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Does The Method of Visualization Impact the Performance of a New Surgical Task in Novice Subjects?

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Abstract

Introduction

Evolution of optical technology from two-dimensional to three-dimensional (3D) systems has come with an associated loss of stereoscopy and 3D depth perception. This report compares performance of surgical tasks in unbiased subjects using these systems.

Methods

Untrained subjects were randomized into two groups, robotically operated video optical telescopic-microscope (ROVOT) or surgical microscope (microscope). Subjects sutured and tied knots. Completion time, NASA-Task Load Index (TLX), and galvanic skin responses were analyzed.

Results

Intergroup analysis of suture completion time indicated that microscope use was significantly faster compared to ROVOT, whether used first or second. Regardless of which methodology was used first, the second modality was faster, indicating a transfer effect. NASA-TLX indicated that mental, performance, effort, and frustration were all greater with ROVOT.

Conclusion

Task completion time and perceived effort were greater with ROVOT. Task completion times improved with repetition regardless of visual modality.

1 INTRODUCTION

The binocular microscope was first introduced in neurosurgery by Theodor Kurze in 1957.[1-3] Visual perception is defined as the ability to interpret the surrounding environment using light that is reflected on objects in the environment. Stereoscopy and proprioception allow for the ability to perceive, appreciate, and detect objects in a three-dimensional (3D) space—a direct function of perception. These principles have been especially crucial in the development of technological advances in microscopy. Subsequent microscopic systems have evolved and permit surgeons to operate with unprecedented light delivery, magnification, and 3D perception and proprioception. Following introduction of the binocular microscope to neurosurgery, it took over 10 years before a rapid increase in the number of papers reported its use (Figure **1**, blue line) in the literature. Although in use in other areas of medicine and science for many years, the introduction of endoscopy to neurosurgery only occurred in the early 1970s.[4] Following its introduction, it was nearly 20 years before there was a rapid increase in the number of neurosurgical endoscopy papers being published (Figure **1**, orange line). Similarly, the exoscope was introduced to neurosurgery in 1994,[5] but did not find a role until port-based subcortical surgery was introduced in 2010 (Figure **1**, grey line).[6, 7] Soon thereafter, the exoscope evolved into the robotically operated video optical telescopic-microscope (ROVOT) and was applied to open cranial and skull base cases (Figure **1**, yellow line).[8] As it is still early in its technological adoption lifecycle,[9] it is useful to reflect on the inherent advantages and disadvantages that might affect the diffusion of the ROVOT technology. The ROVOT has optical advantages compared to the conventional surgical microscope, in particular a larger volume of view. An oft cited disadvantage of the ROVOT is the loss of stereoscopy and 3D perception.[10, 11] However, it is unclear if the learning and performance of surgical tasks is different when using one platform or another, particularly in unbiased trainees.

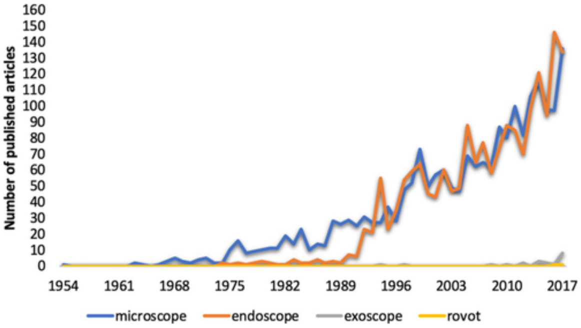

Figure 1 The number of articles published per year for each of the optical modalities used by neurosurgeons. Articles published on Pubmed utilizing a microscope (blue line), endoscope (orange line), exoscope (grey line), and robotically operated video optical telescopic-microscope (yellow line) were compiled for each year and shown as line graphs

Therefore, this study was designed as a preliminary, hypothesis-generating study specifically to compare the effect of 3D and 2D visualization platforms on the performance of a surgical task by naïve subjects to determine whether trainees without prior endoscope experience can learn and perform a new surgical task more readily using either ROVOT or conventional microscope visualization. Instead of working with neurosurgeons of differing experience levels, who may also harbor particular biases for or against one platform, we chose to work with volunteer high school and college undergraduate students who had no prior surgical experience or familiarity with the optical platforms being tested. We hypothesized that there is no difference between untrained subjects learning a surgical task using either a conventional microscope or the ROVOT. Additionally, we hypothesized that performance measures would be no different when untrained subjects learned a surgical task using the ROVOT compared to a conventional microscope. We sought to determine whether there was a transfer effect based on which device was used first and how steep the learning curve was for each device for each task. Understanding the advantages and limitations in the acquisition of a new skill can improve the diffusion of that technology.

