuperscript{103}. The ability to practice such skills with haptic feedback, as well as with authentic laparoscopic instruments and optics are important features of box trainers that are absent from VR systems\textsuperscript{17,115}. Reliable and valid box trainers also offer an accessible and portable alternative to VR systems, but require a trained observer to assess performance and provide feedback to the user. Although physical box trainers require the use of consumable materials that need to be replaced after each use, they remain significantly less of a financial burden than VR simulators ($200 to $7600 USD)\textsuperscript{56}. The non-specific nature of tasks performed in box trainers make them suitable for training basic laparoscopic skills in novices, whereas VR simulators are more appropriate for experienced surgical trainees learning advanced procedures\textsuperscript{56}.

Surgical simulators typically serve dual functions as both education tools for skills training and objective platforms for skills assessment and credentialing. In general, the fidelity of a surgical simulator should match the experience level of the trainee to achieve maximum effectiveness and user satisfaction throughout the course of training\textsuperscript{40,115}. Alternatively, in the event that the simulator is used to assess a trainee’s readiness for the OR, the fidelity of the simulator should be as high as possible.\textsuperscript{40}

1.7.3 - Fundamentals of Laparoscopic Surgery

The Society of American Gastrointestinal and Endoscopic Surgeons (SAGES) developed the Fundamentals of Laparoscopic Surgery (FLS) committee to integrate laparoscopic surgery safely into human medical practice, and improve OR efficiency\textsuperscript{95}. This committee, in conjunction with the American College of Surgeons (ACS) subsequently developed the FLS program, a certification required by the American Board of Surgeons (ABS)\textsuperscript{46}. The FLS program was
designed to teach and evaluate a broad set of cognitive skills, and simulation-based technical skills that would apply to a variety of laparoscopic procedures and surgical domains, such as gynecology and ophthalmology. This initiative was an effort to standardize training in basic laparoscopic skills, and thus, establish a standard of care with which all surgical patients could expect to receive.

Briefly, the cognitive skills training component involves a series of web-based modules. Each module exposes the trainee to potential considerations and complications that can arise throughout the course of a typical laparoscopic procedure in the OR. On the other hand, the technical skills training component encompasses a web-based video tutorial that demonstrates the performance of five simulator-based exercises, while simultaneously providing an explanation of task objectives and the score system used to evaluate performance.

Subsequently, the trainee practices each of the five non-procedure specific laparoscopic tasks repeatedly in an inanimate FLS box trainer (Figure 2). Medical institutions can purchase the FLS box trainer at an affordable price, and incorporate it into their surgical skills labs for an accessible means of training residents prior to their official FLS examination. More experienced surgeons may also take advantage of the box trainer to maintain their technical laparoscopic surgery skills, and test new, unfamiliar instruments in a skills lab prior to an actual surgery in the OR.

Figure 2: FLS box trainer pictured on the left in the Endoscopic Skills Lab at the Ontario Veterinary College. An opaque membrane with two 12mm diameter working instrument portals covers the box trainer. Authentic laparoscopic instruments are inserted through each portal. A camera mounted under the lid transmits images of the working field to a monitor screen positioned in front of the user for visualization.
To become FLS certified, one must pass a 90-minute multiple-choice cognitive skills examination of 75 questions\textsuperscript{47}, and achieve a minimum score of 350. Additionally, one must demonstrate competency in five manual skills tasks on the FLS simulator during a proctored assessment at one of the designated testing centers in North America\textsuperscript{46}. The FLS examination was first administered in 2004, and there has since been a marked rise in the number of participants. Reports from 2009 reveal that surgeons from over 14 different countries have taken part in the rigorous FLS examination, which demonstrates its worldwide acceptance as the “gold standard” approach for the training and assessment of laparoscopic skills\textsuperscript{47} in human medicine.

The five exercises performed within the FLS box trainer are modeled after MISTELS, the technical skills training program developed by Dr. Gerald Fried and colleagues at McGill University\textsuperscript{20,17}. MISTELS is the acronym for the McGill Inanimate System for the Training and Evaluation of Laparoscopic Skills. The exercises increase progressively in difficulty level from a peg transfer, pattern cut, ligature loop placement, extracorporeal suturing, and intracorporeal suturing task (Table 5)\textsuperscript{116}. Each task incorporates distinct elements of laparoscopic surgery that are not encountered in open surgery, such as visualization of a three-dimensional working field on a two-dimensional monitor screen, and the use of unusually long instruments to cut, place, clip, and suture\textsuperscript{17}.
Table 5: A description of MISTELS tasks, in order of difficulty level, and the standard score system for each

<table>
<thead>
<tr>
<th>Task</th>
<th>Description</th>
<th>Score</th>
</tr>
</thead>
<tbody>
<tr>
<td>1. Peg Transfer</td>
<td>Transfer 6 pegs, one at a time, from one pegboard to another, in no particular order. Reverse the process until all 6 pegs are returned to their start position.</td>
<td>300s – time to completion (s) – 10 x number of pegs dropped outside FOV / 2.37</td>
</tr>
<tr>
<td>2. Pattern Cut</td>
<td>Cut a 4cm diameter circle from a piece of 10x15 cm instrument wrapping material along the circular target line.</td>
<td>300s – time to completion (s) - % deviation / 2.80</td>
</tr>
<tr>
<td>3. Ligature Loop Placement</td>
<td>Cinch ligature around foam on marked target line.</td>
<td>180s – time to completion (s) – distance in mm from target / 1.42</td>
</tr>
<tr>
<td>4. Extracorporeal Suturing</td>
<td>Place long suture through marks on penrose drain, tie 3 single throws of a knot extracorporeally, and use a knot pusher to tighten each knot on penrose drain.</td>
<td>420s – time to completion (s) – deviation in mm from marks on penrose drain – 10 if slit on penrose drain remains / 5.20</td>
</tr>
<tr>
<td>5. Intracorporeal Suturing</td>
<td>Place short suture through marks on penrose drain, tie 3 single throws of a knot intracorporeally, and tighten each knot on penrose drain.</td>
<td>600s – time to completion (s) – deviation in mm from marks on penrose drain – 10 if slit on penrose drain remains / 2.97</td>
</tr>
</tbody>
</table>

Modified from Peters et al.\textsuperscript{117}; Ritter & Scott\textsuperscript{118}; Scott et al.\textsuperscript{116}

These MISTELS tasks have undergone a rigorous process of validity and reliability testing to confirm their clinical relevance and appropriateness for the training and assessment of laparoscopic skills in human medicine\textsuperscript{17,48,116,119–122}. Importantly, performance on the FLS simulator, using MISTELS metrics, was positively correlated to intra-operative performance
during a laparoscopic cholecystectomy procedure\textsuperscript{123}. Furthermore, FLS-trained human surgical residents were rated significantly higher on the performance of a partial cholecystectomy procedure, using a Global Operative Assessment of Laparoscopic Skills (GOALS), compared to residents without simulator training\textsuperscript{95}. GOALS is a valid and objective measure of intra-operative laparoscopy performance that is comprised of a global rating scale, a task specific checklist, and two visual analog scales\textsuperscript{124,125}.

Performance metrics for each of the five manual skills tasks are based on time (seconds) and precision in an effort to ensure that trainees receive adequate feedback that is easy to interpret during training\textsuperscript{116}. Published training goals (Table 6)\textsuperscript{118} based on the scores achieved by two expert human laparoscopic surgeons are essential features of the MISTELS system given that simulation alone, in the absence of goal-directed practice, does not guarantee successful training outcomes\textsuperscript{98,105}. A total normalized score of 270 is required to pass the technical skills component of the FLS exam\textsuperscript{65,116}, and a higher score indicates enhanced performance.

**Table 6: MISTELS proficiency requirements**

<table>
<thead>
<tr>
<th>Task</th>
<th>Task Name</th>
<th>Proficiency Level</th>
<th>Time (s)</th>
<th>Allowable Errors</th>
<th>Repetitions</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>Peg transfer</td>
<td>Mean</td>
<td>48</td>
<td>No drops outside FOV</td>
<td>2 consecutive + 10 nonconsecutive</td>
</tr>
<tr>
<td>2</td>
<td>Pattern cut</td>
<td>Mean + 2 SD</td>
<td>98</td>
<td>All cuts within 2mm of line</td>
<td>2 consecutive</td>
</tr>
<tr>
<td>3</td>
<td>Ligating loop</td>
<td>Mean + 2 SD</td>
<td>53</td>
<td>Up to 1-mm accuracy error allowed. Knot must be secure.</td>
<td>2 consecutive</td>
</tr>
<tr>
<td>4</td>
<td>Extracorporeal suture</td>
<td>Mean + 2 SD</td>
<td>136</td>
<td>Up to 1-mm accuracy error allowed. Knot must be secure.</td>
<td>2 consecutive</td>
</tr>
<tr>
<td>5</td>
<td>Intracorporeal suture</td>
<td>Mean + 2 SD</td>
<td>112</td>
<td>Up to 1-mm accuracy error allowed. Knot must be secure.</td>
<td>2 consecutive + 10 nonconsecutive</td>
</tr>
</tbody>
</table>

Adopted from Ritter and Scott\textsuperscript{118}
This proficiency-based training system is considered superior to time-based training because it is sensitive to different rates of learning among individuals\textsuperscript{116}. Therefore, training can be tailored to the individual’s needs and goals\textsuperscript{116,126}. Furthermore, MISTELS provides the opportunity for remedial skills training and the reinforcement of skills if necessary. In terms of assessment, MISTELS metrics accounts for both time and errors to promote quality of performance over speed\textsuperscript{20}. As mentioned, MISTELS metrics have previously demonstrated high intra- and inter-rater reliability, and the highest level of predictive validity attainable\textsuperscript{103,127,123,17}, hence the incorporation of MISTELS into the highly regarded FLS program.

1.7.4 – Laparoscopic Simulators in Veterinary Medicine

In line with human medicine, the veterinary field acknowledges that laparoscopic surgery demands a unique set of technical skills that contribute to a complex learning curve\textsuperscript{65}. Furthermore, there is a consensus that novice surgeons early in their learning curve should seek basic technical skills training outside of the OR to improve patient safety and OR efficiency\textsuperscript{104}. Proven success with simulators for basic technical skills training in human medicine has recently prompted similar research in the veterinary field.

Indeed, one veterinary study demonstrated that scores on the first 3 MISTELS tasks were able to differentiate between novice and experienced veterinary surgeons\textsuperscript{128}. In the same study, scores on the first 3 MISTELS tasks increased significantly with training on a canine abdominal model\textsuperscript{128}. Similarly, total MISTELS scores (sum of 5 tasks) showed a positive and significant association with the level of video-endoscopic surgery experience in a group of ACVS board certified surgeons, ACVS enrolled surgical residents, internal medicine specialists, and residents in disciplines other than surgery\textsuperscript{128}. The combined results of the above studies demonstrate
construct validity of MISTELS in veterinary medicine, despite the relatively small sample sizes evaluated.

The extent of improvement on MISTELS tasks after training on a simulated canine abdominal model was significant for both novice and experienced laparoscopic surgeons; however, novices responded better than experts to this training\textsuperscript{129}. Alternatively, experienced faculty and residents in laparoscopic surgery did not show any improvement in MISTELS scores when trained solely on MISTELS, compared to training with a variety of exercises on a simulated canine abdominal model\textsuperscript{129}. The combination of results suggest that novice veterinary surgeons can effectively train with MISTELS, but perhaps expert veterinary surgeons would benefit from a higher fidelity, procedure specific trainer.

To date, there is no single laparoscopic surgery simulator that has gained as much widespread acceptance in the veterinary field as FLS has gained in the human medical field\textsuperscript{18}. However, the canine laparoscopic simulator (CLS) is an inanimate box trainer developed specifically for veterinarians. It is based on the principles of FLS, with slight variations. In an attempt for veterinary specificity, the box trainer and its dimensions were constructed using a CT scan of the thoracic and abdominal cavities of 3 Beagles\textsuperscript{18}. Rather than opaque, the top cover of CLS is transparent and the background canvas displays accurate canine anatomy. In addition to laparoscopy training, cranial and caudal openings in the box trainer permit the practice of NOTES and flexible endoscopy. Similar to FLS, CLS includes a camera mounted within the box trainer that projects an image to a monitor screen for visualization of four tasks: a coordination task, peg transfer task, cutting task, and suturing task\textsuperscript{18,130}.

