Is Virtual Reality Surgical Performance Influenced by Force Feedback Device Utilized?

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OBJECTIVE: The study objectives were to assess if surgical performance and subjective assessment of a virtual reality simulator platform was influenced by changing force feedback devices.

DESIGN: Participants used the NeuroVR (formerly NeuroTouch) simulator to perform 5 practice scenarios and a realistic scenario involving subpial resection of a virtual reality brain tumor with simulated bleeding. The influence of force feedback was assessed by utilizing the Omni and Entact haptic systems. Tier 1, tier 2, and tier 2 advanced metrics were used to compare results. Operator subjective assessment of the haptic systems tested utilized seven Likert criteria (score 1 to 5).

SETTING: The study is carried out at the McGill Neurosurgical Simulation Research and Training Centre, Montreal Neurological Institute and Hospital, Montreal, Canada.

PARTICIPANTS: Six expert operators in the utilization of the NeuroVR simulator platform.

RESULTS: No significant differences in surgical performance were found between the two haptic devices. Participants significantly preferred the Entact system on all 7 Likert criteria of subjective assessment.

CONCLUSIONS: Our results show no statistical differences in virtual reality surgical performance utilizing the two bimanual haptic devices tested. Subjective assessments demonstrated that participants preferred the Entact system. Our results suggest that to maximize realism of the training experience educators employing virtual reality simulators may find it useful to assess expert opinion before choosing a force feedback device. (J Surg Ed 76:262–273. © 2018 Association of Program Directors in Surgery. Published by Elsevier Inc. All rights reserved.)

KEY WORDS: Neurosurgery, Neurosurgical virtual reality and simulation, Haptic and force feedback, Surgical simulation, Surgical training

COMPETENCIES: Patient Care, Medical Knowledge, System-Based Practice

INTRODUCTION

Haptic feedback is defined as the combination of tactile feedback through sensory skin receptors and the

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kinaesthetic feedback through muscle, tendon, and joint sensory receptors.[1,2] Application of haptic feedback systems to virtual reality scenarios increases virtual tissue manipulation realism.[2,3] The utilization of specific haptic feedback systems has been shown to influence endoscopic and robot-assisted surgery training performance.[4-7] Haptic feedback is important for effective surgical skills training using virtual reality simulation.[2,5,6,8-10] Multiple studies have demonstrated that haptic feedback incorporation into VR training systems results in higher performance accuracy, faster skills acquisition, and expedited skills transfer.[1-3,5,6,9,11,12] Reduced haptic feedback may result in an undesirable training effect.[6,13] Surgeons state that realistic haptic feedback is an important element of virtual reality surgical simulator performance.[4,14] Defining the role played by haptic feedback systems in virtual reality platforms is therefore critical to obtain accurate assessment and training results from these systems.

There are several commercially obtainable haptic devices for use with neurosurgical virtual reality simulators. It is not known how utilization of these different systems influences operator performance and evaluation.[2] The Neurosurgical Simulation Research and Training Centre at McGill University has two haptic and interchangeable feedback devices, compatible with the NeuroVR (formerly NeuroTouch) simulation platform available. The majority of our studies have utilized the PHANTOM Omni (Sensable Technology, Wilmington, MA).[15-17] The availability of a second compatible Entact system (Entact Robotics, ON, Canada) has allowed us to assess if expert operator performance was influenced by the haptic system utilized (Fig. 1). The major technical differences between the two haptic systems studied are outlined in Table 1. This study was designed to address two questions: (1) Is surgical performance on the NeuroVR simulator platform influenced by changing the force feedback device? and (2) Does expert subjective evaluation depend on the haptic device utilized?

METHODS

Subjects

Six NeuroVR system experts participated in this study. The aim of including NeuroVR experts was to eliminate or minimize the effect of learning on performance. This increased the possibility that the critical variable factor being tested was the haptic feedback device utilized and not the experience of the operator. Participants were considered NeuroVR experts if they were using the NeuroVR system on a daily basis for their postgraduate and research studies. Five NeuroVR experts were right handed. Participants signed an approved McGill University Ethics Review Board Consent. There was no financial or other compensation for participation in the study.

The NeuroVR Simulator

The previously described NeuroVR platform was used to conduct this study (Fig. 2).[15-31] Tumor resection was carried out utilizing a simulated ultrasonic aspirator held in the dominant hand and a simulated bipolar instrument held in the nondominant hand (Fig. 1b and d).

Simulation Scenarios

The virtual reality scenario developed for this trial is called the subpial resection scenario. It has two models, a practice and a realistic model (Figs. 3 and 4). The practice model includes a yellow strip, representing the tumor covered by a simulated pial membrane. This practice tumor scenario was designed to be anterior to an initially hidden small-simulated vessel lying just posterior to the tumor (Fig. 3c). The white background simulates the "normal" white matter. A demonstration of the task is shown in Supplemental Video 1. The stiffness of the simulated tumor and white matter are soft (Young's modulus 3 KPa). The realistic scenario simulates an intrinsic glial tumor of irregular shape in the right posterior frontal area (Fig. 4). A demonstration of the task is shown in Supplemental Video 2. Both scenarios have a vessel(s) that can be injured during removal and the realistic model has scattered bleeding points.[17] The reason for including the practice model was to determine if there was evidence of a learning curve that may influence results. This should be less common if only experts are included in the trial. This also added another scenario for comparing expert group performance between the two haptic systems.

