Received: 7 March 2023 | Revised: 11 June 2023 | Accepted: 30 June 2023

DOI: 10.1002/lio2.1114

ORIGINAL RESEARCH

Laryngoscope Investigative Otolaryngology

Binocular microscopes versus exoscopes: Experiences and performance in simulated otologic surgery

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Abstract

Objectives: Exoscopes represent a promising alternative to conventional binocular microscopes (OM) in otology offering potential advantages such as enhanced ergonomics and a more compact device design. While previous research has demonstrated the effectiveness of exoscopes in various surgical specialties, their objective assessment in the field of otology remains limited. Therefore, this investigation aims to assess task-based efficiency associated with exoscopes in the field of otology by use of simulated surgical models.

Methods: A prospective cross-over study design was used to compare an OM to an exoscope in otolaryngology residents and medical students. Participants performed five tasks on 3D-printed ear models using both the exoscope and OM. Data collection included completion time, frequency of predefined errors, mental effort, and user experience. Subgroup analysis was performed based on level of experience.

Results: Fourteen students and fifteen residents participated. Participants completed four of five tasks faster with the OM and there was no difference in number of errors committed. When separated by surgical experience, residents performed four of five tasks faster using the OM while students completed one of five tasks faster with the OM. Students committed more errors with the exoscope for one task with no difference in errors for residents. There was no difference in perceived difficulty performing tasks with either visualization system. Exit survey results showed more favorable opinions of the OM among residents and more favorable opinions of the exoscope among students.

Conclusions: The exoscope permits successful performance in simulated otologic tasks. Task performance and user experience between operative microscopes and exoscopes differ based on level of surgical experience.

Level of Evidence: 2.

Riley Larkin and Jake Langlie contributed equally to this work.

The data presented in this manuscript was accepted for podium presentation at the 2023 Combined Sections Meeting, The Triological Society, Coronado, CA, USA, January 26–28, 2023.

KEYWORDS
exoscope, medical education, operative microscope, otology, surgical simulation

1 | INTRODUCTION

The binocular operative microscope (OM) has been utilized by otologic surgeons as early as 1922, when Gunnar Holmgren first used a Zeiss-manufactured device to treat otitis.[1,2] Expectedly, the early OMs were plagued by a variety of technical limitations including a 6–12 mm limited field of view, a short working distance of 7.5 cm, a lack of maneuverability, and poor illumination.[3] However, advances in technology have made the OM the preferred visualization tool for otologic procedures and a plethora of other microsurgical subspecialties. However, use of these devices for extended periods of time paired with poor posture can contribute to work-related musculoskeletal discomfort. These occupational complaints plague otolaryngologists.[4] Recent studies show that otologists report discomfort at a rate of 28%–87% with the majority being neck and shoulder complaints.[5,6] These surgeons also admit to a very limited knowledge of the importance of ergonomics, or comfortable body positioning, and express that when some basic principles are applied, a large majority see improvement in musculoskeletal discomfort.

Recent investigations have demonstrated that the extracorporeal telescope or exoscope may be beneficial for improving ergonomics. The use of the exoscope has been validated in other fields like urology[7] while showing similar patient outcomes to traditional visualization techniques in neurosurgery and lateral skull base surgery.[8] With a trained user, the exoscope allows for exceptional visualization with improved maneuverability in the "heads-up" position for improved posture. Although retrospective data suggests that the exoscope could be used instead of the OM in certain circumstances, prospective data in otologic surgery is nonexistent. This study explores this question using simulated surgical tasks on 3D-printed models that represent any potential technique an otologist may use in their day-to-day practice.