Previously, CLS has demonstrated face validity\textsuperscript{18}, and construct validity\textsuperscript{130} in its ability to distinguish novice laparoscopic surgeons from experts. Moreover, significant improvements in
time, and on GOALS assessment, were reported in novices after CLS simulation training compared to a novice control group without training\textsuperscript{130}. A limitation of this study was the use of GOALS to measure performance only on the CLS and not in the actual OR environment. Additionally, in the same study, high agreement on video recorded performances of participants by two experienced raters provided proof of reliability for the CLS. In the future, further validation of the CLS is warranted with higher powered studies, an attempt to correlate performance on the CLS with performance on a “gold standard” measure of laparoscopic skills such as MISTELS, and an attempt to correlate performance on the CLS with performance in the actual OR using a validated measure such as GOALS.

A multitude of factors contribute to the safe and successful performance of laparoscopy in the OR. Demonstrated competency in a unique set of technical skills is an important component of laparoscopic surgery\textsuperscript{95} that is most effectively achieved through frequent, repetitive, and deliberate hands-on practice\textsuperscript{105}. Traditionally these fundamental skills were acquired in the OR under the apprenticeship model of training, but increasing evidence suggests that simulation training offers an effective and more ethically sound alternative\textsuperscript{105,101}. The use of simulation training in other high stakes disciplines, combined with the development of MISTELS, and subsequently the FLS program for board certification in human surgery suggests that simulation training is effective, and the way of the future\textsuperscript{131}. It is likely to be only a matter of time before simulation training for laparoscopic surgery in veterinary medicine follows suit\textsuperscript{26}.

1.8 - Thesis Objectives and Hypotheses

The purpose of this research was to investigate the impact of prior nonsurgical and surgical experiences on the performance of baseline laparoscopic surgical skills on a simulator in veterinary students.
Objectives
1. Determine if laparoscopic technical skills performed in the FLS simulator differ between veterinary students in years 1-4 of the DVM program at the OVC
2. Determine if self-reported open surgery experience is associated with laparoscopic technical skills performed in the FLS simulator by DVM students at the OVC
3. Identify associations between laparoscopic skills performed in the FLS simulator and prior experiences that are known to enhance bimanual coordination, depth perception, and manual dexterity (i.e. video games) in DVM students at the OVC
4. Identify the impact of cognitive distraction on performance of the FLS peg transfer task in DVM students at the OVC
5. Identify the impact of sensory distraction on performance of the FLS peg transfer task in DVM students at the OVC

Hypotheses
1. Laparoscopic technical skills performed in the FLS simulator will not differ between DVM students in years 1-4 at the OVC
2. Laparoscopic technical skills performed in the FLS simulator will not be associated with self-reported open surgery experience in DVM students at the OVC
3. Prior video game experience will enhance laparoscopic skills performed in the FLS simulator by DVM students at the OVC
4. Cognitive and sensory distraction will negatively impact the ability of DVM students at OVC to perform the FLS peg transfer task
1.9 - References


95. Sroka, G. FLS simulator training to proficiency improves laparoscopic performance in the operating room—a randomized controlled trial. ProQuest Diss. Theses (2009).
101. Rösch, T. et al. Clinical skills of veterinary students - a cross-sectional study of the self-


Chapter accepted for publication in the *Journal of American Veterinary Medical Association*


**Chapter 2 - Evaluation of Laparoscopic Skills in Veterinary Students**
2.1 Acknowledgements

The authors would like to thank William Sears for statistical support, and all of the veterinary students who volunteered their time to participate in this study.
2.2 Abstract

**Objective** - To compare FLS simulator-assessed laparoscopic skills in veterinary students with level of training, open surgical experience, and non-surgical experiences.


**Sample Population** – 145 veterinary students from years 1 (n=39), 2 (n=34), 3 (n=39), and 4 (n=33) of the veterinary program, without any prior laparoscopic surgery or FLS simulator experience.

**Procedures** – Veterinary students performed a peg transfer (task 1), pattern cutting (task 2), and ligature loop placement (task 3) on the FLS simulator. Self-reported open surgical experience and non-surgical experiences were collected by means of a questionnaire. A Kruskal-Wallis test was used to detect differences in laparoscopic skills between veterinary years, and the relationship between open surgical skills and laparoscopic skills were assessed with a Spearman’s rank order correlation coefficient ($r_s$). A general linear model, fixed effects ANOVA was used to investigate potential predictors of laparoscopic skills in a simulator.

**Results** – The study population was predominantly female (75%), right hand dominant (92%), and between the ages of 20-29 years (98%). Individual ($p>0.05$) and total ($p=0.75$) laparoscopic skills scores were not significantly different between veterinary years, and laparoscopic skills were not significantly ($p=0.19$, $r_s=-0.11$) associated with open surgical experience. Craft experience was a significant predictor of laparoscopic pattern cutting (task 2) skills ($p<0.05$) and total laparoscopic skills scores ($p=0.008$). Ligature loop placement (task 3) scores decreased significantly ($p=0.04$) as prior open surgical experience increased.
Conclusions and Clinical Relevance - Open surgical experience and prior VG experience did not enhance laparoscopic skills in this cohort of veterinary students. These results suggest that the acquisition of basic laparoscopic technical skills in veterinary students may require laparoscopic-specific skills training.

2.3 Introduction

Traditionally, the operating room (OR) served as the predominant learning environment for open and minimally invasive surgery (MIS) skills training in human medicine under the apprenticeship model, “see one, do one, teach one.” However, ethical and legal considerations, coupled with a steep learning curve for MIS suggests this traditional training approach is quickly becoming less feasible. In an effort to improve patient safety, the Society of American Gastrointestinal and Endoscopic Surgeons (SAGES), in conjunction with the American College of Surgeons (ACS), released the Fundamentals of Laparoscopic Surgery (FLS) program. FLS trains and evaluates human medical residents from a broad range of surgical specialties on their MIS cognitive knowledge and technical skills. The technical skills portion of the FLS program is based on a task system called the McGill Inanimate System for the Training and Evaluation of Laparoscopic Skills (MISTELS). Training to a pre-determined proficiency level on MISTELS tasks, and subsequently passing a proctored FLS examination at a designated testing center is mandatory to become eligible for board certification. In other words, FLS certification is a prerequisite to practice MIS on human patients.

The MIS technical skills portion of the FLS program takes place in a surgical simulator outside of the OR and includes five MISTELS tasks- peg transfer (task 1), pattern cutting (task 2), ligature loop placement (task 3), extracorporeal suturing (task 4) and intracorporeal suturing (task 5)- intended to train a basic set of laparoscopic skills (e.g. precision and manual dexterity).
A large body of research\textsuperscript{1,9,10} supports the application and transfer of these basic, non-procedure specific technical skills to the human OR.

MIS is gaining popularity in veterinary medicine\textsuperscript{11} for patient-associated benefits\textsuperscript{12–15}. Evidence of reduced hospitalization time, lower surgical site infections, faster return to normal function, reduced analgesic requirements, and less post-operative pain have been reported in veterinary patients undergoing MIS compared to open surgery\textsuperscript{12–14}. The OR remains one of the primary sources of technical skills training for veterinary surgical residents\textsuperscript{11,16}, despite the same ethical and legal concerns raised in human medicine. To date, few studies\textsuperscript{1,4,6–19} with small sample sizes have explored simulation for the purpose of MIS skills acquisition in veterinary trainees. Existing studies are difficult to compare due to variations in the simulator platform and outcome measures used, and unlike human medicine, a veterinary specific simulator system is not validated to the extent of FLS\textsuperscript{4}.

The primary objective of this study was to evaluate differences in laparoscopic skills, assessed by MISTELS metrics, between veterinary students in years 1-4 of the veterinary program. A secondary objective was to investigate the relationship between laparoscopic skills performed in a simulator with prior open surgical experience. A tertiary objective was to determine if VGs and other non-surgical experiences could predict laparoscopic skills in a simulator. We hypothesized that there would not be a significant difference in laparoscopic skills scores between veterinary years, that open surgical experience and laparoscopic skills in a simulator would not be associated, and that VGs and other activities that facilitate hand-eye coordination would predict laparoscopic skills in a simulator.
2.4 Materials and Methods

Study Population - Approval for this study was obtained from the Research Ethics Board (#14SE031) at the University of Guelph. Veterinary student status at the Ontario Veterinary College (OVC) was the only requirement for inclusion in this study. Individuals were excluded if they had any prior experience with the FLS simulator or prior experience performing laparoscopic procedures. One hundred and twenty year 1 veterinary students, 120 year 2 veterinary students, 116 year 3 veterinary students, and 114 year 4 veterinary students were candidates for inclusion in the study. A short, scripted oral presentation was made by the first and second authors to all veterinary students in an effort to introduce the topic of MIS, and relevance of the study. Included in this presentation was a description of the MISTELS task system that would be used to assess basic laparoscopic skills in participants on the FLS simulator. A subsequent web-based survey of two questions was distributed via email to all veterinary students. The purpose of the first question was to identify interested students, and the purpose of the second question was to collect contact information from those that expressed an interest. Interested students were subsequently contacted and invited to the skills lab for FLS testing. Students were recruited between October 2014 to February 2015, and participation was voluntary.

Prior to FLS testing, subjects consented to participate in the study by completing a survey (see appendix), which was used to collect information on nonsurgical experiences (e.g. craft experience and VG experience) presumed to enhance the performance of laparoscopic skills. Demographic information was also collected. In addition, participants were asked to view three short instructional videos demonstrating how to perform the first three MISTELS tasks.
The MISTELS task system used for training and testing laparoscopic skills has been previously described and validated in human medicine. Briefly, the MISTELS tasks are performed in the FLS box trainer, covered by an opaque membrane. The table-top height is adjusted to accommodate the user for ergonomic reasons. Two working instrument portals, approximately 12mm in diameter, and a camera mounted on the underside of the opaque membrane, are triangulated and fixed in position. An image captured by a camera is transmitted to a 27-inch computer monitor positioned directly in front of the user for visualization.

Participants were assessed on their performance of a peg transfer (task 1), pattern cutting (task 2), and ligature loop placement (task 3) inside the box trainer. The last two extra- and intracorporeal suturing tasks that are usually part of the full MISTELS task training, were excluded from this study, since they are not frequently performed by veterinary general practitioners. Approximately 5-minutes of instrument handling outside the box trainer was allowed prior to testing so that participants could gain familiarity with the laparoscopic instrumentation, however, no warm up exercise/trial run was allowed. The score system was explained to participants and all questions were answered at this time. A single repetition of each task was then performed in sequential order from task 1 to 3, and recorded for time and precision. The same evaluator (first author) timed and recorded penalties for all participants.

Task 1 - Each participant was timed as they transferred six pegs individually from one pegboard to another within the box trainer. A peg was lifted from the first pegboard with laparoscopic grasping forceps in the non-dominant hand, transferred in midair to grasping forceps in the dominant hand, and subsequently placed onto the second pegboard. Pegs dropped outside the field of view were recorded and then returned to their starting position by the observer. The participant was required to repeat the transfer of any pegs dropped outside the field.
of view. Once all six pegs were transferred successfully in one direction, the process was reversed, starting with the dominant hand. Timing started when the first peg was grasped, and timing ended when the final peg was returned to its starting position on the rectangular pegboard. If the time required to transfer all 6 pegs in both directions exceeded 300 seconds, a score of 0 was assigned for task 1. The number of pegs dropped outside the field of view were multiplied by 10 to generate a penalty score. The previously validated equation used to generate the overall score for task 1 was: 300s – time to completion – 10 x number of pegs dropped outside the field of view\textsuperscript{17}.