2 DESIGN AND METHODS

The Aurora IRB approved this study (18-60E). Due to absence of HIPAA and subject safety risks, we were permitted to provide information necessary to make an informed decision to participate through a group discussion that adhered to a script also approved by the IRB.

2.1 Study design

This is a prospective crossover, counter-balanced trial using a repeated measures approach to examine the effect of the conventional microscope visualization and ROVOT visualization on untrained subjects performing a series of surgical tasks, with a specific focus on the initial learning period.[6] We sought volunteers with no surgically relevant experience and therefore enrolled high school and college subjects. Two cohorts of equal numbers with equal numbers of men and women in each cohort were created through random allocation (Figure **2**A). Each subject was assigned a number from 1 to 12. Names were not recorded.

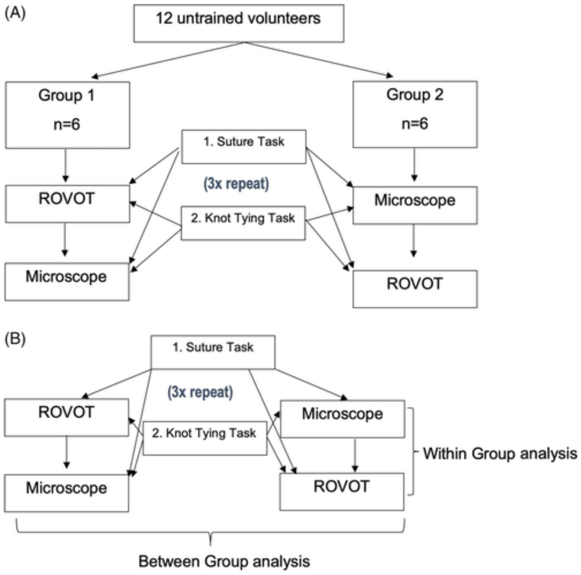

Figure 2 Flow diagram of subject tasks. A, Twelve untrained individuals were randomized into two groups. Group 1 performed a suture task followed by a knot tying task, first with the ROVOT, then with a microscope. Group 2 performed the same tasks but using the microscope first, then the ROVOT. Each task was repeated three times. B, Within group analysis vs between group analysis is indicated. ROVOT, robotically operated video optical telescopic-microscope

Group 1 performed the surgical tasks with the ROVOT first, followed by the microscope. Group 2 performed the surgical tasks first with the microscope, then with the ROVOT. Each surgical task was performed three times (Figure **2**A).

2.2 Surgical tasks

The surgical task consists of two tasks: (a) a suture task and (b) a knot tying task. For the suture task, subjects were instructed to pick up the needle (3-0 nylon suture) with forceps and place it correctly into a needle holder. Immediately following this action, the subjects were to place three continuous simple stitches using a skin suturing simulator (examples shown in Figure **3**, Skin Pad Jig MK 3 (#00550) and Wound Closure Pad-small (#00044), **limbsandthings.com**). For the knot task, after the third stitch, an instrument knot with two throws was to be tied. Each task in sequence was repeated three times. Video recordings of the tasks were used to collect time to complete tasks. No facial features of the subjects were recorded. The subject's assigned number was visible on the video screen throughout each of their tasks. The person recording times was completely blinded to the subject's identity and group. Prior to the tasks, the subjects were provided verbal and visual instruction.