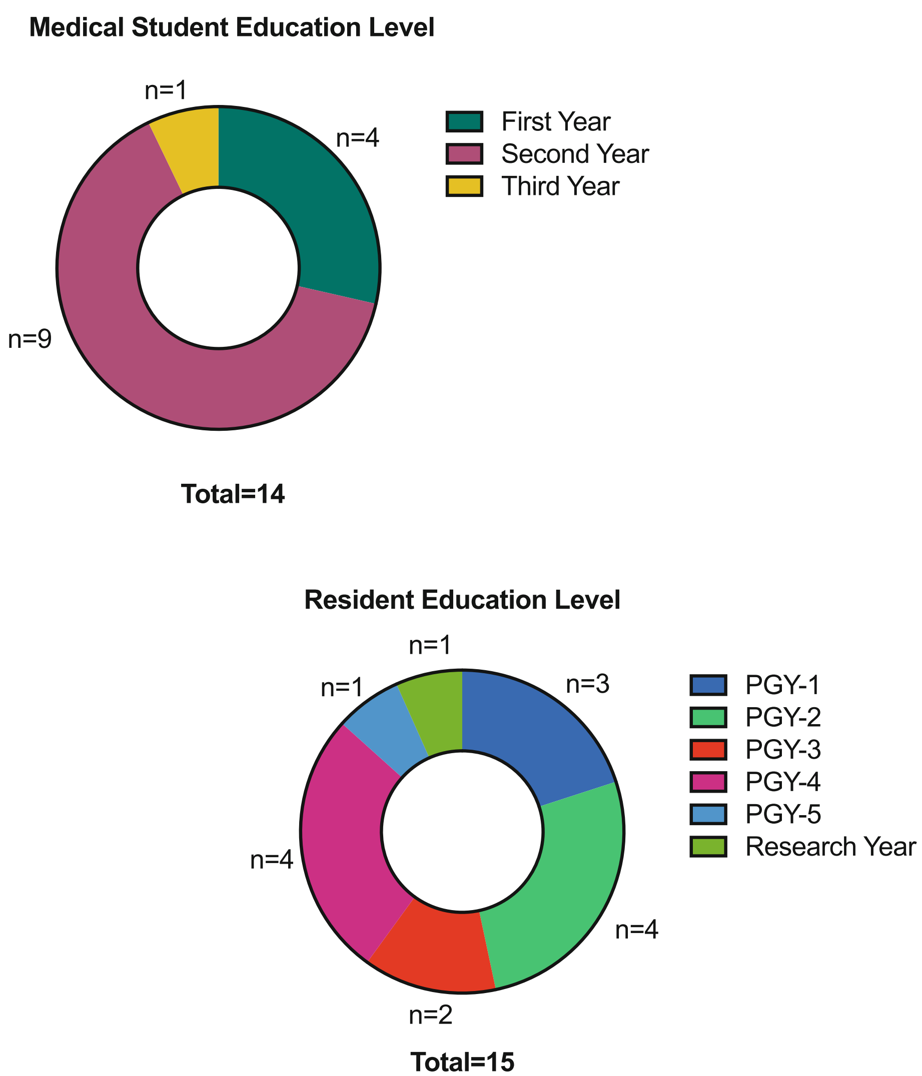


FIGURE 1 Participant training levels. This figure portrays the training levels of the participants in the study. Most medical students were in their second year, while almost half of the residents were either in their PGY-1 or PGY-2 year.

2 | MATERIALS AND METHODS

This study was granted institutional review board exemption by the University of Miami Miller School of Medicine's Human Subject Research Office. Informed consent was obtained from all subjects prior to participation in the study.

The Zeiss Pentero OM and the Olympus Orbeye Exoscope were compared in our study. The 29 participants included medical students and otolaryngology residents at varying levels of training (Figure 1). A prospective cross-over study was designed. Participants were randomized to start with one visualization system before performing tasks with the second visualization system to limit the effect of task familiarity in the results. Ahead of testing, participants were given access to instructional videos that detailed the appropriate way to perform each simulated task in addition to grading criteria. We used five tasks to compare performance and user experience on the OM and exoscope including target identification, target pinning, target transfer, pressure equalization (PE) tube placement, and cochlear implantation. Target identification, target pinning, and target transfer utilized a 3D printed model that reflected the enclosed space of the middle ear. PE tube placement used a separate 3D printed external auditory canal with varying canal lengths. The cochlear implantation task utilized a model temporal bone from Phacon and a dummy cochlear implant electrode (Figure 2). Representative images along with further explanation of each task and predefined error is shown in Figure 3, Table S1, and Videos 1–5. Each task started with the visualization system in a neutral position—pointed away from the task apparatus, the participant was told to start, and time was kept until the participant satisfactorily completed the task. During a brief orientation, participants were shown how to zoom, adjust focus, or change working distance and were allowed to do so as needed. The 3D printed models were stationary for the duration of the task and participants were instructed not to move them. Prior to task onset, participants were informed to not expedite the task due to the time limitation, but to perform it at a comfortable pace that allowed for optimal control of the instrumentation and task completion.

Time to completion, frequency of pre-defined errors, and mental effort using the subjective mental effort questionnaire (SMEQ) was collected for each task. The subjective mental effort questionnaire (SMEQ) (Figure 4) is a cognitive workload survey that asks respondents to rate, on a scale of 0–150 points, the amount of effort involved during a task. Nine scale markers with verbal statements ranging from "no effort at all" to "exceptional amount of effort" are displayed within the SMEQ. The choice of statements and their scale locations are empirically derived.[9]

User experience was assessed using exit surveys sent 24 hours after completion of the five tasks. Participants were asked to compare the ergonomics, ease of navigation, picture quality, depth perception, and to rate their overall experience with the exoscope and OM. Participants were also queried if they thought the exoscope could replace the OM in