Task 2 - Each participant was timed as they cut a pre-marked, 4cm diameter circle from a piece of instrument wrapping paper material (10cm x 15cm) with a set of laparoscopic scissors in the dominant hand. The piece of material was suspended inside the box trainer by a large, plastic overhead clip and two alligator clips to secure the bottom two corners. A set of laparoscopic grasping forceps in the non-dominant hand provided tension on the material as the dominant hand cut out the circular pattern. Timing started when the initial cut was made, and timing ended when the circle was cut free from the material. If time exceeded 300 seconds, a score of 0 was assigned for task 2. Any excess material that resulted from deviations inside or outside of the circle was spread out on a sheet of graph paper, and the surface area covered by this rectangle (with a 5-10 millimeter square sensitivity) was divided by the surface area of the pre-marked circle. This protocol was used to calculate the percent deviation, which was the penalty score for task 2. The previously validated equation used to generate the overall score for task 2 was: 300s – time to completion – percent deviation\textsuperscript{17}.

Task 3 - Each participant was timed as they tightened a pre-tied ligature loop around a pre-marked target line on a foam appendage that was designed to resemble a hollow tubular
structure, such as a blood vessel. A set of laparoscopic grasping forceps held in the non-dominant hand guided the loop into position around the foam. Once the knot was tightly fastened, the grasping forceps were replaced with laparoscopic scissors. The suture material was then cut anywhere above the knot, which marked the completion of the exercise. Timing started when the first instrument entered the field of view, and timing ended when the suture material was cut. If time exceeded 180 seconds, a score of 0 was assigned for task 3. The distance in millimeters of the participant’s knot placement from the pre-marked target line was the penalty applied to the score for task 3. The previously validated equation used to generate the overall score for task 3 was: 180s – time to completion – distance from pre-marked target line\textsuperscript{17}.

Scores - The scores for each MISTELS task were calculated based on time and precision, according to the equation: total score = cut-off time (s) – time to completion (s) – penalty score\textsuperscript{17}. A score of 0 was assigned to any task that exceeded the predefined cut-off time, or any score that would otherwise be negative. Individual task scores were normalized using previously published expert surgeon scores, to ensure that each task contributed equally to the total score\textsuperscript{24}. The total score for each participant was the sum of each individual normalized task score. Higher scores indicated superior performance\textsuperscript{24}.

Sample Size Calculation – We conducted an \textit{a priori} power analysis with a type I error (\(\alpha\)) rate of 5\% and a 95\% confidence interval using an online sample size calculator\textsuperscript{8}. A previously reported standard deviation on the first trial of the peg transfer (task 1) in medical students was 8.8\textsuperscript{25}. The statistical power with approximately 30 veterinary students per year was 88\%.

Questionnaire Data - In order to collect information on prior VG experience, a VAS with qualifiers at 0mm (have never played), 50mm (played 0-3 hours per week for >1 year), and
100mm (played >3 hours per week for a minimum of 8 years) was adopted from Fransson et al.\textsuperscript{19} Prior open surgical experience was also self-reported on a VAS with qualifiers at 0 (none), 50mm (have performed 5-10 minor surgical procedures in the last 5 years as the primary surgeon) and 100mm (have performed >50 canine or feline minor or major surgical procedures as the primary surgeon). To collect information on craft experience, participants answered none, some, or a lot, to the question, “do you have experience with sewing, needlepoint, mini-constructs, or detailed craft making?”

**Statistical Analysis** - The data were not normally distributed, and therefore a Kruskal-Wallis nonparametric test was used to detect differences in laparoscopic skills scores between the four veterinary years. A Spearman’s rank correlation coefficient was used to identify associations between reported open surgical experience and laparoscopic skills scores assessed using MISTELLS metrics. Four general linear fixed effects models were constructed and laparoscopic skills scores on each individual task and total scores were regressed against potential predictors of laparoscopic skills. Results are presented as regression coefficients and 95% confidence intervals (95% CI). Statistical analyses were conducted with a statistical software program\textsuperscript{b}, and for all tests a p-value of <0.05 was considered statistically significant. Laparoscopic skills scores are expressed as median (IQR).

Four general linear regression models with fixed effects were used to estimate the amount of variation in laparoscopic skills scores (Y) that could be explained by each survey parameter (X), after controlling for the other independent variables in the model. The magnitude of this association was expressed as a regression coefficient. For continuous variables, a positive regression coefficient meant that Y increased for every unit increase in X, and vice versa. Regular dummy variables were generated for categorical X variables in the model, and their
regression coefficients were compared to a referent category. Statistically significant associations were defined as a p-value of <0.05, and confounding was defined here as a change of >20% in the regression coefficients. Based on our stated objectives, variables included a priori in the final model were open surgery experience, prior VG experience, and level of veterinary training.

2.5 Results

Study Population – A cohort of one hundred forty-five veterinary students in year one (n=36), two (n=26), three (n=37) and four (n=31) of the veterinary program from the OVC participated in this study. None of the participants had any prior experience with MISTELS tasks, and none had prior laparoscopic surgery experience. The study population was predominantly female (75%), right hand dominant (92%), and between the ages of 20-29 years old (98%).

The total median (IQR) VAS score for prior VG experience was 28 (13-61) and the median (IQR) VAS score for open surgical experience was 6 (0-41) (table 7). Self-reported open surgical experience differed significantly between veterinary years, with the exception of years 1 and 2 (p=1.00).

Table 7: Self-reported open surgery experience, video game experience and craft experience by veterinary year

<table>
<thead>
<tr>
<th>Experience</th>
<th>Year 1</th>
<th>Year 2</th>
<th>Year 3</th>
<th>Year 4</th>
<th>Total</th>
</tr>
</thead>
<tbody>
<tr>
<td>VS</td>
<td>0 (0-0)</td>
<td>0 (0-0)</td>
<td>13 (7-43)</td>
<td>51 (41-53)</td>
<td>6 (0-41)</td>
</tr>
<tr>
<td>VG</td>
<td>44 (16-62)</td>
<td>37 (14-62)</td>
<td>26 (14-61)</td>
<td>25 (7-63)</td>
<td>28 (13-61)</td>
</tr>
<tr>
<td>Craft</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>None</td>
<td>15</td>
<td>13</td>
<td>15</td>
<td>13</td>
<td>56</td>
</tr>
<tr>
<td>Some</td>
<td>21</td>
<td>18</td>
<td>16</td>
<td>19</td>
<td>74</td>
</tr>
<tr>
<td>A lot</td>
<td>3</td>
<td>3</td>
<td>8</td>
<td>1</td>
<td>15</td>
</tr>
</tbody>
</table>

VS (veterinary open surgery) and VG (video game) experience levels reported as median (IQR). Craft experience represents the number of individuals per category.
**MISTELS Scores** - There was no statistically significant difference in laparoscopic skills scores on task 1 (p=0.86), task 2 (p=0.76), task 3 (p=0.69), and on total scores (p=0.75) between veterinary years (table 8).

**Table 8**: Median (IQR) scores on 3 MISTELS tasks and total scores in veterinary students

<table>
<thead>
<tr>
<th>Veterinary year</th>
<th>Task 1</th>
<th>Task 2</th>
<th>Task 3</th>
<th>Total</th>
</tr>
</thead>
<tbody>
<tr>
<td>1 (n=39)</td>
<td>68 (51-80)</td>
<td>10 (0-33)</td>
<td>35 (0-58)</td>
<td>111 (76-165)</td>
</tr>
<tr>
<td>2 (n=34)</td>
<td>75 (53-80)</td>
<td>21 (0-40)</td>
<td>50 (0-73)</td>
<td>136 (78-180)</td>
</tr>
<tr>
<td>3 (n=39)</td>
<td>68 (60-78)</td>
<td>18 (0-31)</td>
<td>38 (11-63)</td>
<td>123 (90-156)</td>
</tr>
<tr>
<td>4 (n=33)</td>
<td>68 (58-76)</td>
<td>11 (0-39)</td>
<td>27 (0-63)</td>
<td>113 (83-151)</td>
</tr>
<tr>
<td>All</td>
<td>69 (58-78)</td>
<td>15 (0-35)</td>
<td>37 (0-68)</td>
<td>120 (81-166)</td>
</tr>
<tr>
<td>p-value</td>
<td>0.86</td>
<td>0.76</td>
<td>0.69</td>
<td>0.75</td>
</tr>
</tbody>
</table>

**Previous experience and MISTELS** - There was a weak negative, but statistically significant association between laparoscopic skills scores on task 3 and self-reported open surgical experience in this cohort of veterinary students (r=-0.17, p=0.04). However, self-reported open surgical experience was not significantly associated with the scores on any other laparoscopic skills task (table 9).

**Table 9**: Relationship between laparoscopic skills scores assessed by MISTELS metrics, and open surgery experience in veterinary students

<table>
<thead>
<tr>
<th>Task</th>
<th>1</th>
<th>2</th>
<th>3</th>
<th>All</th>
</tr>
</thead>
<tbody>
<tr>
<td>Total Score</td>
<td>-0.07</td>
<td>0.03</td>
<td>-0.17</td>
<td>-0.11</td>
</tr>
<tr>
<td>r_s</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>p value</td>
<td>0.42</td>
<td>0.70</td>
<td>*0.04</td>
<td>0.19</td>
</tr>
</tbody>
</table>

r_s = Spearman’s rank correlation coefficient
*p<0.05 considered statistically significant

There were no statistically significant predictors of laparoscopic skills scores on task 1 (P>0.05). However, individuals that reported having no craft experience scored significantly lower on task 2 than individuals with a lot of craft experience (β=-21.85, p<0.001, 95% CI = -32.58 to -11.12). Furthermore, individuals that reported having moderate craft experience scored
significantly lower on task 2 than individuals with a lot of craft experience ($\beta = -16.34$, $p = 0.003$, 95% CI = -26.91 to -5.77). On task 3, increased open surgical experience resulted in significantly lower laparoscopic skills scores ($\beta = -0.35$, $p = 0.034$, 95% CI = -0.68 to -0.03). Finally, when scores for the three tasks were totalled, individuals with no craft experience scored significantly lower than individuals with a lot of craft experience ($\beta = -42.11$, $p = 0.008$, 95% CI = -73.07 to -11.16) (table 10).

**Table 10:** Factors affecting total laparoscopic skills scores assessed by MISTELS metrics

<table>
<thead>
<tr>
<th>Variable</th>
<th>Coefficient</th>
<th>P value</th>
<th>95% CI</th>
</tr>
</thead>
<tbody>
<tr>
<td>Year 2</td>
<td>10.25</td>
<td>0.408</td>
<td>-14.20 - 34.70</td>
</tr>
<tr>
<td>Year 3</td>
<td>6.48</td>
<td>0.621</td>
<td>-19.40 - 32.35</td>
</tr>
<tr>
<td>Year 4</td>
<td>13.49</td>
<td>0.423</td>
<td>-19.71 - 46.69</td>
</tr>
<tr>
<td>Video game experience</td>
<td>0.083</td>
<td>0.548</td>
<td>-0.19 - 0.35</td>
</tr>
<tr>
<td>Open surgery experience</td>
<td>-0.323</td>
<td>0.239</td>
<td>-0.86 - 0.22</td>
</tr>
<tr>
<td>No craft experience</td>
<td>-42.11</td>
<td>*0.008</td>
<td>-73.07 - 11.16</td>
</tr>
<tr>
<td>Some craft experience</td>
<td>-25.32</td>
<td>0.103</td>
<td>-55.81 - 5.17</td>
</tr>
</tbody>
</table>

ANOVA, *p<0.05 considered statistically significant
Year 1 is the referent category
A lot of craft experience is the referent category

**2.6 Discussion**

In the present study, it was not surprising that laparoscopic skills scores did not differ significantly between veterinary years, despite the progressive increase in open surgical experience from years 2-4. The lack of association between open surgical experience and laparoscopic skills provides further evidence that open surgery does not necessarily facilitate the acquisition of skills required for MIS. Indeed, the unique challenges associated with MIS have been extensively cited elsewhere in the literature\textsuperscript{15,18,26}. For example, the use of long instruments accentuates hand tremor, reduces tactile feedback, and challenges both bimanual coordination and depth perception. Fixed access sites in the body wall create a fulcrum effect that produces counterintuitive instrument movements, and finally, surgeons must learn to operate in a 3D field while viewing a 2D image on a monitor screen\textsuperscript{15,18,20,21,26,27}. 
The present findings of no association between open surgery experience and laparoscopic skills are consistent with a study by Figert et al.\textsuperscript{27} that compared laparoscopic knot-tying skills in human surgical residents. Senior residents with ongoing open surgical experience and limited laparoscopic surgical experience did not outperform surgical interns without open or laparoscopic surgery experience, in terms of time and number of errors\textsuperscript{27}. Furthermore, our results are corroborated by a similar study in veterinary medicine that found no association between laparoscopic skills and traditional open surgical skills in third-year veterinary students\textsuperscript{18}.

