The use of surgical simulators has increased rapidly over the past few decades in human and veterinary surgery training.1–6 This equipment removes the ethical concerns and difficulties of cadaver procurement and takes relatively little space and employee training to maintain. Simulators also eliminate practicing on live patients, which can provide an ethical and emotional toll on trainees if complications arise. As with all training devices and methods, there is no one perfect way for surgeons to gain practical skills. Although laparoscopic box trainers are relatively affordable and effective,7,8 they require self-motivation, supervision to ensure trainees are not practicing poor techniques, and self-reporting. This increases the time commitment for trainees and trainers and decreases the appeal and utility. Recently, investigators have examined virtual reality simulation–based devices, which allow for immediate feedback.9–11

OBJECTIVE
To assess attempts to proficiency of experienced veterinary surgeons for 2 surgical tasks when using a robotic simulator (Mimic dV-Trainer; Surgical Sciences) and determine factors associated with the successful performance of these tasks.

METHODS
Veterinary surgeons with rigid, minimally invasive surgery experience performed 2 tasks (“pick and place” and “knot the ring”) using the simulator until they attained proficiency. Individual performance variables were recorded. The number of attempts to proficiency was recorded. Performance variables were also assessed for effect on proficiency by the Kendall tau correlation and hierarchical multiple linear regression. The study period was from July 25, 2022, through December 14, 2022.

RESULTS
The 18 surgeons enrolled required a median of 8.5 attempts (95% CI, 7 to 12; range, 6 to 22) to reach proficiency for the basic task versus 27 attempts (95% CI, 21 to 38; range, 10 to 63) for the advanced task. Surgeons took a median of 6 minutes (range, 3 to 11 minutes) to complete training for the basic task and 12 minutes (range, 4 to 46 minutes) for the advanced task. The number of attempts to reach proficiency correlated strongly with economy of motion (τ = 0.72), instrument collisions (τ = 0.72), and time to completion (τ = 0.96).

CLINICAL RELEVANCE
Although experienced surgeons required a high number of attempts to gain proficiency in robotic simulator tasks, they did achieve proficiency quickly, encouraging future investigations into their use for training. Specific motion metrics were identified which improved efficiency during training.

Keywords: proficiency, surgeons, experienced, veterinary, simulator
computer programming, the system designates proficiency when a trainee achieves a specific number of passing attempts. With information about attempts to proficiency, learning curves, and retention of skills by trainees, surgeons can monitor the progression of their house officers, staff surgeons, and themselves and concentrate on specific areas of improvement.

Robotic simulation training would also be recommended for veterinary surgeons contemplating a robotic surgical program before performing these surgeries on live patients. Investigators have also examined the use of simulators specifically created for training in robotic surgery for training in other surgical modalities, such as laparoscopic and open surgery. The major difference between robotic simulators and laparoscopic box simulators utilizing straight instruments are the 3-D field of view and enhanced dexterity in instrumentation, with improved degrees of freedom and articulation as well as improved ergonomics for the participant that are provided by the robotic simulators. Studies have shown that objective improvement in scores on validated 3-D simulators correlated with improved live surgical procedure outcomes. Robotic simulators have even been used for open surgical training because the psychomotor skills acquired are similar to traditional open surgical skills.

Previous investigations on the use of this simulator with minimally invasive surgery (MIS)-naive students found a short learning curve and specific performance metrics that could be utilized during training for that cohort. It is unknown how minimally invasive surgical experience may affect those results. Given the time constraints of house officers and surgeons, having a device that provides immediate feedback, supplies demonstration videos, tracks and records progress, and is enjoyable to use is desirable. It is essential to understand the time commitment needed to learn a skill with these devices if their application is to be supported. An inordinately long learning curve could dissuade both residents and surgeons from their use.

The objectives were to assess the number of attempts to proficiency of experienced veterinary surgeons on 2 robotic simulator tasks and determine factors associated with successful performance. Our primary hypothesis was that the basic robotic task would be completed in less time and with fewer errors than the advanced task and that time to completion would be the biggest factor affecting the number of attempts to gain proficiency. Our secondary hypothesis was that experienced surgeons would gain proficiency in both tasks in fewer attempts compared to previously tested students.