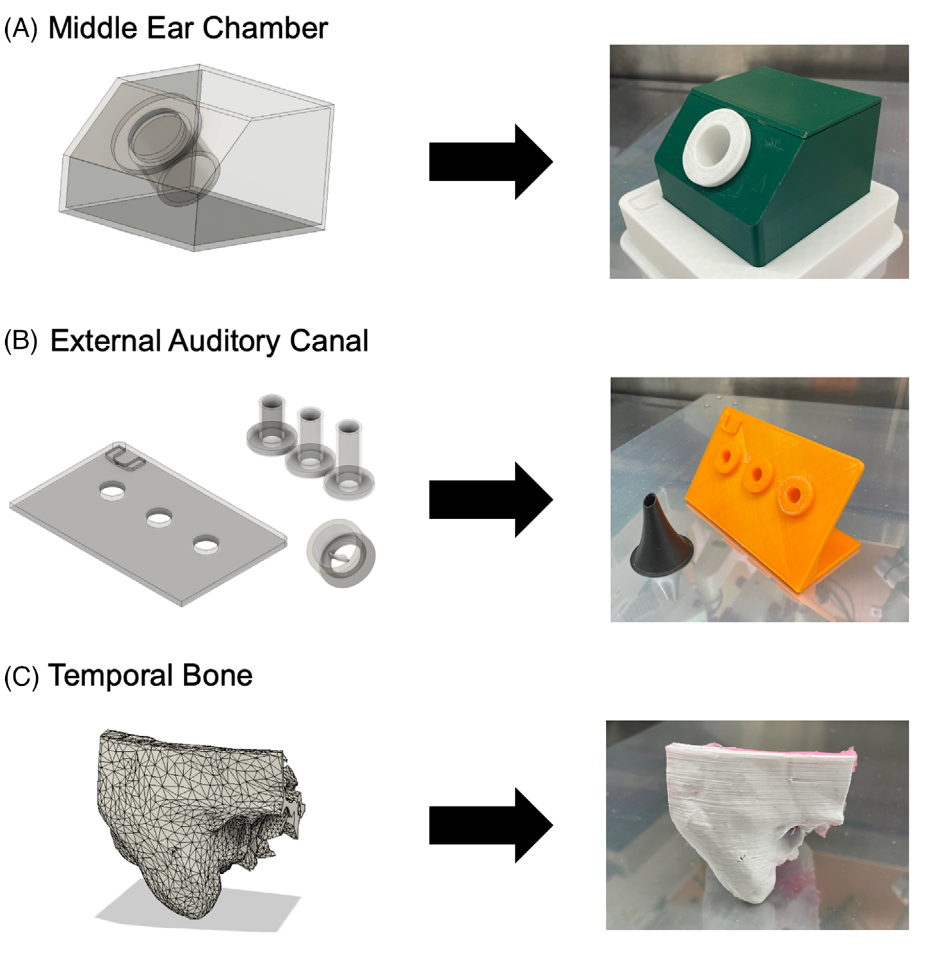


FIGURE 2 3D printed models. (A) A 3D printed middle ear chamber was developed for three tasks: target identification, target pinning, and target transfer. (B) A 3D printed external auditory canal was used for PE tube placement. (C) A Phacon temporal bone model, with access to the round window, was used for cochlear implantation. No simulated mastoidectomy and facial recess approach were tested.