The median (IQR) on task 3 in this cohort of veterinary students was 37 (0-68), which is comparable to the scores obtained by first and second year veterinary students in a similar study on their first trial of the ligature loop placement (task 3) [39 (0–44) and 29 (0–67)]\textsuperscript{17}. As one would expect, these scores were significantly lower than those obtained by a group of experienced veterinarians, many of whom were board certified surgeons\textsuperscript{17}. The statistically significant association observed between open surgical experience and laparoscopic skills scores on task 3 was negative and very weak. The authors feel that the only logical explanation for such a result is type I statistical error.

Researchers are interested in collecting information on non-surgical experiences that may help facilitate the acquisition of MIS technical skills in trainees\textsuperscript{28,29}. Ideally this knowledge will enhance training programs and help to identify individuals that could benefit from remedial skills training. For example, in human medicine one study found a significant association between the use of chopsticks and basic laparoscopic skills in medical students\textsuperscript{28}, but not with typing, musical instruments, sewing, or the use of tools\textsuperscript{29}. Another study investigated the influence of musical instrument use on laparoscopic simulator skills in human surgical residents and found no statistically significant relationship between the two.
In this study of veterinary students, craft experience was the only variable that seemed to influence the performance of basic laparoscopic surgical skills in a simulator. Craft experience is defined here as experience with needlepoint, mini-constructs, sewing, and/or detailed craft making, all of which hone manual dexterity skills. Hughes et al.\textsuperscript{30} suggested that manual dexterity is the most important predictor of technical surgical skills and therefore, it seems intuitive that craft experience was a significant predictor of a laparoscopic pattern cutting (task 2) and ligature loop placement (task 3) exercise in this cohort of veterinary students.

In contrast, craft experience did not appear to influence the performance of a simple peg transfer (task 1). The three MISTELS tasks increase progressively in difficulty level and perhaps the peg transfer (task 1), was too basic to discriminate small differences in this cohort of veterinary students\textsuperscript{20,21}. Interestingly, participants in this study scored especially high on the peg transfer (task 1) [68 (51-80)] when compared to median (IQR) scores obtained in a skills lab, on the same simulator, by novice veterinary trainees [0 (0)]\textsuperscript{17} and veterinarians with video-endoscopic experience [36 (8-50)]\textsuperscript{17,19}. It is possible that the voluntary nature of participation led to a cohort of veterinary students with exceptional innate manual dexterity skills beyond the broader population of veterinary students at OVC.

VGs have been proposed as an adjunct to traditional laparoscopic surgical training mainly for their portability, accessibility, and low cost compared to alternative training modalities like virtual reality systems\textsuperscript{18}. It has been proposed that VG play, especially with modern motion-sensing systems, enhances user familiarity with a computer interface in a stimulated environment\textsuperscript{18,31}. Like laparoscopy, a VG player must process, and translate 2D images to a 3D working environment. Multiple studies published in the human literature suggest that prior VG experience enhances one’s ability to perform basic laparoscopic surgery skills in a simulator\textsuperscript{31–33}. 
To date, the use of VGs as tools to enhance technical skills training in veterinary MIS has yielded mixed results. Millard et al.\textsuperscript{18} conveyed a significant correlation between VG skills and laparoscopic simulator skills in third-year veterinary students. VG experience was collected via a detailed questionnaire, and VG skills were verified using participant scores on three different Nintendo Wii games\textsuperscript{18}. In contrast, Fransson and Ragle\textsuperscript{17}, and results from the present study, did not reveal any significant association between VGs and laparoscopic skills assessed in a simulator. Possible reasons for this discrepancy include, variation in the simulators used to measure laparoscopic skills, variation in terms of the specific VGs played and consoles used, and variation in data collection methods.

In the present study, a VAS was used to collect information on self-reported VG experience. However, VASs have been criticized for their subjectivity\textsuperscript{24}, and it has been suggested elsewhere that students poorly self-evaluate\textsuperscript{31}. If the latter is true, perhaps individual VG skills should have been tested to verify that self-reported experience level translates to ability. In hindsight, a more regimented data collection strategy would have also provided a more complete picture of VG experience (i.e. total number of hours played per day, week, month, year, etc.).

Despite convincing evidence for the use of VGs in training laparoscopic skills, the wide variety of VGs and commercially available consoles makes standardization difficult. Furthermore, it remains to be determined if these skills transfer directly to the OR and improve patient outcomes, which is the ultimate goal of training.

Limitations of this study are acknowledged. We used a convenience sample of undergraduate veterinary students, which does not permit the extrapolation of results to surgical residents, or more experienced laparoscopic surgeons. On the other hand, excluding more
experienced surgical trainees and established veterinary surgeons eliminates formalized training in surgical skills as a source of potential bias\textsuperscript{30}.

The objectives of this study were fully disclosed to veterinary students prior to participation, which may have introduced volunteer bias if a disproportionate number of participants had a vested interest in VGs or laparoscopic surgery. In an effort to minimize this source of bias, eligible participants were recruited with equal rigor, and information was distributed equally amongst veterinary years. In addition, we maintained a balanced number of participants from each veterinary year.

Another limitation of our study is that a single repetition of each task may not adequately reflect the skill level of participants. However, the purpose of a single trial was an attempt to capture baseline skills, and thus eliminate the learning effect that is observed after repeat attempts on a simulator\textsuperscript{17–19}. A further limitation of the present study is the fact that laparoscopic competency was assessed in a simulator on the sole basis of technical skills. Although exceptional technical skill distinguishes surgeons from other medical professionals, in reality, surgical competence is comprised of a much broader set of skills including decision making, communication, compassion, and knowledge of anatomy\textsuperscript{18,26}.

To the authors’ knowledge, this is the largest study conducted to date that assess laparoscopic simulator skills in veterinary students. The results of this study support the hypothesis that open surgical skills do not transfer to basic laparoscopic surgery skills in this cohort of veterinary students. Consequently, there may be a need for laparoscopic-specific skills training in veterinary medicine, and simulation training outside of the OR might offer a safe and feasible adjunct to traditional training approaches. In the future, multi-institution studies that
include participants with various skill levels and experience should be conducted to investigate the value of simulation training on laparoscopic skills acquisition in veterinary medicine.

a. Survey Monkey, Palo Alto, CA
b. FLS box trainer, SAGES FLS Program, Los Angeles, Calif.
c. Dissecting and grasping forceps, 5mm, Karl Storz Veterinary Endoscopy-America Inc, Goleta, Calif.
d. ENDOLOOP Ligature, Ethicon US, LLC
e. Endo Shears, 5mm, Karl Storz Veterinary Endoscopy-America Inc, Goleta, Calif.
g. Sample size calculation: http://www.stat.ubc.ca/~rollin/stats/ssize/n2.html
h. SAS, version 9.3, SAS Institute Inc, Cary, NC.

2.7 Disclosure

The authors report no financial or other conflicts related to this report.
2.8 References

Chapter accepted for publication in *Veterinary Surgery*


**Chapter 3 - The Impact of Distraction on Laparoscopic Skills in Veterinary Students**
3.1 Acknowledgements

The authors would like to thank Kevin Hogg for technical assistance with the sensory distraction, William Sears for statistical support, and all of the veterinary students who volunteered their time to participate in this study.
3.2 Abstract

Objective – To investigate the impact of distraction on the performance of a simulator-based laparoscopic task in veterinary students.

Study Design – Prospective, randomized trial.

Sample Population – Years 1-4 veterinary students (n=41).

Methods – Participants repeated a simulated laparoscopic peg transfer task to eliminate any learning effects, and were subsequently randomized to receive either a cognitive (double-digit addition questions, n=21) or sensory distraction (dogs barking and anaesthetic monitor alerts, n=20). A nonparametric Wilcoxon matched-pairs signed rank test was used to compare laparoscopic task scores in the presence and absence of distraction. The number of addition questions attempted, and the number of questions answered correctly in 1 min were compared at baseline, and, during a concurrent laparoscopic task using a Wilcoxon matched-pairs signed rank test. A p-value of <0.05 was considered statistically significant in each case.

Results – Scores on the laparoscopic task were not significantly different between groups at baseline (p=0.09). Task scores decreased significantly when performed with the cognitive distraction (p<0.001), and improved significantly when performed with the sensory distraction (p=0.005). Participants randomized to the cognitive distraction attempted significantly fewer math questions (p<0.001), and answered significantly fewer math questions correctly (p<0.001) when a concurrent laparoscopic task was performed.

Conclusions – Various forms of unavoidable distractions are invariably encountered in the operating room, but their impact on surgical performance remains to be determined in veterinary
medicine. Cognitive distraction had a negative impact on the performance of a laparoscopic task in this cohort of veterinary students, whereas sensory distraction had a positive effect.

3.3 Introduction

In line with other professional disciplines such as aviation\textsuperscript{1,2}, surgeons are faced with frequent distractions in the operating room (OR). An estimated 10-20 distractions and interruptions take place over the course of a single surgical procedure\textsuperscript{3}, with reported rates of occurrence as high as 1 distraction event every 1.8 minutes\textsuperscript{4}. Typical distractions encountered in the human OR include procedure-related conversation, patient-irrelevant communication, the opening and closing of OR doors, the entrance and exit of OR personnel, cell phones, and background music\textsuperscript{2,5-7}. Moreover, it is not uncommon for distractions to produce noise levels above 85 decibels (dB)\textsuperscript{1,5,7}, which far exceeds the 45dB limit recommended by the Environmental Protection Agency and International Noise Council for working environments\textsuperscript{8,9}.

Distraction events divert the attention of the surgeon and surgical team members from the primary surgical procedure to a less critical secondary task\textsuperscript{10}. Resultant interruptions are linked to performance deficits in the primary task\textsuperscript{1,5,7}, secondary task\textsuperscript{3,6}, or both\textsuperscript{10}. In the face of inevitable OR distraction, there is justified concern for patient safety and quality of care during surgery\textsuperscript{4}. However, an association between reduced surgical performance attributed to distraction, and reduced patient outcome remains to be determined in veterinary medicine.

Given the ethical considerations involved in conducting research involving distractions in the OR, validated surgical simulators make ideal surrogates\textsuperscript{2}. Simulation systems facilitate the assessment of surgical skills in a safe, controlled environment where researchers can manipulate the onset and type of distraction presented.
Despite the fact that distraction events encountered in the veterinary OR are consistent with those described in human medicine, their impact on surgical performance remains to be determined. The effect of distraction is important to investigate especially given the ever-increasing popularity of Minimally Invasive Surgery (MIS) in veterinary medicine\textsuperscript{11}. MIS presents an entirely new dimension of OR distractions, since it involves equipment and technological challenges (e.g. endoscopic navigation) that require an operator’s complete attention and focus\textsuperscript{1,12}.

The purpose of the present study was to investigate the impact of cognitive and sensory distraction on simulated laparoscopic skills of veterinary students in years 1-4 of the veterinary medicine program. We hypothesized that laparoscopic skills would decrease when performed concurrently with both a sensory and cognitive distraction.

### 3.4 Materials and Methods

**Study Population** – Ethics approval for this prospective, randomized trial was obtained from the University of Guelph Research Ethics Board. The only requirement for inclusion in this study was veterinary student status, and individuals were excluded if they had previously performed 1 or more video-endoscopic procedure(s). Prior to testing, participants were asked to fill out a short questionnaire in an effort to collect demographic information, and watch a short, 4-min video demonstration of the Fundamentals of Laparoscopic Surgery (FLS) peg transfer task ([https://www.youtube.com/watch?v=gAQPXHWqdXQ](https://www.youtube.com/watch?v=gAQPXHWqdXQ)). All testing was performed in the Endoscopic Skills Lab at the Ontario Veterinary College by the first 2 authors.