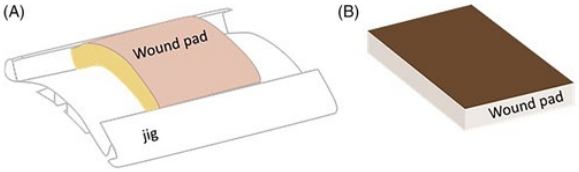

Figure 3 Examples of the Skin Pad Jig and wound pad used for the suture and knot tying tasks

After completing the task repetitions with an optical modality, each subject completed the NASA-Task Load Index (NASA-TLX) survey (**https://ntrs.nasa.gov/archive/nasa/casi.ntrs.nasa.gov/20000021488.pdf**). The NASA-TLX is a well-established, subjective, multidimensional assessment tool that rates perceived effort needed to complete a task (**https://humansystems.arc.nasa.gov/groups/tlx/**). The surveys were taken using the NASA-TLX app for iPad. The raw data were recorded in a spreadsheet for analysis. As a quantifiable, physiological measurement of effort, galvanic skin response (GSR) was collected during the performance of the research testing tasks. The GSR evaluates the autonomic nervous system, specifically the sympathetic component related to stress. Two disposable EKG electrodes were applied to the volar forearm. Using the Mindfield eSense system (**https://www.mindfield.de/en/**), GSR was continuously recorded during the surgical tasks. The trial took place in the Neurosurgical operating rooms at ASLMC. Attending Neurosurgeons skilled in both the microscope and ROVOT provided instruction and operating room setup can be seen in Figure **4**. Two ROVOTs, two microscopes, and two unaided eye stations were used. All testing was completed on the same day.

Figure 4 Image showing layout of operating room setup

2.3 Outcome measures

The primary outcome measure was time to complete each task. The secondary outcome measures were the perceived effort to complete the surgical tasks (NASA-TLX) and the GSR during the task completion.

2.4 Statistical methods

The demographics of the participants were described using appropriate descriptive statistics. Outcome variables were described as mean and SD. Within group and between group analyses were performed using repeated measures and two-way analysis of variance (ANOVA) (Figure **2**B). For all statistical tests, an alpha of 0.05 was used and all statistical analyses were carried out using SAS 9.4 version, SAS Institute, Cary, North Carolina.

3 RESULTS

Twelve subjects were enrolled and completed the study (Figure **2**A). The characteristics of the cohorts are summarized in Table **1**. There were six male and six female volunteers equally divided between the two groups. Each task was repeated for a total of three tries.

Table 1. Characteristics of the task groups

	Group 1 (n = 6)	**Group 2 (n = 6)**
Female	3	3
Right handedness	5	5
Education		
High school student	1	0
High school graduate	2	1
College student	3	4
College graduate	0	1
Classroom notes		
Handwritten	3	5
Digital	3	1
Video game hours/week		
0	3	3
1-5	1	3
6-10	2	0
Reverse driving		
Turn head	1	3
Rearview mirror	1	1
Backup camera	4	2
Racket/stick sports		
None	2	2
1–3 years	3	2
4–6 years	1	2

3.1 Time outcomes

The mean time to complete the tasks as well as the range of times for task completion is summarized in Table **2**. It took longer to complete the suture task with the ROVOT regardless of whether it was used first or second. This is graphically displayed using “time to complete” slopegraphs for individual subjects within each group and task (Figure **5**). For Group 1, all the subjects' times were better when using the microscope as opposed to the ROVOT (Figure **5**A, B *bottom left*). In Group 2, while one subject's time was better with the ROVOT than with the microscope (G2V5), the remaining subjects performed faster using the microscope (Figure **5**C).

Table 2. Time to complete tasks in seconds

		Suture task				**Knot tying task**			
		Mean	SD	Min	Max	Mean	SD	Min	Max
Group 1	ROF	379.3	214.9	105	901	87.2	74.4	20	228
	MSS	129.2	39.9	77	255	64.6	55.1	18	249
Group 2	MSF	207.1	78	119	364	70.3	37.3	25	181
	ROS	228.4	91.8	105	404	55.7	28.9	27	133

Abbreviations: MSF, microscope used first; MSS, microscope used second; ROF, ROVOT used first; ROS, ROVOT used second.