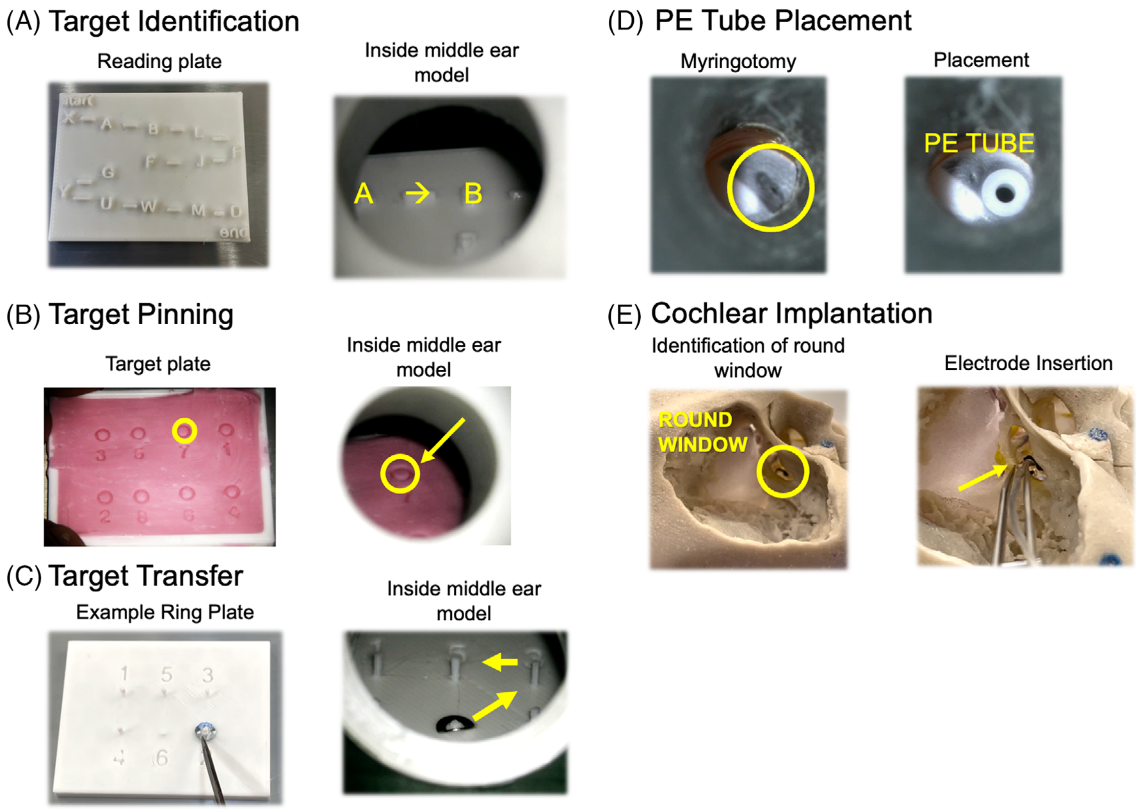
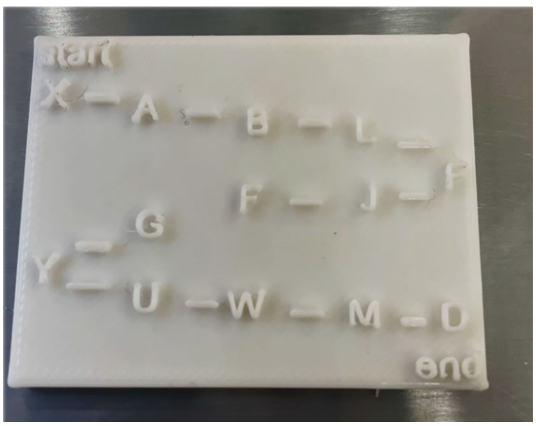
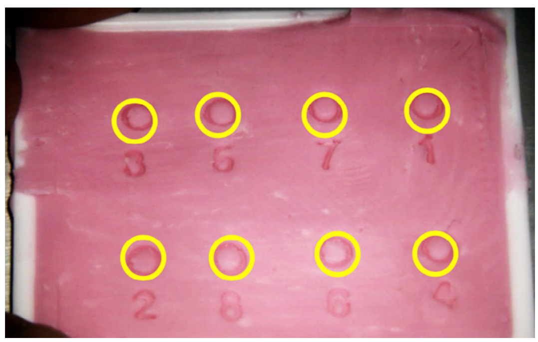


FIGURE 3 Simulated otologic surgery tasks. (A) In the target identification task, the participant must identify letters in the 3D printed middle ear chamber testing the image quality of the device. (B) In the target pinning task, the participant had to mark each circle with a gross anatomy probe testing depth perception. (C) In the target transfer task, the participant is testing the ability of the OM and exoscope to shift views both laterally and vertically. (D, E) Both PE tube placement and cochlear implantation are common otologic procedures and were simulated on both systems.



VIDEO 1 Target identification.
Video content can be viewed at https://onlinelibrary.wiley.com/doi/10.1002/lio2.1114



VIDEO 2 Target pinning.
Video content can be viewed at https://onlinelibrary.wiley.com/doi/10.1002/lio2.1114

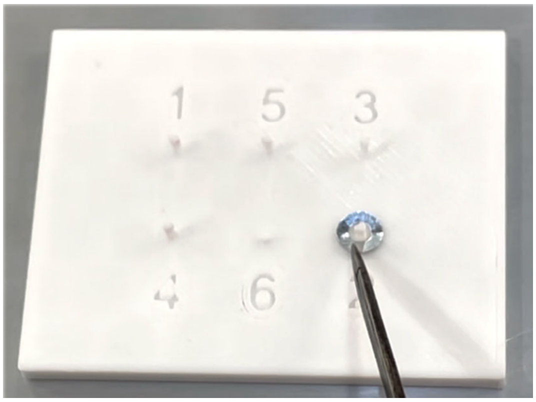
otology practice. A Likert scale was utilized to judge the participants perception of picture quality, depth perception, focusing function, and maneuverability of the microscope system. The utilized survey is illustrated in Table S2.