**Peg Transfer** - The peg transfer task constitutes the first of 5, in a series of tasks, designed to train and assess basic technical skills in human laparoscopic surgeons\textsuperscript{13}. This validated system, designed at McGill University, is referred to as the McGill Inanimate System
for the Training and Evaluation of Laparoscopic Skills (MISTELS)\textsuperscript{14}. MISTELS currently represents the technical skills portion of the Fundamentals of Laparoscopic Surgery (FLS) course, which is a certification required by the American Board of Surgeons (ABS).

Briefly, the peg transfer task was assessed in an FLS inanimate box trainer (FLS box trainer, SAGES FLS Program, Los Angeles, CA) located in the Endoscopic Skills Laboratory at the Ontario Veterinary College. Participants relied on a 27-inch computer monitor screen for visualization, as an opaque membrane covered the top of the box trainer and obstructed a direct view of the working field. A camera mounted on the underside of this membrane, between 2 trocars (Blunt tip trocar, Covidien, Minneapolis, MN), transmitted images to the monitor screen throughout the course of the exercise.

In the peg transfer task, participants had 300s to transfer 6 pegs individually from one pegboard to another within the box trainer. The forward and reverse transfer of 6 pegs constituted 1 trial. Laparoscopic grasping forceps (5mm dissecting and grasping forceps, Karl Storz Veterinary Endoscopy-America Inc, Goleta, CA; laparoscopic duckbill grasper, Faux Medical, Toronto, ON, CAN) held in the dominant and non-dominant hands assisted with each transfer. The most critical component of this task was a midair transfer of each peg from 1 set of laparoscopic grasping forceps to the other, as bimanual coordination was the main skill assessed in this exercise. The validated equation (1) presented below was used to generate a peg transfer score for each participant that incorporated time (s) and precision\textsuperscript{15}.

\begin{equation}
\text{Raw score} = 300 - \text{time to completion} - 10 \times \text{ pegs dropped}
\end{equation}
Error was accounted for by subtracting from 300s, the number of pegs dropped outside the field of view (FOV), multiplied by $10^{15}$. Pegs dropped outside the FOV were returned by the observer to their starting point, and had to be retransferred by the participant. Alternatively, the time taken to recover each peg dropped within the FOV was a penalty in and of itself$^{15}$. Time started when the first peg was grasped and ended when the final peg was returned to the initial pegboard. Time and precision measurements were recorded for all participants. A score of 0 was assigned in the event that the 300s time limit was exceeded, or if the score would otherwise be negative. Based on this scoring method, high scores were interpreted as superior performance.

Individual raw scores were averaged, and then normalized (2) using the score obtained by two expert human laparoscopic surgeons$^{16}$.

(2) Normalized score = raw score/342 x 100

**Stabilization** - Participants performed the peg transfer task repeatedly until they achieved a consistent score that did not vary by more than 10% on 5 consecutive trials. Stabilization was intended to reduce the learning effect that occurs when performing the same task repeatedly in a simulator$^{17}$. Participants were informed that they could pause briefly between trials if they felt sore or fatigued at any point during stabilization. Once stabilization was achieved, peg transfer scores were recorded in the presence and absence of a distraction event.

**Distraction Events** - Each participant was randomized to receive either a cognitive distraction (double-digit addition questions) or sensory distraction (dogs barking and monitor alerts). Participants were aware they would be distracted at some point during testing, but were
blinded to exactly when distraction would occur. Furthermore, participants were not specifically instructed to prioritize the peg transfer over the distraction task, or vice versa.

*Cognitive Distraction* - Individuals that were randomized to receive the cognitive distraction performed a series of 5 consecutive blocks. Within each block, 3 tasks were performed in a random order (SAS version 9.3, SAS Institute Inc, Cary, NC). The 3 tasks included (1) addition questions, (2) peg transfer, and (3) addition questions + peg transfer. Each testing session for the cognitive distraction group took approximately 1h to complete.

The cognitive distraction for this study was a series of double-digit addition questions generated online ([https://www.mathfactcafe.com/worksheet/buildit/](https://www.mathfactcafe.com/worksheet/buildit/)). Questions were set at a moderate difficulty level, such that some questions required participants to “carry a digit” (e.g. 24 + 58). Math questions were asked for 1 min in the absence of distraction to establish math ability at baseline, and during the performance of a concurrent peg transfer task. Questions were asked in succession, immediately after a verbal response to the previous question was elicited. The question was repeated if the participant paused for an extended period of time. In the dual-task condition, addition questions were asked immediately after the first peg was grasped, and ended after 1 min. The number of math questions answered in 1 min, and the number of questions answered *correctly* in 1 min were the outcome measures used to quantify this distraction event in both baseline and dual-task conditions. Normalized laparoscopic task scores were also quantified under both conditions.

*Sensory Distraction* - Individuals randomized to receive the sensory distraction performed a series of 5 consecutive blocks. Within each block only 2 tasks were performed in a random order. The 2 tasks included (1) peg transfer, and (2) noise + peg transfer. Each testing session took approximately 30min to complete.
The sensory distraction for this study was comprised of short, 5s sound clips of either (1) a barking dog, (2) alerts produced by an anesthesia monitor machine, (3) both noises merged, or (4) silence. Each 5s sound clip was randomized to a 60s soundtrack (www.random.org). A total of 5, 60s soundtracks were constructed using Adobe Premiere Pro 6.0, and were played from a laptop computer at 75dB to replicate the noise level of distractions in a typical OR environment. The specific sounds were selected based on those that would be considered common distractions in a veterinary OR. Normalized laparoscopic task scores in both baseline and dual task conditions were recorded, however, the sensory distraction itself was not quantified.

**Statistical Analysis** – Peg transfer scores were not normally distributed as evidenced by a Shapiro-Wilk test for normality. Therefore, a Wilcoxon matched-pairs signed rank test was used to compare scores on the peg transfer task when performed in the absence (baseline) and presence of a cognitive and sensory distraction. The average number of math questions answered, and the number of questions answered correctly were compared at baseline and during the performance of a concurrent peg transfer task using a Wilcoxon matched-pairs signed rank test. Peg transfer scores and math questions are presented as median (range) in Tables 1 and 2. All statistical analyses were performed using a computerized statistical software program (STATA version 13.1, StataCorp LP, College Station, TX), and a p-value of <0.05 was considered statistically significant in each case.

### 3.5 Results

**Study Population** – Veterinary students (n=41) in years 1-4 at the Ontario Veterinary College participated in this study and received a sensory distraction (n=20) or cognitive distraction (n=21) upon recruitment. The average age of participants was 25 (±3) years, the
majority of participants were female (73%), and right hand dominant (90%). There was no significant difference in age (p=0.59), sex (p=0.67), or baseline laparoscopic task scores between groups (p=0.09). The average number of laparoscopic task trials required to reach stabilization was 10 (±15).

**Sensory Distraction** – In the sensory-distracted group, scores on the laparoscopic task increased significantly in the presence of background noise (p=0.005) when compared to baseline scores (Table 11).

**Table 11**: Comparison of normalized laparoscopic task scores in the absence (baseline) and presence of sensory distraction

<table>
<thead>
<tr>
<th></th>
<th>Baseline</th>
<th>Sensory Distraction</th>
<th>P value</th>
</tr>
</thead>
<tbody>
<tr>
<td>Median (range) laparoscopic task score</td>
<td>97.5 (70-100)</td>
<td>99 (72-100)</td>
<td>p=0.005</td>
</tr>
</tbody>
</table>

Wilcoxon matched-pairs signed rank test
*p<0.05 statistically significant from baseline

**Arithmetic Distraction** – Both the number of math questions answered (p<0.001) and the number of math questions answered correctly (p<0.001) were significantly reduced when participants were required to perform a concurrent laparoscopic task (Table 3.2). Scores on the laparoscopic task were significantly reduced (p<0.001) when addition questions were answered simultaneously (Table 12).

**Table 12**: Comparison of normalized laparoscopic task scores in the absence (baseline) and presence of cognitive distraction, and arithmetic performance

<table>
<thead>
<tr>
<th></th>
<th>Baseline</th>
<th>Dual Task</th>
<th>P value</th>
</tr>
</thead>
<tbody>
<tr>
<td>Median (range) laparoscopic task score</td>
<td>99 (88-100)</td>
<td>93 (80-100)</td>
<td>P&lt;0.001</td>
</tr>
<tr>
<td>No. math questions/min</td>
<td>9 (6-12)</td>
<td>7 (5-11)*</td>
<td>P&lt;0.001</td>
</tr>
<tr>
<td>No. correct math questions/min</td>
<td>8 (5-12)</td>
<td>6 (4-10)*</td>
<td>P&lt;0.001</td>
</tr>
</tbody>
</table>

Wilcoxon matched-pairs signed rank test
*p<0.05 statistically significant from baseline
3.6 Discussion

MIS is gaining popularity in veterinary medicine for the patient-derived benefits associated with small incisions\textsuperscript{11}. MIS improves the standard of care that veterinary patients receive as evidenced by shorter hospitalization time, reduced recovery time, reduced post-operative pain, and reduced surgical site infections when compared to traditional open surgery\textsuperscript{17,19–21}. However, accompanied with MIS is a unique set of technical challenges presented to the veterinary surgeon. A loss of depth perception, difficulties with bimanual coordination, loss of tactile feedback, and counterintuitive instrument movements\textsuperscript{22} are among the cited complexities that make MIS more stressful and cognitively demanding than open surgery\textsuperscript{23}. In the context of veterinary surgery where there are unavoidable and frequent sensory and cognitive distractions, it is important to investigate the impact of distraction on an already complex task.

To the authors’ knowledge this is the first study to investigate the impact of distraction on simulated MIS performance in veterinary medicine. Consistent with our hypothesis, cognitive distraction negatively impacted laparoscopic skills performance in this cohort of veterinary students. Sensory distraction however, enhanced surgical performance in the same cohort of veterinary students.

In the sensory-distracted group, laparoscopic task performance increased significantly in the presence of background noise. In a similar study by Moorthy et al.\textsuperscript{1} involving human surgeons, performance on a laparoscopic transfer task, as measured by economy of motion and error scores, did not decrease significantly in the presence of background OR noise, nor did performance increase. In the same study, in addition to the transfer of sponge pieces from one plate to another, participants were expected to position sponge pieces in a specific orientation and location on each plate. Perhaps a significant improvement in performance on the
A laparoscopic task would not have been observed in the present study, had a more challenging simulator task been presented to participants in the face of sensory distraction. Previous studies have also found that background noise and music have no impact on the performance of a simulated surgical task in medical students, surgical residents, and/or experienced surgeons.

Furthermore, the validated laparoscopic task score system used in the present study is based solely on quality metrics, whereas the 2 previously cited studies used a combination of both quality and efficiency-based performance metrics (e.g. total path length and number of hand movements). Use of the latter may have been more sensitive to errors in this cohort of veterinary students. Additionally, in the present study, only pegs dropped outside the FOV were directly applied to an error score, despite the fact that pegs dropped inside the FOV subjectively increased in the presence of distraction. These seemingly insignificant errors observed in a simulated environment could have potentially more severe consequences in the OR, such as inadvertent damage to vasculature and/or organs.

Despite the fact that dog barks and monitor alerts were played in a random order on each soundtrack, it is possible that the sounds became redundant over the course of 5 blocks. Perhaps participants became accustomed to the selected noises and were able to anticipate their occurrence on successive trials. This would imply that background noise did not function as an adequate distraction throughout the course of this study. Perhaps a louder noise would have been a more effective distraction; however, the 75dB level used here already far exceeds the recommended 45dB limit for working environments, and is consistent with the noise level sampled across various human surgical ORs. Therefore, a slight increase in noise level would not likely produce a measurable difference. Additionally, in the context of a safe and controlled simulation lab, participants naturally responded differently than they would in a more realistic
OR setting. Sensing this disparity, it would be expected for participants to “tune out” noise in an effort to focus on the primary laparoscopic task.

Exactly why individuals improved on a laparoscopic task in the face of a sensory distraction is unclear, and the authors question the clinical relevance of this finding, given the minimal extent of overall improvement on the laparoscopic task. The authors acknowledge the possibility that individuals improved with practice on successive attempts at a simple laparoscopic task. However, we believe that our rigorous study design accounted for this potential learning effect by incorporating a pre-study stabilization period within which participants were required to repeat the task until consistent scores (within 10%) were achieved on 5 consecutive trials. In previous studies such as Hsu et al.\textsuperscript{6}, 3 consecutive, consistent trials was deemed appropriate to overcome the learning effect on the same laparoscopic task.