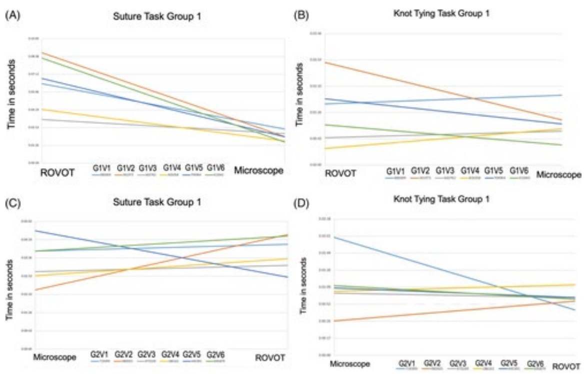

Figure 5 Slopegraphs showing individuals' performance during each task, divided by group. Each line is the time for an individual within that group, as indicated in the key for each part of the figure (ie, individuals within Group 1 are indicated by G1V1, G1V2, etc.). A,B, Group 1 performed either the suture task (A) and the knot tying task (B) using the ROVOT first followed by the microscope. C,D, Group 2 performed the suture task (C) and the knot tying task (D) using the microscope first, then the ROVOT. ROVOT, robotically operated video optical telescopic-microscope

For the knot tying task, using the microscope was faster in Group 1 (Figure **5**B), while the ROVOT was generally faster in Group 2 (Figure **5**D *bottom right* and Table **2**). One subject in Group 1 was able to complete the knot tying task faster using the ROVOT than the microscope (Figure **5**B, G1V1), while one of the subjects in Group 2 demonstrated a dramatically faster time using the ROVOT compared with the microscope (Figure **5**D, G2V1).

When the groups were analyzed for their time to complete the suture task, times to complete the task were significantly faster when using the microscope vs the ROVOT in Group 1 (129.2 ± 39.9 seconds vs 379.3 ± 214.9 seconds, *P* = .02, Table **3**), and although the microscope was faster in Group 2 as well, it did not reach statistical significance (207.1 ± 78 seconds vs 228.4 ± 91.8 seconds, *P* = .46, Table **3**). Upon comparison of Group 1 vs Group 2 for the suture task, using the ROVOT second was faster compared to using it first (*P* = .01). Using the microscope first was also faster than using the ROVOT first, although it did not reach statistical significance (*P* = .09). When the microscope was used second, the microscope was faster than when ROVOT was used second (*P* = .04). When the microscope was used second, the task was completed faster than when the microscope was used first (*P* = .05, Table **3**). This led to an analysis of the initial learning curve associated with either the microscope or the ROVOT. When the suture task was analyzed, time to complete the task significantly decreased with each try, regardless of whether the subjects were using the ROVOT (*P* = .01) or the microscope (*P* = .05, Table **4** and Figure **6**A). For the knot task, however, there was no significant improvement for either the ROVOT or microscope (Table **4** and Figure **6**B). When the data for the knot task were analyzed, analysis within the groups showed that Group 1 subjects completed the task faster with the microscope then the ROVOT, although it did not reach statistical significance (64.6 ± 55.1 seconds vs 87.2 ± 74.4 seconds, *P* = .31). However, subjects in Group 2 completed the task faster with the ROVOT than the microscope (55.7 ± 28.9 seconds vs 70.3 ± 37.3 seconds, *P* = .02, Table **3**).

Table 3. Analysis of task performance time within and between groups

	Suture task					**Knot tying task**				
	First variable		**Second variable**			**First variable**		**second variable**		
	Mean	SD	Mean	SD	*P*-value	Mean	SD	Mean	SD	*P*-value
Within group										
ROF vs MSS (Group 1)	379.3	214.9	129.2	39.9	**.02**	87.2	74.4	64.6	55.1	.31
MSF vs ROS (Group 2)	207.1	78	228.4	91.8	.46	70.3	37.3	55.7	28.9	**.02**
Between groups										
ROF vs ROS	379.3	214.9	228.4	91.8	**.01**	87.2	74.4	55.7	28.9	.1
ROF vs MSF	379.3	214.9	207.1	78	0.09	87.2	74.4	70.3	37.3	.63
MSF vs MSS	207.1	78	129.2	39.9	**.05**	70.3	37.3	64.4	55.1	.72
ROS vs MSS	228.4	91.8	129.2	39.9	**.04**	55.7	28.9	64.4	55.1	.73

Abbreviations: MSF, microscope used first; MSS, microscope used second; ROF, ROVOT used first; ROS, ROVOT used second.