Statistical analysis was performed using Wilcoxon matched pairs signed rank tests with continuity correction when applicable. Figures were created using GraphPad Prism v9.5.0.

3 | RESULTS

3.1 | Combined performance in simulated otologic surgery (Figure 5)

For the target identification task, there was no difference in time to completion or task accuracy between the OM and exoscope. For the target pinning task, participants completed tasks more quickly with the OM than the exoscope ($p < .005$). However, there was no difference in task precision. For this task, an error was defined as making a mark outside the delineated area. For target transfer, participants were quicker and more accurate with the OM ($p < .001$ and $p = .013$, respectively). For PE tube placement and the cochlear implant task, participants completed the task faster with the OM than the exoscope ($p < .005$ and $p = .0058$, respectively). There were no predefined errors for PE tube placement and cochlear implantation. Ranges of task time completion and accuracy can be found in Tables S3 and S4, respectively.



VIDEO 3 Target transfer.
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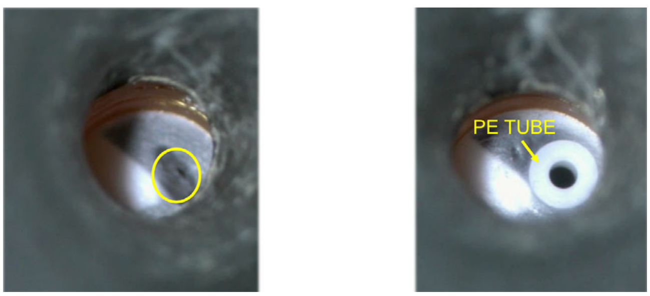

VIDEO 4 Pressure equalizer tube placement.
Video content can be viewed at https://onlinelibrary.wiley.com/doi/10.1002/lio2.1114

3.2 | Performance delineated by training in simulated otologic surgery (Figure 6)

Subgroup analysis was performed based on surgical experience demonstrating marked differences between residents and students. Residents performed target identification, target transfer, target pinning, and PE tube placement tasks faster ($p = .0329$, .0014, .0001, and .0063, respectively) with the OM while no difference was observed in accuracy. For medical students, only the target transfer task was completed faster and with greater accuracy using the OM ($p = .0015$ and $p = .0036$, respectively). All other tasks among students demonstrated similar completion times and accuracy.

3.3 | Subjective mental effort

There were no differences in subjective mental effort between the OM and exoscope. This holds true for all participants and all tasks, including upon stratification by surgical training (Table S5).

3.4 | Exit survey

The exit survey, consisting of 17 questions, yielded a response rate of 93% (27/29) among participants ($n = 13/15$ PGY1-PGY5; $n = 14/14$ medical students). The survey focused on current level of training, prior experience with the OM and exoscope, ergonomics, depth perception, picture quality, ease of performing basic functions, and perceived benefits and limitations of each visualization system.

No medical students 0% ($n = 0/14$) and a small fraction of residents 23% ($n = 3/13$) had previous experience with the exoscope. Among all participants, 89% rated the ergonomics provided by the exoscope superior to the OM. Medical students displayed an overall favorability with the exoscope, citing improved picture quality (64%) and ease of repositioning the scope (57%) as a primary factor in their experience. Residents overall favored the OM, citing completion of the task easier to perform with the OM. No significant differences were elicited between side-to-side maneuverability, up and down maneuverability, picture quality, depth perception and zooming in and out among medical students or residents. Most participants strongly agreed ($n = 6$ medical students, $n = 7$ residents) or agreed ($n = 8$ medical students, $n = 3$ residents) that the study helped them

VIDEO 5 Cochlear implantation.
Video content can be viewed at https://onlinelibrary.wiley.com/doi/10.1002/lio2.1114