Methods

The study was approved by the Cornell University Institutional Review Board (Protocol #0144284). Surgeons experienced with rigid endoscopy of equal or greater than 3 years were recruited to maintain consistency with our previous study. Participants were limited in the time they were allowed to practice each day, and the investigator did not provide procedural advice during training sessions. Surgeons were instructed to begin with the basic task and were allowed to move on to the advanced task only once proficient. A passing score was

employing verbal and email communication from the first author (NJB). We provided no incentive to surgeons who volunteered to participate in this study. We documented demographic data using a previously published survey in the same manner as a previous study investigating learning curves in students. Briefly, the original survey asked questions about handedness, general surgical experience, and experience with certain crafting hobbies. Differences to the survey for these participants included questions related to their subjective degree of videoendoscopic surgical (VES) experience, rated using a visual analog scale, where 0 mm indicated no prior experience, 50 mm indicated prior performance of 5 to 10 VES procedures as primary surgeon in the last 5 years, and 100 mm indicated prior performance of VES procedures weekly to monthly for the past 5 years. Diplomates were also asked to state their years of VES experience, estimated number of total laparoscopic/thoracoscopic procedures performed throughout their career, and estimated number of laparoscopic/thoracoscopic procedures performed in the last 3 years.

Complete details of the specific simulator device can be found in the previous study, but briefly, this virtual reality robotic device consists of a tabletop two-handed nonhaptic system (Supplementary Figure S1). Each hand has a master grip with force feedback and tracking, and the user views the virtual environment in 3 dimensions using a simulator-mounted stereoscope eyepiece. A foot pedal unit can be used to control camera movement and simulated electrosurgery applications. This system provides several training modules that focus on all aspects of robotic surgery, including camera movement, targeting, robotic arm movement, object manipulation, and suturing. The simulator has no physical requirements beyond those typical for performing surgical procedures and is adjustable for ideal arm and head height and angulation; however, the user must be able to sit to use the device.

To maintain consistency with our previous study on veterinary students, we chose 2 robotic tasks to differentiate between basic and advanced robotic skills. The full description of the training protocol, tasks, and role of the primary investigator can be referenced in the previous study but briefly, the basic task, named “pick and place,” required surgeons to pick up jacks of 3 colors and put them in identical-colored dishes (Supplementary Video S1), whereas the advanced task, named “knot the ring 1,” required surgeons to tie a square knot around a loop in the center of the simulated floor (Supplementary Video S2). These tasks test hand-eye coordination and command of the simulated space and introduce the idea of instrument collisions. Participants were limited in the time they were allowed to practice each day, and the investigator did not provide procedural advice during training sessions. Surgeons were instructed to begin with the basic task and were allowed to move on to the advanced task only once proficient. A passing score was

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required in each outcome variable to pass the task. The passing score was established using a proprietary algorithm developed and validated by Mimic Technologies. Participants had to pass the task at least 5 times, with 2 attempts being consecutive, to obtain proficiency.

Performance variables documented by the proprietary algorithm included time to completion (in seconds), economy of motion (cm), mastery of workspace range (cm), number of instrument collisions, and excessive force incidents. Time to completion is the time in seconds from when the participant first takes control of the simulated instruments until the task is complete. Economy of motion calculates the total distance (in centimeters) traveled by all instruments during a task. Mastery of workspace range relates to a calculated spherical volume (radius in centimeters) surrounding all the positions of each master grip during the task. Instrument collisions were recorded any time 2 instruments came into contact during the task, and the excessive force incidents were noted as the total time (in seconds) excessive force was applied to the shaft of a simulated instrument above a prescribed threshold. An overall score was calculated from a proprietary algorithm that combined a selection of these variables. The total number of attempts and the total time needed to obtain proficiency were documented for each surgeon.

Statistical analysis
The proficiency data learning curves were examined by several methods. All attempts made after surgeons had obtained proficiency were omitted. For both tasks, nonparametric descriptive statistics were performed. Demographic variables, including gender, experience level, dominant hand, species specialty, surgical interest, perceived hand-eye coordination, and experiences with hand-related crafts, were examined for an impact on the number of attempts to achieve proficiency for both tasks. Because surgeons achieved proficiency rapidly for the basic task, the analysis was restricted to nonlinear correlation analyses (Kendall tau) of each variable against the total number of attempts to achieve proficiency. For the advanced task, the correlation between each variable and the total number of attempts to achieve proficiency was tested using the Kendall tau. A multivariable regression analysis assessing the relationship between the total number of attempts to obtain proficiency and those variables that individually correlated with proficiency was then utilized. Lastly, after ensuring that major assumptions of linear regression would not be defied, we performed a simple linear regression to test whether the number of attempts required to achieve the first successful time to completion (regardless of other errors) could predict the overall number of attempts needed to achieve proficiency. We excluded 1 surgeon who was identified as an outlier due to their need for extended practice to gain proficiency. All statistical analysis was performed with statistical software (jamovi software, version 2.3.18), and significance was set to \( P < .05 \).