Study Procedure

To deal with the issue of participants gaining knowledge of the simulations that could be utilized to enhance their performance on the second haptic system being assessed, the 6 participants were divided into 2 groups of 3. Group 1 started the trial by doing the subpial resection scenarios, first the practice and then immediately the realistic model using first the Omni haptic feedback device and then repeating the same scenarios using the Entact system. Group 2 started the scenarios using the Entact force feedback device and then repeated the scenarios using the Omni system. Participants were given verbal and written instructions stating that the goal of the scenarios was to remove the simulated tumor using the simulated ultrasonic aspirator without damaging the adjacent simulated normal brain tissue and vessel(s). The simulated bipolar instrument could be used to lift and retract the simulated pial membrane to gain access to the simulated tumor and cauterize bleeding vessels as needed. Using each haptic device, participants did the practice scenario 5 times and then the realistic scenario (total of 12 resections). The duration of the simulated resection procedure was 3 minutes for each practice model (total 15 minutes) and 13

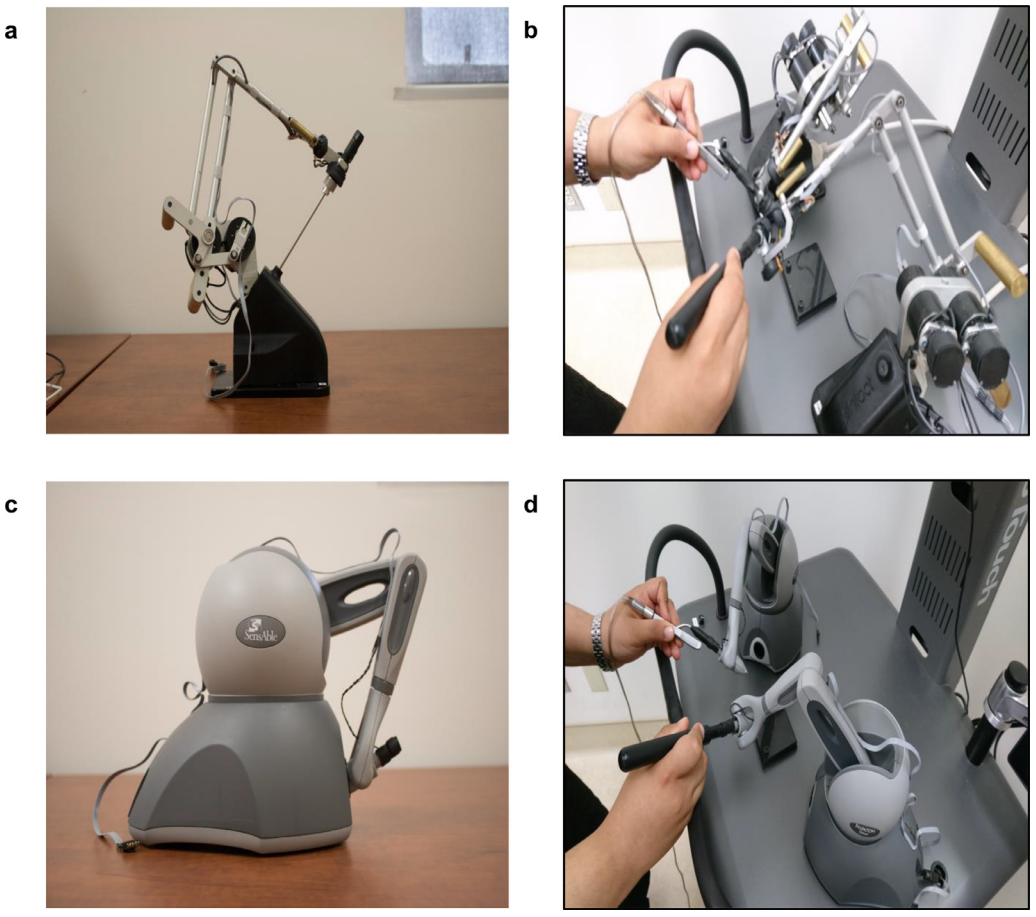

FIGURE 1. (a) The Omni force feedback device. (b) Participant using the force feedback Omni device. The right hand is holding the simulated cavitron and the left hand the simulated bipolar instrument. (c) Entact force feedback device. (d) Participant using the force feedback Entact device. The right hand is holding the simulated cavitron and the left hand the simulated bipolar instrument.

TABLE 1. Major Characteristics of the Omni and Entact Force Feedback Devices

Haptic Device Specification	3D Systems Touch (Omni)	Entact Dual 3DOF
Workspace (mm x mm x mm)	160 × 120 × 70	135 × 150 × 150
Maximum peak force (N)	3.3	2.0
Maximum continuous force (N)	0.88	0.7
Backdrive friction (N)	0.26	0.0025

Millimeter (mm), Newton (N)

minutes for the realistic model. These time periods had been previously determined to allow experts adequate time to resect the simulated tumors. Immediately following completion of the scenarios utilizing both haptic devices, the participant filled a 7 Likert criteria assessment questionnaire of their subjective assessment (score 1-5) of the NeuroVR with the haptic feedback devices they had just used.