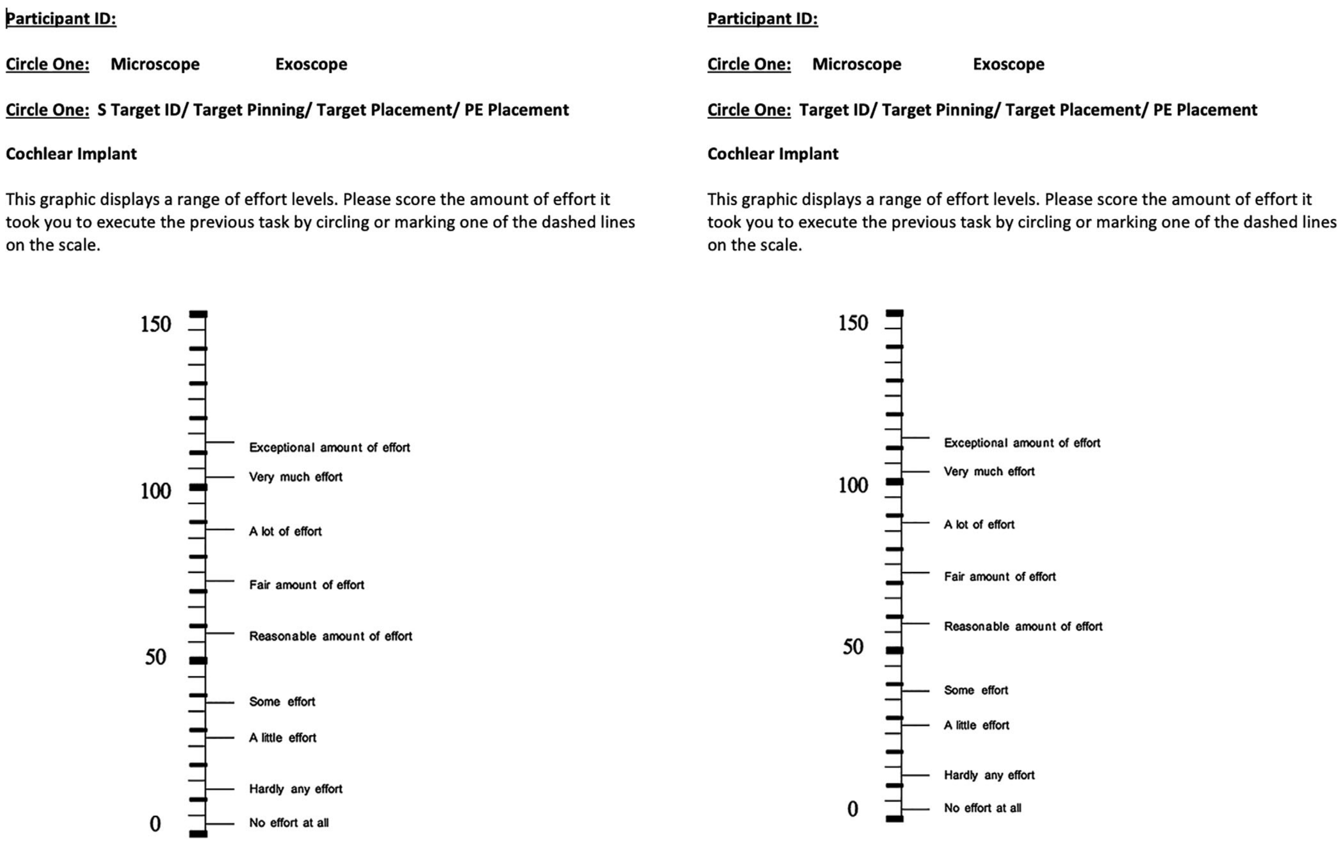

FIGURE 4 Subjective mental effort questionnaire (SMEQ). This is an example of the SMEQ each participant filled out for every task and for both visualization systems during the study.