Results

Demographic data
Eighteen experienced veterinary surgeons participated in this study (Table 1). All surgeons had at least 3 years of experience with rigid endoscopy, with 5 of 18 consisting of third-year surgical residents. All but 1 surgeon were from the same institution. Half of the participants were large animal focused, and 8 of 18 provided surgical care in both soft tissue and orthopedics. The median visual analog scale (VAS) for video game experience was 11 (range, 0 to 100), with only 5 surgeons having scores ≥ 50. The median video analog scale for VES experience was 98 (range, 58 to 100), with 12 surgeons having scores > 90.

<table>
<thead>
<tr>
<th>Variables</th>
<th>Number of participants (percentage out of 18)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Experience level</td>
<td></td>
</tr>
<tr>
<td>Resident</td>
<td>5 (28%)</td>
</tr>
<tr>
<td>Board certified with &lt; 5 years experience</td>
<td>4 (22%)</td>
</tr>
<tr>
<td>Board certified with ≥ 5 years experience</td>
<td>9 (50%)</td>
</tr>
<tr>
<td>Gender</td>
<td></td>
</tr>
<tr>
<td>Male</td>
<td>7 (39%)</td>
</tr>
<tr>
<td>Female</td>
<td>11 (61%)</td>
</tr>
<tr>
<td>Dominant hand</td>
<td></td>
</tr>
<tr>
<td>Right</td>
<td>18 (10%)</td>
</tr>
<tr>
<td>Left</td>
<td>0 (0%)</td>
</tr>
<tr>
<td>Ambidextrous</td>
<td>0 (0%)</td>
</tr>
<tr>
<td>Species specialty</td>
<td></td>
</tr>
<tr>
<td>Small animal</td>
<td>9 (50%)</td>
</tr>
<tr>
<td>Large animal</td>
<td>9 (50%)</td>
</tr>
<tr>
<td>Surgical interest</td>
<td></td>
</tr>
<tr>
<td>Soft tissue</td>
<td>5 (28%)</td>
</tr>
<tr>
<td>Orthopedics</td>
<td>5 (28%)</td>
</tr>
<tr>
<td>Both</td>
<td>8 (44%)</td>
</tr>
<tr>
<td>Perceived hand-eye coordination</td>
<td></td>
</tr>
<tr>
<td>1 (poor)</td>
<td>0 (0%)</td>
</tr>
<tr>
<td>2</td>
<td>1 (5%)</td>
</tr>
<tr>
<td>3</td>
<td>3 (17%)</td>
</tr>
<tr>
<td>4</td>
<td>12 (67%)</td>
</tr>
<tr>
<td>5 (excellent)</td>
<td>2 (11%)</td>
</tr>
<tr>
<td>Experience with metal work, machining, or leather work</td>
<td></td>
</tr>
<tr>
<td>None</td>
<td>6 (33%)</td>
</tr>
<tr>
<td>Some</td>
<td>7 (39%)</td>
</tr>
<tr>
<td>A lot</td>
<td>5 (28%)</td>
</tr>
<tr>
<td>Experience with sewing, needlework, crafting</td>
<td></td>
</tr>
<tr>
<td>None</td>
<td>8 (44%)</td>
</tr>
<tr>
<td>Some</td>
<td>7 (39%)</td>
</tr>
<tr>
<td>A lot</td>
<td>3 (17%)</td>
</tr>
<tr>
<td>Experience building</td>
<td></td>
</tr>
<tr>
<td>Yes</td>
<td>9 (50%)</td>
</tr>
<tr>
<td>No</td>
<td>9 (50%)</td>
</tr>
</tbody>
</table>

Table 1—Demographic data for 18 experienced surgeons performing 2 tasks to proficiency on a robotic simulator from July 25, 2022, through December 14, 2022.
No significant associations were found between demographic data and proficiency with either task.