Table 4. Learning curve

	Try 1	**Try 2**	**Try 3**
Suture task			
ROVOT	441.2	233.6	223.8
Microscope	206.8	157.6	140.1
Knot tying task			
ROVOT	73.3	83.5	54.8
Microscope	76.1	70.7	55.6

Note: Time for each try is in seconds.
Abbreviation: ROVOT, robotically operated video optical telescopic-microscope.

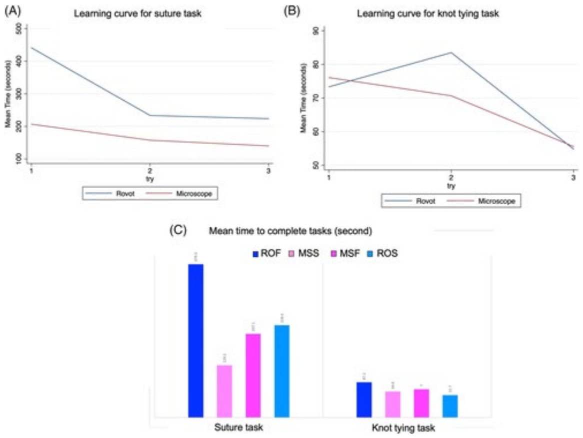

Figure 6 Learning curves for each task. All of the times for each of the 12 subjects involved in the study were compiled and are shown for the suture task (A) and the knot tying task (B). The time is shown on the *Y*-axis and each of the three[3] tries is shown on the *X*-axis. The blue line is the time when using the ROVOT, while the red line is the time using the microscope. (C) Bar graph showing the mean times for each component. The suture task is shown on the LEFT and the knot tying task is shown on the RIGHT. ROF ➔ ROVOT used first (blue bars), MSS ➔ microscope used second (light pink bars), MSF ➔ microscope used first (magenta bars), ROS ➔ ROVOT used second (light blue bars). MSF, microscope used first; MSS, microscope used second; ROF, ROVOT used first; ROS, ROVOT used second; ROVOT, robotically operated video optical telescopic-microscope

Between group analysis shows the ROVOT may have been faster when used second compared to being used first (*P* = .10). Thus, transfer effects were analyzed to determine whether the time to complete the tasks with a particular instrument improved (times decreased) when it was second. For example, was the time to complete a task with the ROVOT quicker than the microscope when it was used after the microscope to complete the task? If so, this would imply that the technical skills learned using one modality could be transferred to the second modality. For Group 1, both suture and knot task completions were faster with the microscope than with the ROVOT, suggesting practice with the ROVOT helps performance with the microscope. And for both tasks, using the microscope second was faster than using it first (Figure **6**C). For Group 2, completion time for the suture task using the microscope was faster than completion time using the ROVOT. However, the ROVOT completion time in Group 2 was considerably faster than in Group 1. For the knot task, Group 2 subjects completed the task quicker with the ROVOT than with the microscope and the ROVOT time was once again faster when it is used second than when it is used first (Figure **6**C).

Using a two-way ANOVA, a model was fitted with “group,” “gender,” and “interaction” as factor variables and “time to complete task” as the response variable. For the suture task, group was the only significant factor variable for both the ROVOT (*F*[34] = 7.01, *P* = .013) and the microscope (*F*[35] = 14.97, *P* = .0005). For the knot tying task, group, gender, and their interaction were not significant factor variables. No statistically significant differences in time to complete the suture and knot tasks based on gender were found.