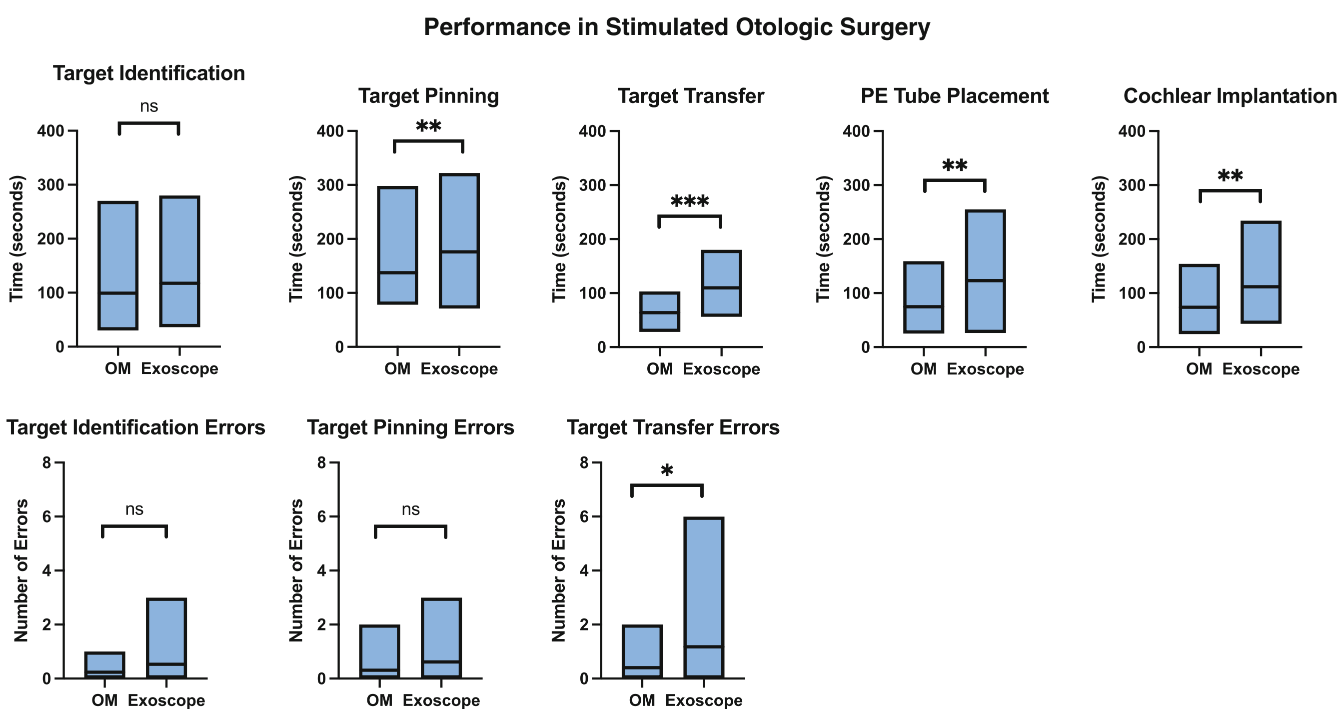

FIGURE 5 Simulated otologic surgery performance. ns = not significant, *p-value < .05, **p-value < .01, and ***p-value < .001. Completion time for all participants is displayed for each task and number of pre-defined errors for all tasks where applicable. Graphs are high-low plots with a horizontal line indicating the mean.

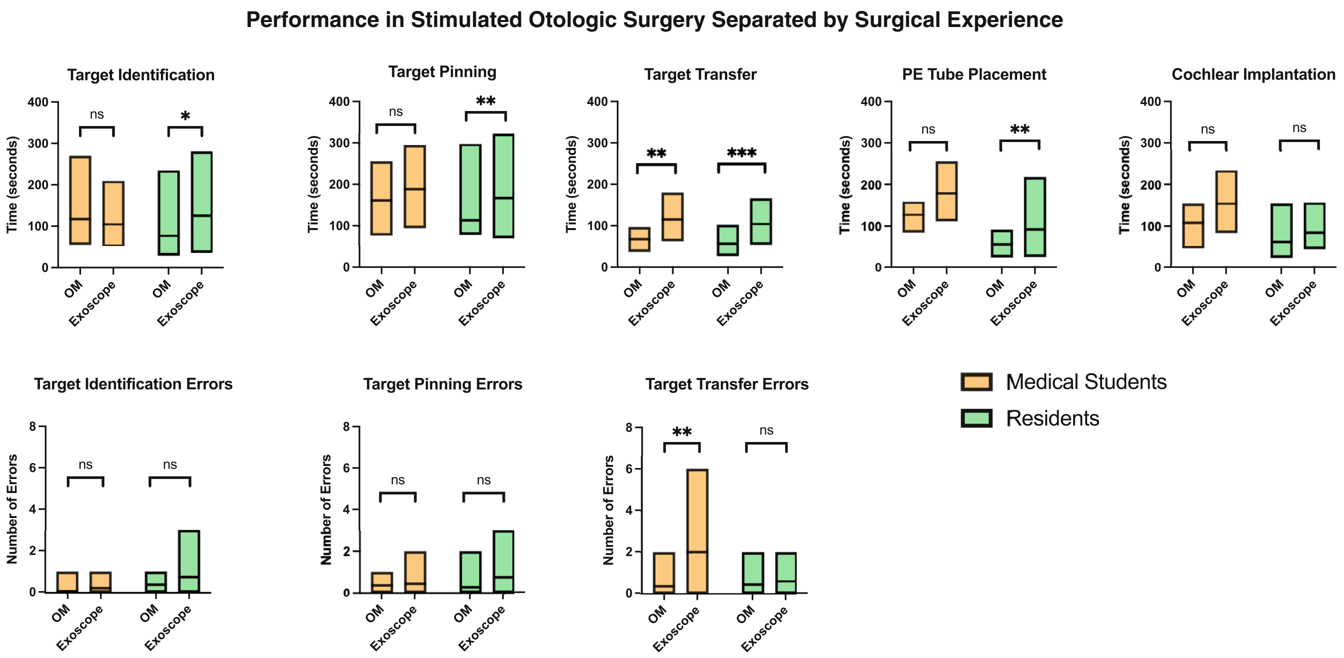

FIGURE 6 Simulated otologic surgery performance separated by surgical experience. ns = not significant, *p-value < .05, **p-value < .01, and ***p-value < .001. These graphs demonstrate time to completion and number of pre-defined errors for all tasks where applicable. Graphs are high-low plots with a horizontal line indicating the mean.

understand the benefits and limitations of an exoscope but would need additional training before using the device in clinical practice.