Participants' psychomotor performance during the simulated resection procedure was assessed using metrics previously published by our group.[16] Tier 1 metrics included: tumor percentage resected, volume of simulated normal brain removed (surrounding 'normal' white and grey matter), and amount of blood loss. Tier 2 metrics involved: total tip path length, sum of forces utilized, and maximum force applied. Advanced tier 2 metrics assessed included efficiency and coordination indices.

Statistical Analysis

All statistical analyses were performed using R software version 3.2.3 (The R Foundation for Statistical Computing). For comparison between the participants' Entact haptic device performance versus their Omni haptic

FIGURE 2. The NeuroVR virtual reality platform.

device performance on each metric, Paired Samples Wilcoxon Test was used. For comparing performance on the 5 practice models, Friedman test was used followed by Paired Samples Wilcoxon Test for pairwise comparison. Values are represented as means ± standard error of mean and p values < 0.05 were considered significant.

RESULTS

Demographics

The mean age of participants was 32.2 ± 5.4. Two participants were board certified neurosurgeons and 4 were neurosurgical residents and researchers.

Practice Scenario

Learning Curve

All tier 1, tier 2, and advanced tier 2 metrics were able to be assessed. Statistical comparison of performance on the 5 practice scenarios for individual haptic devices showed no statistical difference in the metrics for both haptic devices for 10 of the 12 metrics assessed (Figs. 5-7). When using the Omni device tumor percentage removed showed statistically significant increases between practices 1 and 5 and between practices 2 and 4 (Fig. 5). Significant increases in brain volume removed were also found between practices 1 and 4, 1 and 5, and 2 versus 3, 4, and 5 using the Omni device (Fig. 5). Brain volume removed showed statistically significant increases between practices 1, 2, 3, 4 versus 5 when utilizing the Entact device.

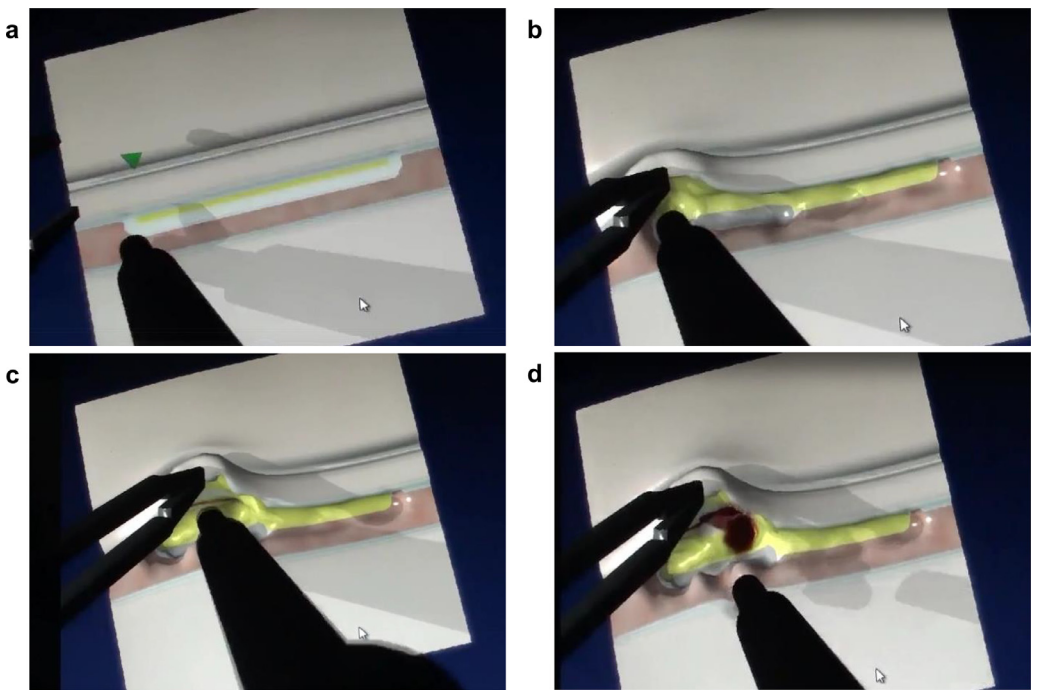

FIGURE 3. Simulated practice scenario operative view with simulated cavitron and bipolar instruments.
(a) Practice scenario before resection. (b) The participant elevating the pia with the bipolar and resecting the tumor. (c) Practice scenario exposing the presence of hidden vessel behind the tumor. (d) Injury to the vessel with subsequent bleeding.

