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ORIGINAL ARTICLE

Assessing performance in brain tumor resection using a novel virtual reality simulator

Nicholas Gélinas-Phaneuf · Nusrat Choudhury · Ahmed R. Al-Habib · Anne Cabral · Etienne Nadeau · Vincent Mora · Valerie Pazos · Patricia Debergue · Robert DiRaddo · Rolando F. Del Maestro

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Abstract
Purpose NeuroTouch is a virtual reality (VR) simulator developed for neurosurgical skill training. Validation demonstrating that the system is useful and reliable is required for formal adoption into training curriculums. Face and content validity have been demonstrated for some neurosurgical simulators, but construct validity remains difficult to establish. A pilot validation study was conducted for a NeuroTouch training exercise.
Methods Participants completed the internal resection of a simulated convexity meningioma and filled out questionnaires to provide feedback on the experience. Performance metrics included volume of tissues removed, tool path lengths, duration of excessive forces applied and efficient use of the aspirator. Results were analyzed according to participants' level of training, gender, handedness, surgical experience in meningioma removal and hours/week playing musical instruments or video games.
Results Seventy-two participants (10 medical students, 18 junior residents and 44 senior residents) were enrolled. Analyses demonstrated statistically significant increase in tumor removed and efficiency of ultrasonic aspirator use between medical students and residents, but not between junior and senior residents. After covariate adjustment for the number of meningioma cases operated on, multivariate analysis of the level of training became non-significant. Participants judged the exercise appropriate and realistic, desiring use of the system in current training programs.
Conclusion We have conducted a pilot validation study for the NeuroTouch tumor resection scenario and demonstrated for the first time, face, content and construct validity of a VR neurosurgical simulation exercise. Future full-scale studies will be conducted in noncompetitive settings and incorporate expert participants.

Keywords NeuroTouch · Virtual reality simulation · Haptic feedback · Brain tumor resection · Neurosurgical oncology · Performance metrics

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N. Gélinas-Phaneuf (✉) · R. F. Del Maestro (✉)
Department of Neurosurgery and Neurology,
Neurosurgical Simulation Research Center,
Montreal Neurological Institute and Hospital, McGill University,
4th floor, Montreal Neurological Hospital, 3801 University,
Suite 438M, Montreal, QC H3A 2B4, Canada
e-mail: nicholas.g.phaneuf@gmail.com

R. F. Del Maestro
e-mail: rolando.delmaestro@mcgill.ca

N. Choudhury · A. Cabral · E. Nadeau · V. Mora · V. Pazos ·
P. Debergue · R. DiRaddo
National Research Council Canada, Boucherville, QC, Canada
e-mail: nusrat.choudhury@nrc.ca

A. R. Al-Habib
Royal College of Surgeons in Ireland, Dublin, Ireland

Abbreviations

AANS	American Association of Neurological Surgeons
NRC	National Research Council
VR	Virtual reality
PGY	Postgraduate year

Introduction

Virtual reality (VR) surgical simulators have evolved over the last 20 years [1,2] and have been assessed, validated and utilized, predominantly in the field of laparoscopic surgery [3]. Simulation technologies have also been developed for more intricate neurosurgical procedures [4–6]. A number of simulators, employing different hardware configurations, are being used to achieve specific training objectives. One such advanced technology, called NeuroTouch [7,8], has been developed by the National Research Council Canada (NRC) along with a Consortium of Canadian Universities and Hospitals. The platform provides the user with an immersive experience approaching reality with haptic touch feedback and stereoscopic (3D) vision.

In order to integrate a technology into a formal training curriculum, it must be proven that training on the simulator is useful and appropriate. There is a well-established series of validation steps to be undertaken: face, content, construct and concurrent validity [9,10]. Face and content validity determine that the simulation is realistic and targets training skills that are required to be trained. The most important goal is determining whether the simulator is useful as a training tool is to demonstrate its construct validity [11]. Construct validity establishes that the scores obtained in simulation correlate with actual operative technical skill by discriminating novices from experts. This will enable novices to practice and train on the simulator until they reach the performance of an expert. The final step, concurrent validity is particularly important, should be the simulator used for assessment as it demonstrates that the skills acquired during training on the simulator reflect performances in the operating room.

Although a number of currently marketed simulators have demonstrated up to construct and concurrent validity [12–18], this has yet to be shown for a neurosurgical simulator [19,20]. In neurosurgery, we have only begun the validation process for existing simulators. Face and content validity have been demonstrated for some neurosurgical simulation exercises [21–23], but construct validity has been more difficult to establish. The objective of this work was to conduct a pilot validation study to begin to investigate face, content and construct validity for the NeuroTouch brain tumor resection training exercise.

To this end, the simulator was used in a competitive setting at the Young Neurosurgeons Committee's Top Gun competition held at the AANS annual meeting in Denver, CO (April 2011). The NRC team was invited to submit a challenge as part of this event. The Top Gun challenge is a friendly competition with the purpose of pitting residents against each other on their technical skills proficiencies. The setting permitted the investigation of output performance scores of medical professionals who had varying baseline characteristics.

To design a simulated VR task that could be used in a competitive setting, we modified the existing software and hardware of the NeuroTouch platform. The primary objective of this study was to assess whether specific characteristics of participants would impact their performance on a simulated neurosurgical exercise using NeuroTouch. The removal of a meningioma-like convexity tumor was chosen as the exercise since this simulation involved a bimanual task employing both an ultrasonic aspirator (right hand) to remove tumor and a suction (left hand) to remove bleeding in a stereoscopic VR environment with haptic feedback.