**Simulator task data**

Surgeons required a median of 8.5 attempts (95% CI, 7 to 12; range, 6 to 22) to reach proficiency for the basic ("pick and place") task versus 27 attempts (95% CI, 21 to 38; range, 10 to 63) for the advanced ("knot the ring 1") task (Figure 1). The number of attempts to reach proficiency for the basic task correlated modestly with economy-of-motion errors ($\tau = 0.52; P = .0003$), mastery-of-the-workspace errors ($\tau = 0.51; P = .0004$), and time-to-completion errors ($\tau = 0.3; P = .0004$).

The number of attempts to proficiency for the advanced task correlated moderately to strongly with economy of motion ($\tau = 0.72; P = .0003$), instrument collisions ($\tau = 0.72; P = .0003$), excessive-force errors ($\tau = 0.45; P = .007$), and time to completion ($\tau = 0.96; P < .0001$). When

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*Figure 1*—Box and whisker plots depicting the number of attempts versus proficiency for 18 experienced minimally invasive surgeons on a robotic simulator from July 25, 2022, through December 14, 2022. A—Results for the “pick and place” basic task. B—Results for the “knot the ring 1” advanced task. For each box and whisker plot, the bold line within the box represents the median number of attempts to achieve proficiency, the lower and upper limits of the box represent the interquartile (25th and 75th percentiles) range, respectively, the whiskers delimit the range, and circles represent participants.

*Figure 2*—Scatter plot of total number of time-to-task-completion errors versus number of attempts to proficiency for the study participants listed in Figure 1. The dotted line represents the line of best fit.

*Figure 3*—Scatter plot of total number of attempts to first successful time to task completion versus number of attempts to proficiency for the study participants listed in Figure 1. The dotted line represents the line of best fit. The red dot represents an extreme outlier, which was excluded from the linear regression analysis.
applying a multiple regression analysis, instrument collisions and time-to-completion errors continued to be highly correlated \((R^2 = 0.97; P < .0001)\). The number of time-to-completion errors alone almost perfectly predicted the total number of attempts to proficiency \((R^2 = 0.96; P < .0001)\) (Figure 2). The number of attempts to first successful time to completion moderately predicted the number of attempts to achieve proficiency \((R^2 = 0.6; P < .001)\) (Figure 3). An additional 15 attempts were required after the initial successful time to completion.

Surgeons took a median of 6 minutes (range, 3 to 11 minutes) to complete training for the basic task and a median of 12 minutes (range, 4 to 46 minutes) to become proficient in the advanced task (Figure 4). All surgeons surveyed after their participation enjoyed the simulation and would sign up for additional training opportunities in the future if offered.

**Discussion**

The results of this study confirmed our primary hypothesis that experienced veterinary surgeons would gain proficiency in a basic task faster than in an advanced robotic simulator task. This is consistent with a previous report\(^\text{19}\) on MIS-naïve students performing the same tasks and previous validation studies\(^\text{16,23–25}\) in human and veterinary medicine. Experienced surgeons achieved proficiency in less time than students (6 minutes vs 13.5 minutes for the basic task and 12 minutes vs 26.5 minutes for the advanced task), but the number of attempts to the first successful time to completion was still the strongest predictor of the total number of attempts to gain proficiency.

The number of attempts to proficiency for experienced surgeons (8.5 attempts for the basic task and 27 attempts for the advanced task) mirrored those of MIS-naïve students (8 attempts for the basic task and 22 attempts for the advanced task) examined in our previous study,\(^\text{19}\) which required us to reject our secondary hypothesis. It is possible the novelty of the simulator equipment and the tested psychomotor skills, coupled with the surgical experience with straight (compared to articulated) instruments, affected the outcomes for experienced surgeons.\(^\text{26}\)

The physical setup of the master grips and stereo- scope was different than any surgical system the sur- geons had utilized previously, and the psychomotor skills are also distinctive. Participating surgeons most commonly mentioned the loss of haptic feedback as causing difficulty during task completion. New simulator systems have added haptics back into the instrumentation and as robotic surgical systems continue to advance, this difficulty may be overcome.\(^\text{27}\)