3.2 Perceived workload

In addition to the quantitative measure of time, the subjects' perception of their workload was also analyzed. The NASA-TLX survey was completed after each set of tasks. The mean scores for each of the six subscales, segregated by group, are presented in Table **5** and graphically in Figure **7**A,B. In Group 1, perceived workloads were greater with ROVOT use in all but the physical scale. Perceived performance was better with the microscope (*P* = .006), and workload was perceived to be lower in the mental (*P* = .002), effort (*P* = .003), and frustration (*P* = .023) scales. Physical demands were perceived to be greater with the microscope (*P* = .67). In Group 2, there were no statistically significant differences, although there was a tendency toward a reduced workload and increased performance when using the microscope (Figure **7**C).

Table 5. NASA-TLX results

	Group 1					**Group 2**				
	ROF		**MSS**			**ROF**		**MSS**		
	Mean	SD	Mean	SD	*P*-value	Mean	SD	Mean	SD	*P*-value
Mental	75.8	4.9	53.3	13.3	**.002**	68.3	14.4	79.2	10.2	.13
Physical	23.3	16.9	25.8	14.6	.67	33.3	22.3	40.8	32.9	.28
Temporal	45.8	24	40	26.8	.51	45.8	28.9	53.3	24.8	.32
Performance	57.5	24	26.7	13.7	**.006**	39.2	20.8	45.8	22.7	.44
Effort	75	9.5	54.2	13.6	**.003**	74.2	9.2	78.3	5.2	.34
Frustration	61.7	15.7	31.7	20.9	**.02**	50	26.5	52.5	20.7	.87

Abbreviations: MSF, microscope used first; MSS, microscope used second; NASA-TLX, NASA-Task Load Index; ROF, ROVOT used first; ROS, ROVOT used second.

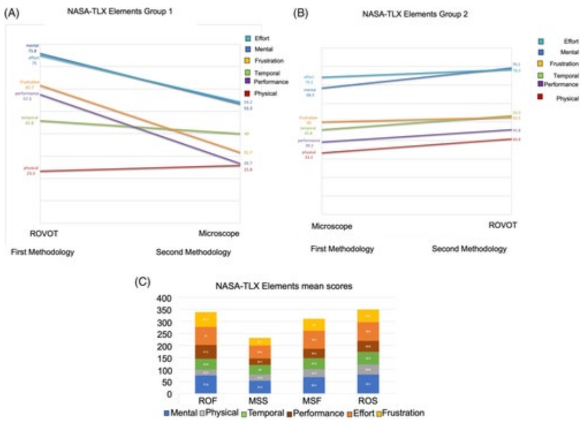

Figure 7 Analysis of NASA-Task Load Index (TLX). A,B, Slopegraph comparisons between the ROVOT and the microscope, whether used first (Group 1, A) or second (Group 2, B). C, Element means are shown for each method and time. ROF ➔ ROVOT used first, MSS ➔ microscope used second, MSF ➔ microscope used first, ROS

➔ ROVOT used second. MSF, microscope used first; MSS, microscope used second; ROF, ROVOT used first; ROS, ROVOT used second; ROVOT, robotically operated video optical telescopic-microscope

3.3 Physiological measures

Lastly, a physiological measure of effort using GSR was analyzed. In Group 1, the GSR was higher during microscope use compared to ROVOT use (approximately twice as high). In Group 2, there was an increase in GSR from microscope to ROVOT (Table **6**).

Table 6. Galvanic skin response results

	Group 1					**Group 2**				
	ROF		**MSS**			**MSF**		**ROS**		
	Mean	SD	Mean	SD	*P*-value	Mean	SD	Mean	SD	*P*-value
Maximum	16.7	4.5	32.6	25.1	**.04**	15.5	8.3	19.5	5.3	.17
Minimum	2.6	4.9	7.8	7.2	.05	2.8	4.1	2.2	2.2	.66
Difference	14.1	4.5	24.8	21.8	.11	12.7	7.8	17.4	6.6	.13

Note: Units are in microsiemens.
Abbreviations: MSF, microscope used first; MSS, microscope used second; ROF, ROVOT used first; ROS, ROVOT used second.