Participants randomized to the cognitive distraction answered significantly fewer math questions in total, and correctly during a simultaneous laparoscopic task. Furthermore, participants scored significantly lower on the laparoscopic task when presented with concurrent math questions. A similar study by Hsu et al.\textsuperscript{6} reported reduced performance by surgical residents on a mental arithmetic task when performed simultaneously with the FLS peg transfer task. Scores on the laparoscopic task, however, did not decline in the dual-task condition\textsuperscript{6}.

Likewise, a concurrent arithmetic exercise had no impact on the performance of an anterior segment surgery task in a virtual reality simulator in expert and novice ophthalmic surgeons in a study by Park et al\textsuperscript{3}. However, the rate of correctly answered addition questions was significantly lower in the dual-task state, regardless of experience level. Participants in both of the aforementioned studies\textsuperscript{3,6} likely perceived the simulated surgical task as more important than arithmetic questions, given the surgical nature of the study, and their extensive backgrounds in
surgery. Consequently, it appeared the surgical task was prioritized over the arithmetic distraction. In contrast, participants in the present study were veterinary students with basic introductory open surgical training at most, and no laparoscopic experience. Rather than focus exclusively on 1 task, it is likely that participants divided their attention between tasks to the detriment of both.

In line with our findings, Goodell et al. reported a significant increase in the time it took medical students and surgical residents to complete 5 Minimally Invasive Surgical Trainer-Virtual Reality (MIST-VR) simulator exercises when mental arithmetic questions were posed concurrently. In another study, the performance of both medical students and residents on the da Vinci surgical system was adversely affected by distractions, which included mental arithmetic questions. Similarly, Moorthy et al. found significant reductions in the performance of a simulated laparoscopic task in human surgeons when presented with simultaneous arithmetic questions, among other distractions. It is noteworthy that the above studies did not attempt to quantify the arithmetic distraction.

The main difference between the cognitive and sensory distraction used in this study was that the cognitive distraction required a response from participants. Perhaps this discrepancy offers 1 reasonable explanation for the adverse effects that mental arithmetic, but not background noise, had on simulator performance in this cohort of veterinary students. In cognitive psychology, the concurrent performance of 1 or more tasks is termed dual- or multi-tasking. Evidence suggests that both tasks in a dual-task state compete for a limited pool of cognitive resources. This manifests clinically into decreased performance on 1 or both tasks, depending on the difficulty of the task and individual factors like surgical experience.

Several limitations of this study are acknowledged. We recruited a convenience sample
of novice veterinary students and therefore the results of this study cannot be extended to board certified surgeons that are experienced with MIS, as it has been demonstrated elsewhere that the burden of distraction decreases with increased MIS surgical experience\textsuperscript{6,25}.

Furthermore, this study took place in a controlled, clinical setting (Endoscopic Skills Laboratory) with 2 isolated distraction events. In reality, the OR is a complex environment\textsuperscript{1,26} that is inundated with distractions from a multitude of sources. Moreover, these distractions are often random, unanticipated events. That being said, simulation is likely the only platform available to pursue research in this area, since ethical considerations prohibit the intentional introduction of distractions into the OR\textsuperscript{4,10}. Essentially, simulation offers a means to identify individual distractions that pose an exceptional challenge to surgical performance, since simulator performance translates to performance in the OR\textsuperscript{14,17}.

Another limitation of this study was the simplicity of the laparoscopic task evaluated. In reality, MIS procedures in the OR are much more complex and demand a highly advanced set of skills. Furthermore, the surgeon is required to operate as part of a team, often under a time constraint\textsuperscript{1}. We felt that the laparoscopic task, a basic psychomotor skills test, was appropriate and practical for the purposes of this study involving novice veterinary students without prior MIS experience. One could argue that arithmetic is an irrelevant cognitive distraction that does not typically occur in the OR\textsuperscript{10}. In this study, mental arithmetic was not intended as a surrogate for OR distraction, but rather served as a quantifiable and objective measure of cognitive burden in a single- and dual-task scenario. Similar studies report cognitive distraction in the form of random conversation and questions about previously presented patient cases\textsuperscript{2,10}. While highly relevant, these distractions are difficult to quantify and standardize among participants with varying levels of veterinary experience and knowledge. We believe that mental arithmetic serves
as an appropriate cognitive distraction, thereby making the reasonable assumption that veterinary students enrolled at the same institution have similar cognitive processing skills for mental arithmetic. The difficulty of arithmetic questions was set to a moderate level. Here, moderate difficulty level referred to double-digit addition questions, which included questions that required one to “carry a digit” (e.g. 23+48). In terms of difficulty level, it was imperative to maintain realistic expectations, considering the questions were to be solved by mental arithmetic. The authors’ believe that the moderate difficulty level achieved was suitable, given that participants expressed feeling challenged, but not discouraged by the task.

In reality it is impractical to eliminate all sources of distraction from the OR, as some so-called distractions are necessary to ensure patient safety. For example, the surgical team must remain attentive to anesthesia monitors, and conversations pertinent to the surgical procedure throughout the course of an operation. On the other hand, irrelevant distractions that adversely effect surgical performance should be limited or moderated appropriately. Perhaps in the future, predictable OR distractions will be incorporated into surgical simulation training so that surgeons first learn to manage these adverse events in a safe and controlled environment.

Further studies are warranted to investigate the impact of single and cumulative distraction events on surgical performance in more experienced surgeons, and on more complex simulated tasks. Moreover, it remains to be determined whether a decline in surgical performance translates negatively to patient outcome.

3.7 Disclosure

The authors declare no conflict of interest related to this report.
3.8 References


Chapter 4 - General Discussion
Chapter II

In chapter II we observed no difference in the performance of laparoscopic skills between veterinary students in years 1-4 of the DVM program, and no association between prior open surgery skills or VG experience and laparoscopic skills. Craft experience appeared to be the only significant predictor of laparoscopic skills in veterinary students.

Since male medical students tend to achieve higher scores initially on laparoscopic surgical simulators compared to females\(^1\), the authors decided to include this variable in the preliminary univariate linear regression analysis. However, no gender effects were observed and it was subsequently removed from the final multivariable model. The unequal distribution of female to male participants (3:1) in part II might explain the absence of a gender effect. Perhaps in a more equally distributed population, gender would have been a significant predictor of laparoscopic skill. However, it should be noted that the proportion of male and female participants in this study accurately reflects the demographics of veterinary graduates from the United States in 2013\(^2\). The demographic shift that has occurred in veterinary medicine from a predominantly male profession to one dominated by females requires one to consider how gender differences impact the learning process\(^1\). Furthermore, the current one-size fits all approach to the design of laparoscopic instruments and equipment may not be the most appropriate from an ergonomics standpoint if it hinders learning\(^3\). It has previously been established that round-handed instruments require significantly more muscle activation than
axial-handled instruments, and it would be interesting to add gender to this analysis since hand sizes and muscular strength differ between males and females\textsuperscript{3}.

It is also likely that the voluntary nature of recruitment led to a homogenous sample of veterinary students that shared an interest in surgery, and had similar psychomotor, manual dexterity, and visuospatial abilities. Ideally, testing all veterinary students at OVC would have eliminated this selection bias and offered a more heterogeneous sample of participants, but this was not feasible. In hindsight, it also would have been worthwhile to collect information on each participants’ interest in the surgical specialty to confirm this as source of bias. Furthermore, dependence on veterinary students to accurately self-report their prior nonsurgical experiences on a VAS was subjective and likely resulted in overestimates of performance, which has been reported elsewhere\textsuperscript{22}.

The fact that prior video game experience did not enhance laparoscopic skills in a simulator was unexpected. The underlying theory behind the use of video games to support laparoscopic skill development is derived from the idea that user interaction with a 2D computer interface establishes a sense of depth perception and visuospatial abilities\textsuperscript{4–6}. This scenario accurately replicates the demands of laparoscopic surgery in the OR environment. That being said, individuals interact with a multitude of technologies on a daily basis that could be interpreted as VG experience (i.e. television, computer, cell phone). Therefore, self-reported VG experience was likely an underestimate of exposure to all sources of computer interfaces. In addition, survey responses are inherently subject to recall bias. Rather than relying on participants to accurately document prior VG experience, an alternative would have been to verify VG skills on a VG console, as reported by Millard et al.\textsuperscript{7}. One could make a case that
surgeons today are more adequately prepared for the challenges of laparoscopy given society’s dependence on technology.8

Chapter III

For chapter III, participants’ performance of a simple peg transfer task within the FLS simulator improved in the presence of a sensory distraction, but was negatively impacted by a concurrent cognitive distraction. These results accurately reflected participant opinions on how burdensome each distraction felt while performing the primary peg transfer task concurrently. Approximately 90% of those randomized to the cognitive distraction and only 10% of those randomized to the sensory distraction felt burdened by the distraction (Appendix I). We decided to use anesthesia monitor alarms and dogs barking as the sensory distraction, and double-digit addition questions as the cognitive distraction. Although not directly encountered in the OR, there seems to be consensus in the human literature that arithmetic problems function as adequate cognitive distractions that can be objectively measured and standardized9–12. One of the main reasons for the selection of arithmetic problems as the cognitive distraction for this study was the ability to compare results with similar human studies. Furthermore, arithmetic questions were easily quantified, which allowed us to measure performance on both the primary, and the secondary distraction task in a dual task condition. Alternatively, questions related to a veterinary case study were contemplated for the cognitive distraction, but the authors felt that veterinary experience and knowledge would introduce a significant source of bias.

It is important to keep in mind that although technical skills are a mandatory component of a laparoscopic surgeon’s repertoire, they are by no means comprehensive. Non-technical skills such as communication, compassion, reasoning and judgment, knowledge of anatomy, etc. are
equally important to the surgical craft\textsuperscript{13}. Therefore, technical skills should not be used as the only measure of surgical competence. Instead, the performance of laparoscopic technical skills should be judged as one component of a broader surgical skill-set.

One must acknowledge that surgical simulators are not substitutes for OR training, nor are they all encompassing in terms of the complex, unpredictable challenges encountered in the OR\textsuperscript{14}. Without a doubt, the highest quality laparoscopic skills training occurs in the OR\textsuperscript{15}. That being said, simulators serve as valuable tools for technical skills training because they remove the novice surgeon from the OR at a time when they are most prone to making amateur mistakes\textsuperscript{16}. Moreover, simulators provide a platform for the performance of new or rare procedures, and allow for the maintenance of technical skills. Additionally, laparoscopic simulators are ideally suited for the repetitive, deliberate, goal-directed practice that is necessary for novices to acquire a basic technical skill set\textsuperscript{17}. Importantly, an increasing body of evidence suggests that training on validated surgical simulators translates to improved performance in the OR\textsuperscript{17}. All of these factors contribute to enhanced patient safety in the OR, which is the ultimate goal of any training program.

Laparoscopic surgery is currently the “gold standard” approach in human, but not veterinary medicine. MIS and laparoscopy are projected to become the standard of care in the future of veterinary medicine as well\textsuperscript{18}, however, more randomized controlled trials comparing clinical outcomes of conventional surgery to MIS are warranted. Furthermore, the lack of highly powered, multi-institutional studies on the value of simulation for training laparoscopic surgery in veterinary medicine needs to be addressed.

To date, much of our knowledge in the veterinary field is drawn from the human literature. Despite the fact that human medicine has positively shaped many of the ways in which
we treat veterinary patients and understand disease processes, it is necessary to verify the results in a veterinary-specific context. Therefore, it is justifiable and absolutely necessary to recreate human studies and modify them to serve the needs of veterinarians. An important consideration is the wide variety of animal species that veterinary surgeons must treat. In some instances, the abdominal cavities of veterinary patients are much smaller than the typical human patient, underscoring the importance of proficient and precise instrument movements in a confined space. Thus, the repetition of human simulation studies is useful to verify that the dimensions of simulators like the FLS box trainer are equally suitable for training veterinarians. Furthermore, the development of new surgical simulators is expensive, not to mention time consuming. Therefore, from an efficiency standpoint it only seems logical to investigate existing human simulation systems in order to determine their applicability to veterinary medicine. Of course higher fidelity systems that incorporate human anatomy need to be revamped for the purposes of veterinary medicine. Ultimately, collaboration between the human and veterinary fields should be encouraged, and overlapping results should be favoured, to further validate existing knowledge.