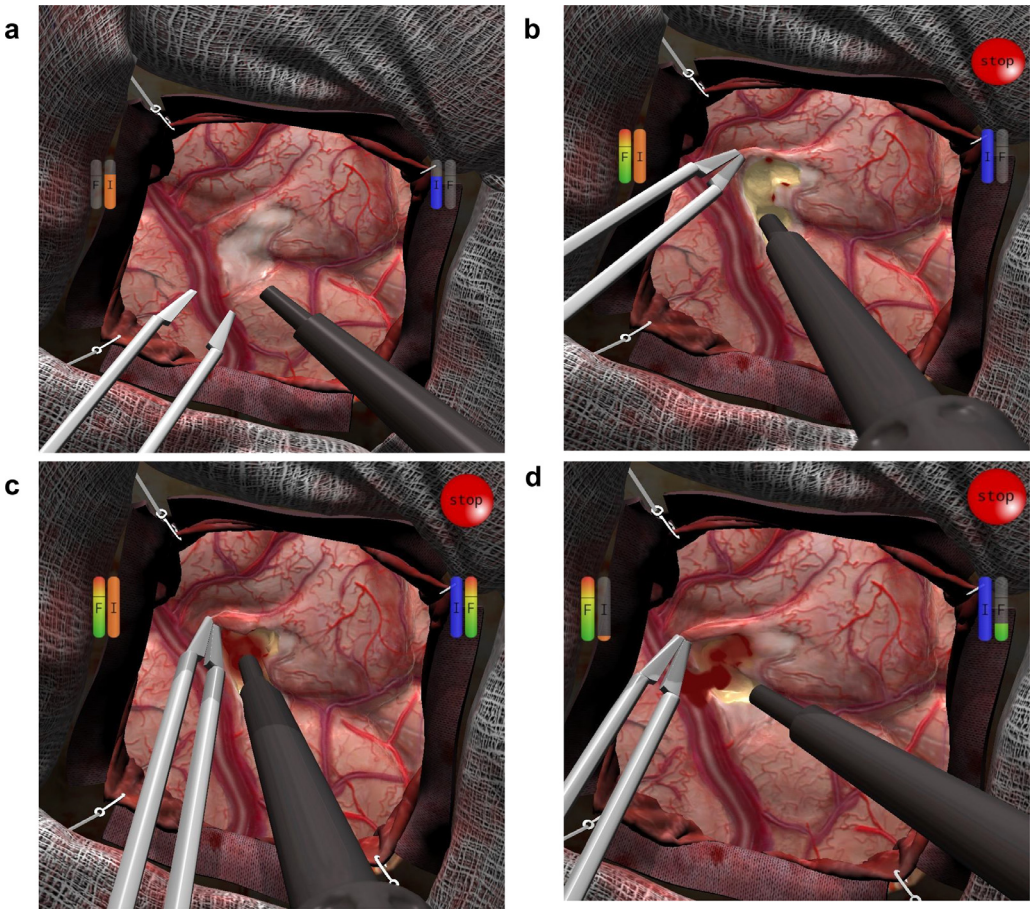

FIGURE 4. Simulated realistic scenario operative field view with simulated cavitron and bipolar instruments.
(a) Realistic scenario before resection. (b) The participant elevating the pia and resecting the yellow tumor with bleeding points. (c) Blood escaping from the tumor simulated vessels during resection. (d) Injury to large vein with subsequent bleeding. (Color version of figure is available online.).

Our results are consistent with the absence of a learning curve for the majority of the metrics assessed (10 of 12 metrics). However, the NeuroVR experts studied did significantly increase tumor percentage removed with the Omni haptic device and brain volume removed with both devices tested suggesting learning was occurring during these two metrics.

Performance Using the Entact System Compared to the Omni System

Participant performance showed no statistical differences in all the assessed metrics on the 5 practice scenarios when the Entact and Omni haptic devices were compared. On the total tip path length metric, a trend toward higher total tip path length was noted when using the Entact device for both the dominant and nondominant hands (Fig. 6). Therefore, we averaged the five practice scenarios total tip path length results and compared the two devices. Statistically significant higher total tip path lengths were found when using the Entact device for both the dominant and nondominant hands (Fig. 8).

Realistic Scenario

Statistical analysis of performance on the realistic model when using the different haptic systems showed no significant differences in all the assessed metrics (results not shown).

Subjective Evaluation

On the Likert questionnaire, participants showed statistically significant participant preference for the Entact device in all 7 subjective assessments (Fig. 9). Two participants commented that the Omni haptic device was heavier and the element of instrument friction needed to be improved. The Entact system comments stated that the simulated instruments appeared lighter, smoother and had a more realistic resemblance to instruments used in the operating room.