Younger students and house officers with more familiarity with technology, especially augmented and virtual reality games or devices, might have an advantage when utilizing this equipment.\(^\text{28,29}\)

Even though experienced surgeons required a similar total number of attempts to gain proficiency, they achieved proficiency in both tasks.
in approximately half the time that students in our previous study did. Experienced surgeons achieved proficiency in a median of 6 minutes (range, 3 to 11 minutes) for the basic task compared to 13.5 minutes (range, 8 to 24 minutes) for students. For the advanced task, experienced surgeons achieved proficiency in a median of 12 minutes (range, 4 to 46 minutes) compared to a median of 26.5 minutes (range, 11 to 82 minutes) for students. Completing the same number of attempts in half the time suggests that the experienced surgeons were able to move through each attempt more efficiently. This is consistent with previous work comparing timed scores for novice and experienced surgeons on a variety of simulators. It is unknown if it was the surgeons’ experience with rigid endoscopy or general surgical experience or a combination of both that led to this finding as both could affect hand-eye coordination and accuracy.

The results of this study suggest that experienced surgeons could be trained to proficiency in these 2 robotic tasks quickly, with the slowest surgeon completing all training within 46 minutes, which we consider a reasonable amount of time for the demanding schedule of house officers and surgeons. Specific metrics for successful completion of tasks were identified, the most repeatable of which was completing the task within a specified time. The time-to-completion metric assesses efficiency and has been validated repeatedly in both laparoscopic and robotic skills tests. For the advanced task, experienced surgeons required an additional 15 attempts after the initial successful time-to-task completion to become proficient compared to students who only required 8 attempts, which may be related to difficulties adapting to this technology. This task was frustrating for every participant, and it is also possible that the years of real-life experience suturing hampered the surgeons’ ability to accept a new technique.

Significant motion metrics were also identified for both tasks. For the basic task, both metrics (economy of motion and mastery-of-the-workspace errors) were associated with the amount of space the instrument traveled or the use of the instrument within the specified space. These metrics directly relate to foundational skills, such as hand-eye coordination and instrument control, and are crucial in clinical procedures to decrease the chance of inadvertent injury. For the advanced task, significant motion metrics (economy of motion, instrument collisions, and excessive-force errors) were identified. In this case, instrument movement was important, but 2 metrics related to instrument safety were identified. Because robotic systems usually do not include haptics, it is critical that surgeons use visual keys to alert them if the torque placed on an instrument is too great or the instruments are clashing. If not, patients can be injured, and equipment can become damaged.

These findings can help guide surgeons and training sites in determining the time requirements and skills necessary to become proficient in simulation tasks. A benefit of the simulator tested in this report is the immediate feedback provided by the computer algorithm to guide the participant in the absence of a proctor. Although surgeons could be performing tasks inappropriately and still passing, it is less likely as the participant has access to task videos and objective data analysis. This provides the surgeon with quantitative data and support, and this can be accessed anytime the lab is available, improving interest in training.

The major limitation of this study is the relatively small sample size. The sample size was determined based on the availability of experienced surgeons at the institution, but a larger group of participants may have generated different data. Unlike the previous study on students, the participants were not demographically homogenous. Even with better heterogeneity, the small sample size precluded meaningful statistical analysis of the demographic variables compared to simulator task metrics. Our current study had an even division of small- and large-animal surgeons, a more balanced representation of males and females (7/18 vs 11/18, respectively), and a nearly balanced division between surgeons specializing in orthopedics, soft tissue, and both interests. This may have allowed for higher recruitment but could have affected the outcomes as orthopedic surgeons do not commonly suture during arthroscopy; therefore, the advanced robotic task may have been more difficult for them. Even though we did not find a significant association, future studies should continue to assess the effect of demographic variables on robotic simulator or surgical performance as these psychomotor skills differ from other minimally invasive skills.

In conclusion, experienced veterinary surgeons displayed a difference in the number of attempts to proficiency when performing varied robotic simulator tasks. Training to proficiency required a short time commitment, and specific execution metrics were identified that could encourage proficiency during training. The addition of alternative tools to aid in training veterinary surgeons will allow increased access to instrumentation and psychomotor preparation, avoiding the ethical dilemma of practicing on live patients and preparing surgeons for the future.

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Disclosures

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Supplementary Materials

Supplementary materials are posted online at the journal website: avmajournals.avma.org.