Chapter II and III studies were conducted solely at the OVC and therefore participants were comprised of a convenience sample of years 1-4 veterinary students. Unless veterinary students obtain extra-curricular surgery experience, official live animal surgical experience does not begin until third year of the DVM program at OVC, and this training is restricted to conventional open surgery. Junior surgery involves 5-6 spay or neuter procedures on humane society dogs and cats, performed in groups of three. Students rotate every procedure so that they have the opportunity to experience all three of the following roles: 1) anesthesiologist, 2) primary surgeon, and 3) assistant surgeon. Training is largely dependent upon the availability of
humane society animals. The fourth year of the DVM program is comprised of clinical rotations exclusively, and therefore surgical experience varies according to individual interests, and clinical placements. As such, it is debatable whether third and fourth year veterinary students at OVC obtain sufficient surgical experience in their undergraduate education to solidify an “expert” open surgery skill-set. Future studies on surgical residents and board certified surgeons with extensive open surgery experience are necessary before a lack of association between prior open surgery experience and laparoscopic skills performed in a simulator is confirmed in veterinary medicine. That being said, a lack of association would be anticipated in a more experienced subset of individuals as well, based on previously published data in both the human and veterinary fields

Despite the need to evaluate a more experienced group of surgeons, the assessment of laparoscopic skills in veterinary students is particularly relevant to the veterinary field and validates this research. Where human medical students that intend to specialize in surgery are required to pursue post-graduate education, the majority of veterinary school graduates (~70%) choose to delve directly into private practice. A DVM graduate interested in laparoscopy can purchase the necessary equipment and practice any number of laparoscopic techniques without attaining further credentials or certification. Although educational courses in laparoscopy are available to general veterinary practitioners, the courses are not mandatory and the amount of material that can be learned and retained over a few days is questionable. The projection that MIS will become the future “gold standard” surgical approach in veterinary medicine underscores the need to make laparoscopic-specific skills training available to veterinarians that wish to incorporate these challenging techniques into their practice. However, the most effective and efficient method of training remains to be determined since the current research was not
designed to investigate the outcomes of simulation training. Perhaps investigating the effects of simulator training and skills retention in both novices and experienced veterinary surgeons is an appropriate place to begin future research.

**Future Directions**

Recently, a team of board certified veterinary surgeons at Washington State University developed the Veterinary Applied Laparoscopic Simulator (VALS), which is modeled after the FLS system. VALS consists of 5 simulator-based tasks (peg transfer, pattern cut, loop placement, extra- and intracorporeal suturing) scored on the basis of time and accuracy. Veterinary teaching institutions across North America, including OVC, have been designated as future VALS testing centers in an effort to establish a certification program that will hopefully encourage veterinarians interested in laparoscopic surgery to engage in basic technical skills training. Initial studies using the VALS system would ideally assess an expert group of surgeons with extensive open surgery experience to fully evaluate the relationship between prior open surgery experience and laparoscopic skills performance. These results could subsequently be compared to the scores obtained by a group of board certified veterinary surgeons with expertise in the performance of laparoscopic techniques. In addition, a proficiency-based training program specific to veterinarians could be developed using expert laparoscopic surgeon scores, as has been demonstrated successfully in human medicine.

In an effort to provide proof of simulator construct validity a database could be developed whereby VALS scores of veterinary students and residents from multiple institutions are recorded at the start of their training, and every year thereafter. This database might reveal important information about short and long term performance trends in addition to laparoscopic skills retention following simulator practice. Specifically, improvement on VALS scores over
time and high correlation with FLS scores would support VALS construct validity in veterinarians. An added advantage of this system would be the exposure of veterinary students to the unique challenges of laparoscopic surgery early in their education.

A natural progression would require validation of GOALS or a similar objective, standardized, veterinary specific OR evaluation tool. A device like GOALS is necessary to confirm the transfer of training from the skills lab to the OR in order to justify the use of VALS for technical laparoscopic skills training in veterinarians. Repeated trials would be required to demonstrate reliability and validity of the assessment tool on the performance of multiple laparoscopic procedures, perhaps starting with some of the most commonly performed procedures in private practice (i.e. laparoscopic ovariohysterectomy and laparoscopic prophylactic gastropexy). Similar performance scores on two separate occasions and by two different raters would help establish intra-rater and inter-rater reliability, respectively. Furthermore, a high correlation between performance in the OR and prior surgical experience or another valid OR assessment tool could be used to support validity. Once a sufficient evidence-base was established for the use of this OR evaluation tool, a series of randomized controlled trials would be necessary. To identify the impact of VALS training on OR performance, perhaps one could randomize a group of novice veterinarians to VALS training plus traditional clinical curriculum training, versus a control group of novices receiving the latter training only.

In addition to improved OR performance, the ultimate test of simulator efficacy would require evidence of a significant positive correlation between proficient performance on a VALS and improved patient outcomes, which could be measured by the incidence of SSIs for example. Accurate and detailed patient follow-up data would need to be recorded and documented in order to verify this relationship.
Following validation of VALS and an intraoperative evaluation tool, the research opportunities are endless. For example, veterinarians could begin to investigate the use of VALS exercises as “warm-up” prior to laparoscopy in the OR. Moreover, investigation into the effects of sleep deprivation or caffeine intake on VALS performance would be possible and ethical to study in a skills lab setting. One could use VALS tasks to expand the investigation of OR distractions to include a more experienced group of surgeons that might manage interruptions and disturbances differently than a novice group. It would also be possible to introduce different audio, visual, cognitive, and technical distractions to the skills lab environment in order to explore the individual and combined impact of each disturbance on laparoscopic skills performance. Perhaps in the future, exercises such as cautery, cannulation, and camera navigation could be incorporated into the box trainer for additional relevant practice. Since a laparoscopic surgeon relies on other OR personnel for assistance, it might also be useful to develop team training exercises whereby one individual performs basic VALS training tasks while the other navigates the camera to establish optimal visualization for their partner. Conceivably, communication skills would also be improved upon in the process.

Moreover, one could take the opportunity to further explore the hypothesis that manual dexterity and visuospatial abilities are significantly correlated with laparoscopic technical skills at baseline. One could begin to investigate this hypothesis by using participants as their own controls and correlating baseline VALS scores with performances on validated measures of manual dexterity (i.e. Purdue Pegboard test) and visual spatial abilities (Purdue 3D Spatial Rotations test). This information could offer insight into the types of daily activities that enhance laparoscopic technical skills performance, and could further help to identify individuals that might benefit from remedial skills training.
Finally, as veterinarians begin to experiment with even less invasive laparoscopic techniques, it would be interesting to investigate whether or not VALS or another box trainer could be modified to create a single instrument port to practice single incision laparoscopic surgery (SILS) during basic and more advanced surgical exercises. From here, it would be interesting to compare surgeons’ upper and lower body muscle activity, hand movements, and perceived mental workload in novices and experts as they engage in open, laparoscopic, and SILS tasks in a box trainer. One could attempt to differentiate the physical and mental burden presented by each of the three surgical techniques using different instrument designs and further, how each affects surgical performance differently based on gender and experience level.

References

Appendix A

Chapter II participant consent form

ONTARIO VETERINARY COLLEGE
Department of Clinical Studies

CONSENT TO PARTICIPATE IN RESEARCH

Research Project Title: Evaluation of Laparoscopic Skills in Doctor of Veterinary Medicine Students

Investigators:
Dr. Ameet Singh, Assistant Professor, Department of Clinical Studies, Ontario Veterinary College, University of Guelph.
Jessica Kilkenny, MSc Candidate, Department of Clinical Studies, Ontario Veterinary College, University of Guelph

Purpose of the Study:
To evaluate whether laparoscopic skills, assessed using a validated training device, are associated with year of training and veterinary surgical experience.

Procedures:
If you chose to participate in this research project we ask that you:
Perform three laparoscopic skills on a training device
Fill out the accompanying survey

Testing will take place in the Endoscopic Skills Laboratory located in the Department of Clinical Studies, Ontario Veterinary College, room 2132. We expect ~ 15 minutes is required to complete all three laparoscopic exercises.

Once you have read this form and completed the survey, your answers to the survey questions and your scores on the laparoscopic skills test will be incorporated into this study.

Potential Risks and Discomforts:
We do not anticipate any risks or discomforts from enrolment into this study.

Potential Benefits to the Participant and/or Society:
Minimally Invasive Surgery (e.g. laparoscopy) is gaining tremendous popularity in veterinary medicine and has recently been incorporated as a requirement in the training of veterinary surgical residents. Further evaluation of laparoscopic skills training is required in veterinary
medicine. Results of this study will be reported in the veterinary literature and contribute to this relatively new area of research.

**Payment for Participation:**
There is no payment for participating in this study.

**Confidentiality:**
Your identity will not be attached to the results in an effort to ensure confidentiality. Furthermore, results will be presented in an aggregate format that will not identify any one person.

**Participation and Withdrawal:**
You can choose whether to be in this study or not. If you volunteer to be in this study, you may withdraw at any time without consequences of any kind. You may exercise the option of removing your data from the study. You may also refuse to answer any questions you don’t want to answer and still remain in the study. The investigator may withdraw you from this research if circumstances arise that warrant doing so.

**Rights of Research Participants:**
You may withdraw your consent at any time and discontinue participation without penalty. You are not waiving any legal claims, rights or remedies because of your participation in this research study. This study has been reviewed and received ethics clearance through the University of Guelph Research Ethics Board. If you have any questions regarding your rights as a research participant, contact:

Director, Research Ethics Officer  
University of Guelph  
437 University Centre  
Guelph, ON N1G 2W1  
Telephone: (519) 824-4120, ext. 56606  
Fax: (519) 821-5236  
Email: sauld@uoguelph.ca

**Questions:**
If you have any questions regarding this research project or this consent form, please contact Dr. Ameet Singh at (519) 824-4120, ext. 54292 or by email at amsingh@uoguelph.ca

**Research Participant:**
I have read the information provided for the study, “Evaluation of Laparoscopic Skills in Doctor of Veterinary Medicine Students” as described herein. My questions have been answered to my satisfaction, and by completing the accompanying survey I agree to participate in the study.
Appendix B

Chapter II participant survey
I have watched the instructional videos pertaining to the three tasks to be performed.

Please circle the appropriate response

Level of Training: 1  2  3  4  Intern  Resident  ACVS Diplomat

Gender:  M  F

Age:  20-30  31-40  41-50  >50

Dominant Hand:  L  R  Ambidextrous

Anticipated Future/Current Focus:  Small animal  Mixed  Large animal

Perceived hand-eye coordination:  1 poor  2  3  4  5 excellent

Do you have experience with woodworking, machine/metal working, leathery work, drills/saws, etc?
None  Some  A lot

Do you have experience with sewing, needlepoint, mini-constructs, detailed craft making?
None  Some  A lot

Do you have experience building anything that you feel enhances your hand skill? i.e. home, boat
Yes  No

If yes, what? ________________

Please place a mark on the line to indicate your level of experience

Videogame Experience:

0mm – have never played videogames
50mm – played videogames 0-3 hours per week for >1 year
100mm – played videogames >3 hours per week for a minimum of 8 years

Veterinary Surgery (VS) Experience:
0mm – none
50mm – have performed a total of 5-10 minor surgical procedures (e.g. canine castration, and/or canine/feline ovariohysterectomy as the primary surgeon) in the last 5 years.
100mm – have performed >50 canine or feline minor or major surgical procedures (e.g. exploratory laparotomy, enterotomy, intestinal resection and anastomosis) as the primary surgeon in the last 10 years.