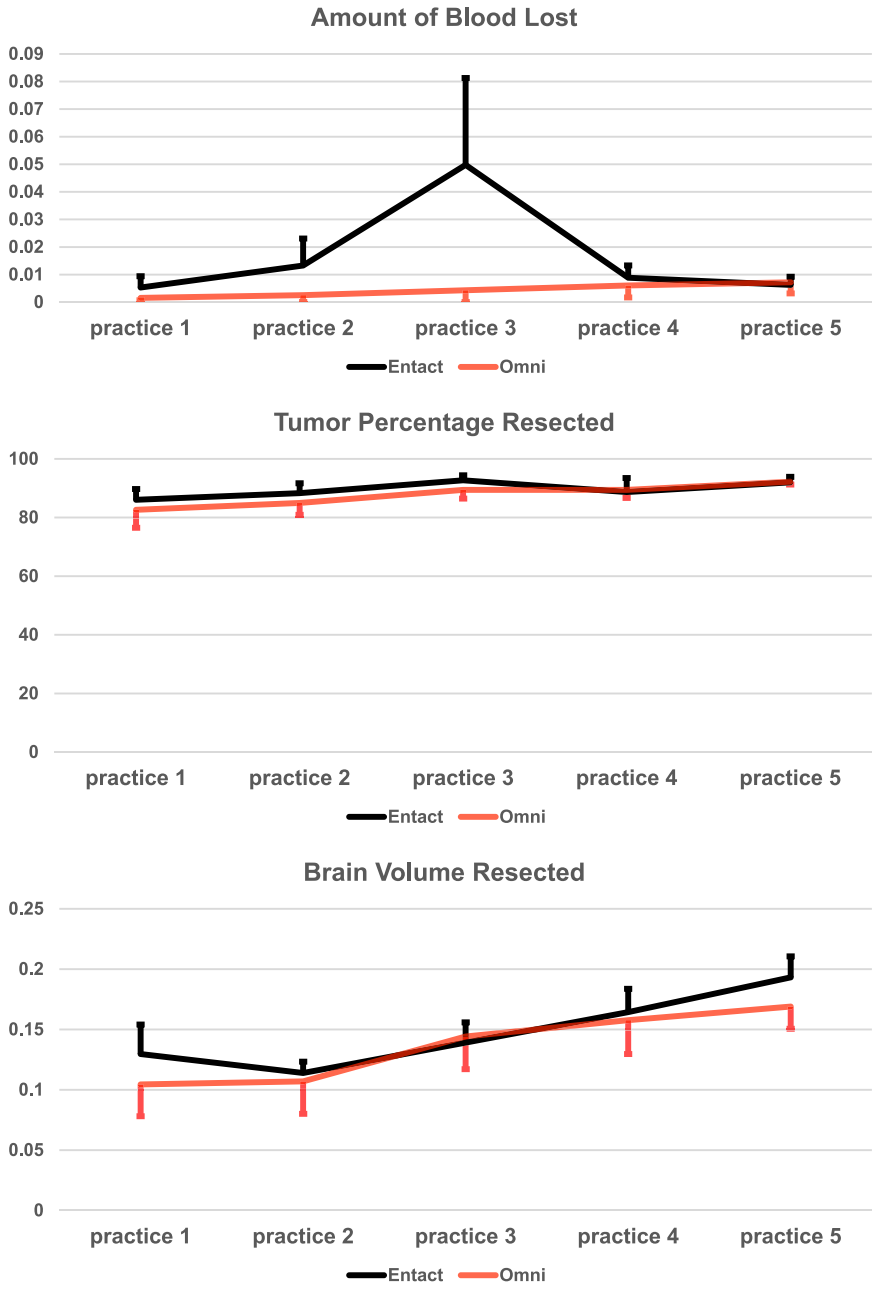

FIGURE 5. Tier 1 metrics results for the 5 practice scenarios for the Omni and Entact haptic devices. To improve understanding overlying values are represented as means and standard error of mean.

DISCUSSION

To assess the first study question of whether surgical performance on virtual reality simulator was affected by different force feedback devices, a number of concerns needed to be addressed. First, to deal with the possibility of a learning curve only NeuroVR platform experts participated in the trial. NeuroVR platform experts were recruited from neurosurgical researchers who were doing their virtual reality research on the NeuroVR platform. A practice scenario involving the repeated removal of an identical simple subpial tumor on 5 occasions employing each haptic system was designed to assess the presence of a learning curve. Our results showed that there were no statistically significant differences when progressing from practice 1 to practice 5 in 10 out of the 12 metrics assessed. Some learning may have occurred in both haptic systems assessed in the other 2 metrics. Second, to address the possibility that carrying out the initial trial on the