4 DISCUSSION

Visual perception, stereoscopy, and 3D proprioception and perception have been guiding principles in the development of optical technologies to enable neurosurgery. As a result, these systems have greatly evolved from the standardization of the operating microscope, to the validation of the endoscope, and to the recent addition of exoscopic visual systems including the robotically operated video optical telescopic system or ROVOT. The benefits of the ROVOT include maneuverability, ergonomics, and increased volume of view, while the inherent disadvantages include the lack of stereoscopy and 3D perception and proprioception.[10, 11] In this study, naïve subjects with no preconceived notions or biases were asked to complete surgical tasks using either the ROVOT or a microscope with the aim of assessing the relative impact of these critical visual cues on the performance of surgical tasks.

Not unexpectedly, our volunteers found the lack of stereoscopy and 3D proprioception challenging. The time to complete the suture task was longer with the ROVOT compared to the microscope, regardless of whether it was used before or after the microscope. The time to complete the knot tying task took longer when the ROVOT was used first, although Group 2 subjects completed the knot tying task more quickly with the ROVOT. Similarly, perceived workload was greater with the ROVOT compared to the microscope in all domains of the NASA-TLX survey except for the physical domain in Group 1. In regard to the GSR measurement, the mean values were greater for the second modality used by each group, suggesting increased physiological stress over time. Several reports have documented the impact of stereoscopic depth perception, 3D perception, and proprioception in neurosurgery with the use of certain optical systems. Moisi et al[12] described their initial experience with exoscopic optical systems in neurosurgery and commented on the operating microscope's inherent advantage due to stereoscopic depth perception, especially in deep-seated surgery (ie, aneurysm clipping or skull base surgery) where deep drilling and delicate nerve and vessel manipulation is required.[12] The lack of these optical cues has led to the hesitancy in the adoption of two-dimensional (2D) exoscopic systems in neurosurgery. Additionally, several reports have assessed the time needed for adaptation to nonstereoscopic optical systems in performing surgical tasks. In one specific example in a spinal surgery, which required 24 spine decompressions and fusions, Shirzadi et al[13] commented on the distinct visual discomfort when transitioning to exoscopic systems lacking stereopsis.[13] Other studies have shown that even an experienced surgeon requires approximately 60 minutes of time and up to 17 procedures to adapt and accommodate exoscopic visualization in widely used visualization methods such as transnasal or endonasal skull base surgeries.[7, 14] Our data confirm that there is a learning curve with both of the optical platforms we evaluated. The time to complete the third try of a task with either the ROVOT or the microscope was shorter than the time to complete the first try. Not unexpectedly, a transfer effect was also documented. The time to complete the tasks with the microscope were faster when it followed ROVOT use and vice versa. This suggests that practice with either modality improves performance with the subsequent modality.

In this a preliminary, hypothesis-generating study, we sought to assess the impact of stereoscopic depth perception, 3D perception, and proprioception on learning and performing tasks with a 3D (ROVOT) and 2D (surgical microscope) device in unbiased, untrained subjects. Although we hypothesized that performance would be no different between the two modalities, in actuality, we observed greater effort in task performance and a longer time to successfully complete tasks when using the ROVOT as compared with the microscope, indicating that there is a lag in performance in untrained subjects. However, similarly to previous authors, the task performance and acquisition of stereoscopic depth perception, 3D perception and proprioception improved after several attempts, indicating that even untrained subjects are able to perform tasks using unfamiliar methodologies.

A major limitation of this study is its small sample size. Several observations might become significant with a larger sample size. Future studies will focus on increasing the number of naïve subjects recruited as well as include neurosurgeons in training and practicing neurosurgeons with varying degrees of experience with 2D and 3D optical systems.

In conclusion, the times to complete the surgical tasks were longer and perceived effort greater when using the ROVOT compared to the surgical microscope, most likely related to the 2D vs 3D experience. More importantly, times improved with repeated attempts and the skills learned when using one modality apply to the other (transfer effect). Taken together, the modalities are not mutually exclusive and practice with one modality will improve competency with the other.

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CONFLICT OF INTEREST

Amin Kassam reports involvement as a consultant to Synaptive Medical, KLS Martin Medical, the Medtronic Advisory Board, and founder and CEO of Neeka Health, LLC.

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