Videoendoscopic Surgery (VES) Experience:

0mm – none
50mm – have performed 5-10 VES procedures as the primary surgeon
100mm – perform regular (weekly to monthly) VES procedures as the primary surgeon

You have now completed the survey! If you are an ACVS resident/diplomat please continue

Year(s) of Experience Performing Videoendoscopic (VES) Surgery:

0 up to 1 year up to 2 years up to 3 years

Estimated Number of laparoscopic/thoracoscopic procedures (more than just camera-driving) performed total: ________________

Estimated Number of laparoscopic/thoracoscopic procedures (more than just camera-driving) performed over the last 3 years: ________________

Thank you for your participation!
Appendix C

Chapter II percent deviation calculation for pattern cut task

1. Cut excess material that deviates from the circular pattern
2. Place excess material on mm graph paper and determine the surface area of all squares covered by the material
   a. \( l \times w = \_ \text{cm}^2 \)
3. Calculate the area of each circle
   a. \( = \pi r^2 \)
   b. \( = \pi (2\text{cm})^2 \)
   c. \( = 12.56\text{cm}^2 \)
4. Divide the surface area covered by the material by the surface area of the circle
   a. Surface area of square / surface area of circle
Appendix D

Chapter II linear regression models constructed in STATA for individual MISTELS tasks

Table 1: Predictors of task 1 performance

| test_1  | Coef.  | Std. Err. | t     | P>|t|  | [95% Conf. Interval] |
|---------|--------|-----------|-------|-------|----------------------|
| _Level_2 | 0.6931678 | 4.054441 | 0.14  | 0.087 | -8.904924 - 10.29126 |
| _Level_3 | 1.448741 | 5.951604 | 0.29  | 0.775 | -8.539177 - 11.43666 |
| _Level_4 | 0.7328282 | 6.582826 | 0.11  | 0.912 | -12.28339 - 13.74745 |
| VG      | 0.0504866 | 0.0536121 | 0.94  | 0.348 | -0.6555141 - 0.1564073 |
| VS      | -0.0345737 | 0.1068973 | 0.32  | 0.746 | -0.2455332 - 0.1763858 |
| _cons   | 62.43831  | 4.085275 | 15.28 | 0.000 | 54.35901 - 70.5176 |

Table 2: Predictors of task 2 performance

| test_2  | Coef.  | Std. Err. | t     | P>|t|  | [95% Conf. Interval] |
|---------|--------|-----------|-------|-------|----------------------|
| _Level_2 | 4.875085 | 4.28604 | 1.14  | 0.257 | -3.602044 - 13.35222 |
| _Level_3 | -1.219639 | 4.537419 | -0.27 | 0.788 | -10.19207 - 7.752794 |
| _Level_4 | 1.038502 | 5.821849 | 0.18  | 0.859 | -10.4738 - 12.55081 |
| VG      | 0.060503 | 0.0476959 | 1.69  | 0.094 | -0.0136123 - 0.1748164 |
| VS      | 0.0829037 | 0.0946559 | 0.88  | 0.383 | -0.1042718 - 0.2709792 |
| _Icraft_2 | -21.84937 | 5.427691 | -4.03 | 0.000 | -32.58226 - 11.11649 |
| _Icraft_3 | -16.34231 | 5.346079 | -3.06 | 0.003 | -26.91382 - 5.770869 |
| _cons   | 30.19478 | 6.144934 | 4.90  | 0.000 | 17.95359 - 42.25596 |

Table 3: Predictors of task 3 performance

| test_3  | Coef.  | Std. Err. | t     | P>|t|  | [95% Conf. Interval] |
|---------|--------|-----------|-------|-------|----------------------|
| _Level_2 | 4.871242 | 7.468431 | 0.65  | 0.515 | -9.855174 - 19.63766 |
| _Level_3 | 7.124978 | 7.771762 | 0.92  | 0.361 | -8.241176 - 22.49113 |
| _Level_4 | 10.42004 | 10.12751 | 1.03  | 0.305 | -9.603838 - 30.44393 |
| VG      | -0.0356634 | 0.0824889 | -0.43 | 0.666 | -0.1987428 - 0.1274519 |
| VS      | -0.356242 | 0.164151 | -2.14 | 0.034 | -0.6751799 - 0.026685 |
| _cons   | 41.61288 | 6.286627 | 6.62  | 0.000 | 29.10831 - 54.04266 |
Appendix E

Chapter II survey data

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<th>Participant Characteristic</th>
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Appendix F

Chapter II self-reported previous experiences

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<td>Open surgery experience (VS)</td>
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<tr>
<td>Videoendoscopic surgery experience (VES)</td>
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Appendix G

Chapter III participant consent form

ONTARIO VETERINARY COLLEGE
Department of Clinical Studies

CONSENT TO PARTICIPATE IN RESEARCH

Research Project Title: The Effect of Distraction on Laparoscopic Skills in Veterinarians and Veterinary Trainees

Investigators:
Dr. Ameet Singh, Assistant Professor, Department of Clinical Studies, Ontario Veterinary College, University of Guelph.
Jessica Kilkenny, MSc Candidate, Department of Clinical Studies, Ontario Veterinary College, University of Guelph
Victoria Mrotz, Student Veterinarian Class of 2018, Ontario Veterinary College, University of Guelph

Purpose of the Study:
To examine the influence of expertise on a simple laparoscopic task performed concurrently with distractions.

Procedures:
If you chose to participate in this research project we ask that you:
Perform a laparoscopic task on a training device
Fill out the accompanying survey

Testing will take place in the Endoscopic Skills Laboratory located in the Department of Clinical Studies, Ontario Veterinary College, room 2132. We expect the procedure to take ~1 hour.

Once you have read this form and completed the survey, your answers to the survey questions and your scores on the laparoscopic skills test will be incorporated into this study.

Potential Risks and Discomforts:
We do not anticipate any risks or discomforts from enrolment into this study.

Potential Benefits to the Participant and/or Society:
There are no direct benefits associated with participation in this study.

Payment for Participation:
There is no payment for participating in this study.
Confidentiality:
Every effort will be made to ensure confidentiality of any identifying information that is obtained in connection with this study. Only the graduate student and summer student will have access to identifying information. This information will be stored on password-protected computers and will be destroyed once the research is completed (approximately 1 year). You will be assigned an Identification Code. Results will be presented in an aggregate format that will not identify any one person.

Participation and Withdrawal:
You can choose whether to be in this study or not. If you volunteer to be in this study, you may withdraw at any time without consequences of any kind. You may exercise the option of removing your data from the study. You may also refuse to answer any questions you don’t want to answer and still remain in the study. The investigator may withdraw you from this research if circumstances arise that warrant doing so.

Rights of Research Participants:
You may withdraw your consent at any time and discontinue participation without penalty. You are not waiving any legal claims, rights or remedies because of your participation in this research study. This study has been reviewed and received ethics clearance through the University of Guelph Research Ethics Board. If you have any questions regarding your rights as a research participant, contact:

Director, Research Ethics
(519) 824-4120, ext. 56606
reb@uoguelph.ca

Questions:
If you have any questions regarding this research project or this consent form, please contact Dr. Ameet Singh at (519) 824-4120, ext. 54292 or by email at amsingh@uoguelph.ca

Research Participant:
I have read the information provided for the study, “The Effect of Distraction on Psychomotor Skills in Veterinarians and Veterinary Trainees” as described herein. My questions have been answered to my satisfaction, and by signing on the line below I agree to participate in the study.

____________________________________
Participant Signature

____________________________________
Date
Appendix H

Chapter III participant survey

I have watched the instructional video pertaining to the task that will be performed

Please circle the appropriate response

Level of Training: DVM student Intern Resident Board Certified Specialist

If intern or resident:

Years since graduation from DVM program _____________

If board certified specialist:

Certification title (i.e. ACVS, ACVR) _____________

Years since board certification _____________

Gender: M F

Age: _____________

Dominant Hand: L R Ambidextrous

Do you have any prior surgery experience? Yes No

If yes, how many years? _____________

Do you have any prior experience performing laparoscopic surgery? Yes No

If yes, how many years? _____________

Do you have any prior experience with MISTELS? Yes No

If yes, how many years? _____________

Do you regularly partake in activities that require a high level of focus/discipline? (i.e. puzzles, playing chess, playing a musical instrument) Yes No

If yes, how many years? _____________

Do you regularly partake in sports that require a high level of manual dexterity/bimanual coordination? (i.e. tennis, racquet ball, squash, baseball) Yes No
If yes, how many years? ________

There is value in simulation training in veterinary medicine:

Strongly disagree  Disagree  Neutral  Agree  Strongly Agree

I would make use of simulation training if it was accessible to me:

Strongly disagree  Disagree  Neutral  Agree  Strongly Agree

How many hours have you played video games in the last (estimate to nearest hour)

_____________ week
_____________ month
_____________ year
_____________ 5 years

What video game consoles have you played in the past?

a. XBox  yes  no
b. Nintendo Wii  yes  no
c. PlayStation  yes  no
d. Other __________________________

What video game consoles do you currently use the most?

XBox  Nintendo Wii  PlayStation  None

Other ____________

Of the disciplines below, which do you have more interest in?

a. Internal medicine  b. Surgery  c. Other ______________

Do you have experience with woodworking, machine/metal working, leathery work, drills/saws, etc?

None  Some  A lot
Appendix I

Chapter III survey data

<table>
<thead>
<tr>
<th>Participant Characteristic</th>
<th>Sensory Distraction</th>
<th>Cognitive Distraction</th>
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<tbody>
<tr>
<td>Age (years) *</td>
<td>25 (21-34)</td>
<td>24 (22-33)</td>
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<tr>
<td>Sex</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Male</td>
<td>7</td>
<td>6</td>
</tr>
<tr>
<td>Female</td>
<td>13</td>
<td>15</td>
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<tr>
<td>Dominant hand</td>
<td></td>
<td></td>
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<tr>
<td>Right</td>
<td>4</td>
<td>21</td>
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<tr>
<td>Left</td>
<td>16</td>
<td>0</td>
</tr>
<tr>
<td>Open surgery experience</td>
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<td></td>
</tr>
<tr>
<td>Yes</td>
<td>3</td>
<td>5</td>
</tr>
<tr>
<td>No</td>
<td>17</td>
<td>16</td>
</tr>
<tr>
<td>Focus</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Yes</td>
<td>13</td>
<td>10</td>
</tr>
<tr>
<td>No</td>
<td>7</td>
<td>11</td>
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<tr>
<td>Prior participation in sports</td>
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<td></td>
</tr>
<tr>
<td>Yes</td>
<td>5</td>
<td>8</td>
</tr>
<tr>
<td>No</td>
<td>15</td>
<td>13</td>
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<tr>
<td>Prior MISTELS experience</td>
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<td>5</td>
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<td>14</td>
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<td>Interest in veterinary specialty</td>
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<tr>
<td>Surgery</td>
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<td>Internal Medicine</td>
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<td>A lot</td>
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<td>Craft experience</td>
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<td>2</td>
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<td>Most distracting condition</td>
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<td>Math</td>
<td>17</td>
<td>16</td>
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<tr>
<td>Noise</td>
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<td>2</td>
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</table>

*median (range)
Appendix J

Chapter III performance data

Performance on Primary Peg Transfer Task

<table>
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<tr>
<th>Condition</th>
<th>Median Peg Transfer Score (Range)</th>
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<tbody>
<tr>
<td>Baseline</td>
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<tr>
<td>Sensory distraction</td>
<td>97(70-100)</td>
</tr>
<tr>
<td>Cognitive distraction</td>
<td>99(88-100)</td>
</tr>
<tr>
<td>Concurrent Distraction</td>
<td></td>
</tr>
<tr>
<td>Sensory distraction</td>
<td>98(72-100)</td>
</tr>
<tr>
<td>Cognitive distraction</td>
<td>93(80-100)</td>
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</table>

Performance on Secondary Cognitive Distraction Task

<table>
<thead>
<tr>
<th>Conditions</th>
<th>Median Number of Math Questions (Range)</th>
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<td>Baseline math</td>
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<tr>
<td>Total answered</td>
<td>9(6-12)</td>
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<tr>
<td>Answered correctly</td>
<td>8(5-12)</td>
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<tr>
<td>Math with peg transfer</td>
<td></td>
</tr>
<tr>
<td>Total answered</td>
<td>7(5-11)</td>
</tr>
<tr>
<td>Answered correctly</td>
<td>6(4-10)</td>
</tr>
</tbody>
</table>
Appendix K

Chapter III Burden Questions

Did you feel burdened by the distraction?

Yes  No

Which distraction (if any) did you feel most burdened by?

Arithmetic Noise Equivalent