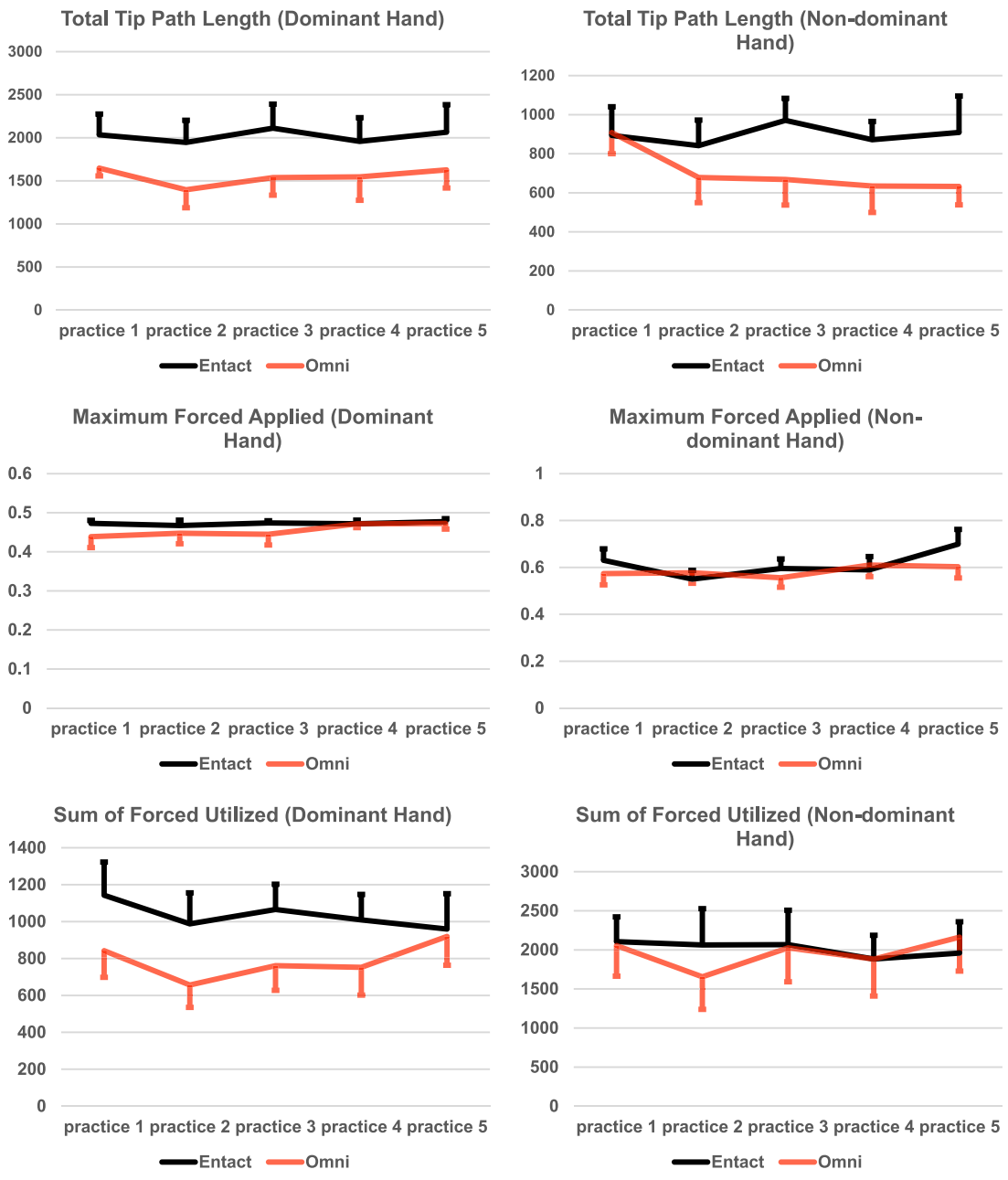

FIGURE 6. Tier 2 metrics results for the 5 practice scenarios for both the Omni and Entact haptic devices. To improve understanding overlying values are represented as means and standard error of mean.

first of the two platforms would influence the second trial the participants were divided into two groups. Group 1 started with the Omni followed by the Entact system and Group 2 did the opposite to address this concern. Beginning with the Omni or Entact system did not have a statistical influence on results. The trial was not designed to assess if initial exposure to one or the other haptic device would influence results on the following realistic scenario. However, since no statistical differences were identified using the realistic scenario model this would suggest participants operated the same scenario twice. Once using the Entact and the second using the Omni system. If all participants started by systematically using one specific system e.g Omni and then used the second, the Entact, improvements in performance with the second system might be because of previous exposure using the first system. We overcame that in the study design by dividing the groups into two. Each group started with a different system and then shifted to the other. Like that if any differences in performance are found, it should not be