4 | DISCUSSION

The exoscope was introduced to overcome ergonomic limitations of the OM by allowing surgeons a "heads up" approach to the surgical field.[10,11] To date, the exoscope is frequently utilized within the fields of gynecologic[12] and urologic microsurgery,[7] with a slower adoption in the fields of otolaryngology and neurosurgery.[13,14]

Given the novelty of exoscope technology, simulation surgery is useful in testing its application in otology whereas it has already showed promise in subdivisions of ENT including facial plastic surgery,[15] head and neck surgery,[16,17] and sleep medicine.[18] Simulation surgery allows for a controlled, safe environment for initial exposure to the procedure and allows for a standardized approach to assess performance with existing technology, the OM.[19]

Within our simulated environment, medical students largely displayed a preference for the exoscope while residents favored the operative microscope. Multiple factors may explain this trend. Our medical student cohort had limited to no experience with the operative microscope, while residents are almost universally trained on the OM for microsurgery.[20,21] Although hard to quantify the exact number of surgical procedures performed using the OM by each resident, our institution provides early access to the operating room for all residents. All indicated some previous experience with the OM. This familiarity most likely established preference and gave residents a stronger foundation to perform tasks faster than medical students.

Among all participants, target pinning, target transfer, PE tube placement, and the cochlear implantation tasks were completed faster with the operative microscope (p < .005, p < .001, p < .005, and p = .0058, respectively). Faster completion was largely attributed to resident familiarity with operating the OM but may be partially explained by the number of adjustments that must be undertaken to clear and direct the image with the exoscope. Operating the exoscope may be less intuitive than the OM as it does not rely on direct line of sight making it more difficult to find appropriate placement to gain the right viewing angle. To gauge participants thoughts on the difficulty of the use of the exoscope and OM, an SMEQ scale was used to elicit any bias towards one system or the other. Although no significant trends emerged, either based on training level or task, residents often rated tasks easier with the microscope and more difficult with the exoscope. This was further evidenced through the exit survey where residents demonstrated preference for the operative microscope, citing improved focusing function (60%), while medical students noted improved picture quality (64%) and mobility of the scope while performing simultaneous tasks (57%) in their evaluation of the exoscope. No significant trend in resident preference for visualization system was noticed when comparing junior residents with senior residents. An interesting future study would aim to look at the medical students and residents as they advance through their training to see if greater preference is achieved for the OM with more experience.

A trend emerged among residents of increased ease with PE tube placement, regardless of system utilized. As this is one of the primary procedures taught early in residency, the familiarity as well as practice performing the task may have influenced the residents ease of rating regardless of the system used.[22]

With all simulation studies of the operative environment, this study is not free from limitations. We acknowledge that the simulated environment while using the operative microscope and exoscope does not encompass all aspects of surgery. However, this limitation was balanced with the ability to recreate identical surgical models which is not feasible in clinical studies. A second limitation lies in the performance measures that were used to sample elements of surgical skill and accuracy. Much of our data collection relied on subjective measures such as the Likert scale and SMEQ which could cause some deviation from the standard due to human subjectiveness. The measures used within the study were intended to sample, not fully capture, all surgical skills and performance. Standardized scales were used to offer meaningful data measurements. Finally, participants with experience in otology were limited. However, we can conjecture that results would be similar to that of residents with better performance with the OM given previous experience. Further evaluation may also benefit with comparison of the exoscope to the endoscope as endoscopic ear surgery is growing in the fields of otology and neurotology.[23]

5 | CONCLUSION

As the exoscope's applicability continues to expand into the various subdivisions of otolaryngology, we can expect to see a rise in its usage within the field of otology as its limitations are minimized and applications are defined. In the field of otology, our preclinical model showed that the development of the exoscope has allowed a comparable alternative to the classical OM, offering improved ergonomics and increased visualization for all within the surgical suite.

FUNDING INFORMATION

Funding for this original report was provided by the University of Miami Department of Otolaryngology.

CONFLICT OF INTEREST STATEMENT

The authors declare no relevant conflicts of interest.

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SUPPORTING INFORMATION

Additional supporting information can be found online in the Supporting Information section at the end of this article.

How to cite this article: Larkin R, Langlie J, Roldan LP, Thielhelm T, Mahfood C, Chiossone JA. Binocular microscopes versus exoscopes: Experiences and performance in simulated otologic surgery. *Laryngoscope Investigative Otolaryngology*. 2023;8(5):1337-1344. doi:10.1002/lio2.1114