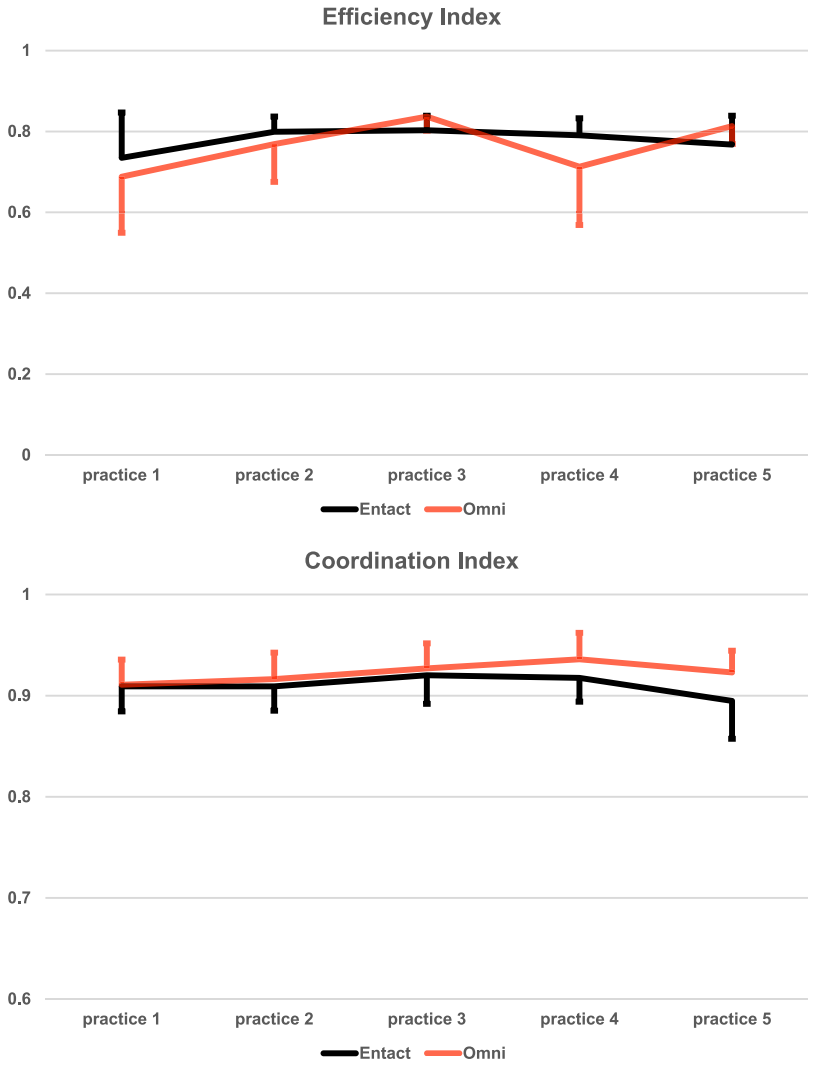

FIGURE 7. Advanced tier 2 metrics results for the 5 practice scenarios for both the Omni and Entact haptic devices. To improve understanding overlying values are represented as means and standard error of mean.

because of learning from the previous system as one group should have started by the system. Anyhow, after analyzing the results we did not find any differences in performance which means that the two systems are equivalent.

There were no statistical differences, in all the assessed metrics, in participant performance on the 5 practice scenarios and the realistic scenario when Omni and Entact devices were compared. A trend for participants utilizing the Entact system to employ higher total tip path lengths was found. This was only significant if all values were averaged. This may be related to the Entact device having 2.3 times the workspace of the Omni system which allowed more freedom of movement (Table 1).

To answer the second study question to evaluate the subjective assessment of NeuroVR experts of the two force feedback devices a Likert questionnaire with 7 subjective assessments was designed. The results of the subjective evaluation showed that the Entact system was statistically significantly preferred in all subjective assessments studied. Participants commented that the Entact haptic devices were lighter, smoother, and more realistic. The larger working area and the less back-drive friction in the Entact haptic system may have contributed to this impression (Table 1). Although the two haptic systems assessed provided equivalent results on the metrics assessed the subjective results show that expert participants preferred the Entact handles. The reasons for the divergence of these two results may need to be considered in the further development of bimanual haptic devices.[32] Our results indicate that educators involved in training using virtual reality simulators should evaluate expert opinion before choosing the force feedback device to maximize realism of the training experience.

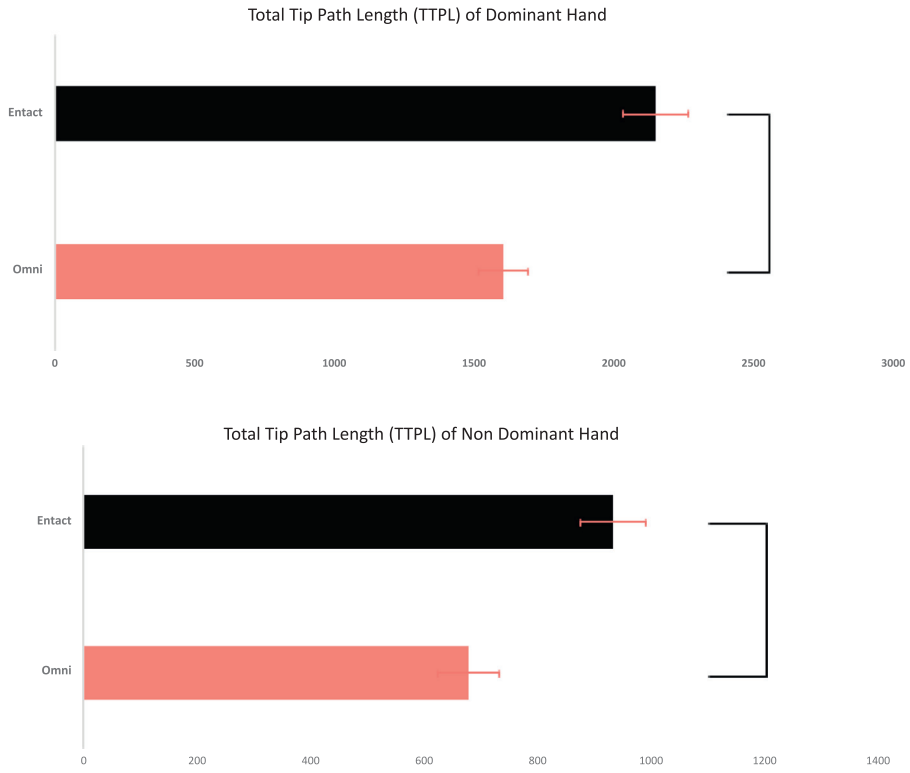

FIGURE 8. Mean total tip path length of the dominant and nondominant hands. Values represent the mean ± standard error of mean. Lines indicate statistical significance $p < 0.05$.

Strength and Limitations of the Study

To our knowledge, this is the first study comparing expert performance on two different force feedback devices involving the same simulator and identical scenarios. Our results demonstrate equivalency of the two systems assessed in terms of expert performance. However, experts' subjective evaluation showed statistically increased resemblance of one system to the real surgical environment. This study has a number of limitations. First, the low number of NeuroVR experts included in this study was due to our desire to include only participants with substantial virtual reality experience and whose research was dependent on the NeuroVR platform. Our reason for doing this was to limit the influence of learning on results. The fact that no statistical evidence of learning occurred in 10 of 12 metrics for the Omni and 11 of 12 metrics for the Entact systems supports this approach. Whether increasing the number of NeuroVR experts or including less expert participants would alter results is unknown. Second, the information provided is limited to the scenarios tested. Different scenarios may have provided other results but the utilization of the most complex practice and realistic brain tumor virtual reality scenarios available suggests that our results may be representative of virtual reality scenarios on the NeuroVR platform. To develop and assess virtual reality scenarios for the multiple disciplines involved in surgical care will require the creation and testing of haptics specifically designed to simulate the haptic realism of the operations involved. For example, the simulation of some orthopedic procedures will clearly involve haptic systems capable of providing feedback of higher force application then assessed in the studies outlined in this communication. We have developed a series of validated metrics with haptics specifically designed for endoscopic sinus surgery which confirms that haptic systems can be modified to accomplish individual virtual reality simulation goals.[19,20] It seems reasonable to suggest that the principle of evaluating expert opinion for choosing the most realistic haptic feedback to employ is both useful and applicable for all surgical disciplines. Third, we have developed a number of more complex tier 3 metrics utilizing the force pyramid approach.[27,28,31] Our results do not allow us to assess if operator performance employing the force pyramid approach would be influenced by the different haptic devices utilized. Fourth, since we were only able to assess expert performance on two available force feedback systems our results can only be applied to these two systems and the NeuroVR simulator platform.

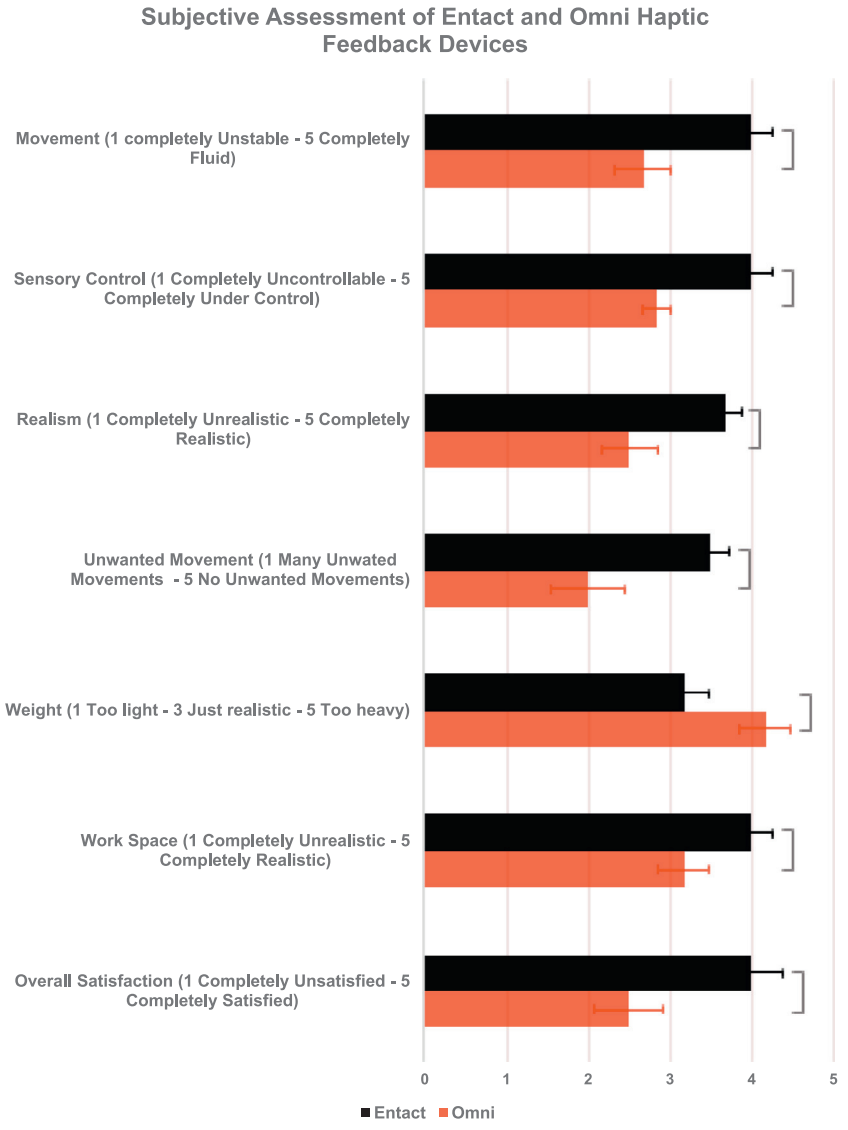

FIGURE 9. Subjective evaluation questionnaire with results. N = 6, values represent the mean ± standard error of mean. Lines indicate statistical significance $p < 0.05$.

CONCLUSION

Our results show equivalency in expert performance utilizing the Omni and Entact haptic feedback devices utilizing the scenarios and metrics assessed. Subjective assessments demonstrated that participants preferred the Entact system. Our results suggest that to maximize realism of the training experience, educators employing virtual reality simulators may find it useful to assess expert opinion before choosing a force feedback device.

DISCLOSURE

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SUPPLEMENTARY INFORMATION

Supplementary data associated with this article can be found in the online version at doi:10.1016/j.jsurg.2018.06.012.