Methods

Study population

This study was conducted during the AANS annual meeting in Denver (April, 2011). NeuroTouch was one of the stations of the Young Neurosurgeon Committee Top Gun event. The study population consisted of eligible participants for the competition (residents) along with noneligible competitors (medical students, consultant neurosurgeons, etc.). Before entering the study, each participant signed a consent approved by the McGill University and NRC Ethics Review Boards. Any individual was allowed to perform the task without participating in the study. Trial participants were limited to three specific groups based on their level of training: medical students, junior residents (PGY 1–3) and senior residents (PGY 4 or above). All other participant results were excluded from this study. Baseline user characteristics assessed included age, gender, handedness, level of training, number of hours of video games played/week, number of hours of musical instruments played/week and the number of meningioma cases carried out.

Simulated tasks

NeuroTouch was conceived and developed by a team at the NRC in collaboration with teaching hospitals from across Canada. This VR simulator with haptic feedback is being utilized to both train and assess technical skills in cranial microneurosurgery, focused on neurosurgical oncology. The NeuroTouch platform features the surgical workspace of an open neurosurgical procedure by replicating the stereoscopic view and ergonomics of an operating room microscope. NeuroTouch houses two haptic devices permitting tactile interaction of virtual soft tissue with a surgical instrument in each hand (Fig. 1). The software allows physics-based simulation of tissue properties and behavior, the interaction of surgical instruments with brain tissue and bleeding dynamics using a high-end computer. Information detailing the VR technology and the simulation techniques employed in NeuroTouch has been reviewed [7,8,24–28].

Fig. 1 NeuroTouch simulator showing stereoscopic display and haptic controllers

The simulated tumor resection task utilized for the Top Gun competition involved a modification of the tasks available on the NeuroTouch system. This exercise was chosen since the training objectives of the task are to improve bimanual dexterity in the use of surgical aspirators and to clear the surgical field of blood during coordinated tumor resection under the operating microscope. The specific exercise is to core out a simulated meningioma-like tumor with an ultrasonic aspirator without resecting underlying simulated healthy brain tissue. As the vascular tumor tissue is removed, simulated bleeding occurs, and suction is used to clear the operating field of blood, thus requiring the use of both hands in the exercise (see Video 1). The simulator is equipped with realistic tools allowing the suction to be turned on/off via a thumb switch and the ultrasonic aspirator to be activated via a foot pedal. The blood could be cleared from the operative field using suction allowing better delineation and therefore resection of the underlying tumor. To ensure that a reasonable amount of the simulated tumor could be resected in a specified time, a suitable meningioma-like lesion was designed for the competition. The lesion shape and VR-simulated tumor used in the competition is shown in Fig. 2. An arbitrary limit of 150 s was used to allow the maximum number of participants to enroll both in the study and in the competition.

Measures

Performance metrics were divided into two themes: outcome metrics and efficiency metrics. The outcome metrics include percentage of tumor removed and error involving damage to

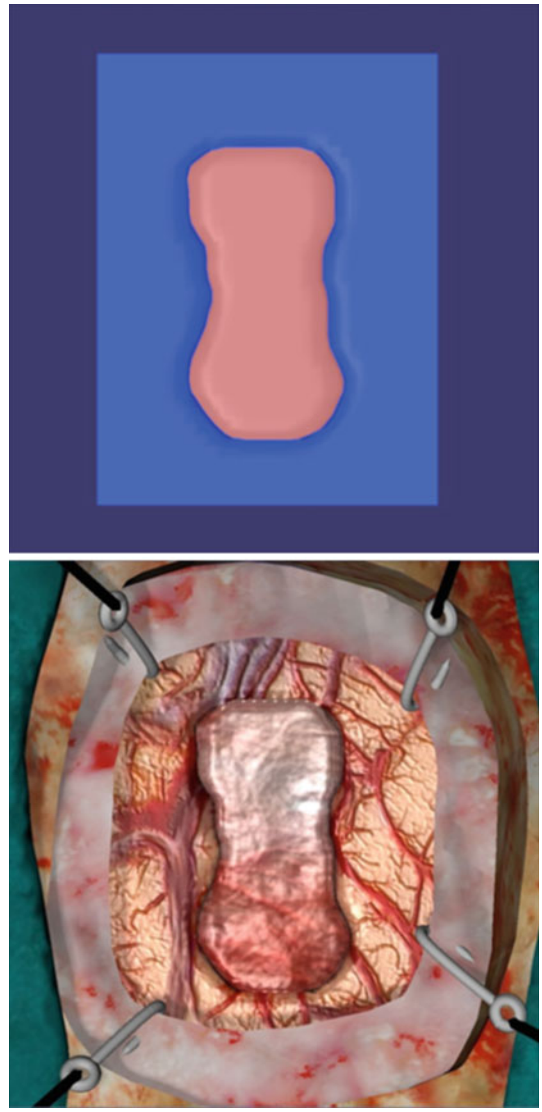

Fig. 2 (*up*) Practice session view. (*down*) Competition view of the meningioma-like lesion

healthy tissue. Damage included the duration (s) of excessive force applied to tissue and inadvertent removal of healthy brain (cc). The efficiency metrics included the time required to finish the task (s), and the path length of each instrument (mm). After pilot testing, a threshold of 0.4 Newtons (N) was defined as the upper limit of an acceptable force applied on tissue by the tip of a given surgical instrument. The associated metric for excessive force was the duration in seconds spent above this threshold. These metrics were automatically recorded by the software. An additional efficiency score, the ratio of the ultrasonic aspirator path length and percentage of tumor resection was processed after the simulation trials. The efficiency was calculated to ensure that a large percentage of tumor removal was associated with an optimal motion of the ultrasonic aspirator. Each participant was briefed using a standard instruction sheet that explained the goal of the task and how to operate the simulator. Each participant was then given one practice trial run on a similar tumor case so that he/she could become familiar with using the surgical instruments and to adjust to the various components of the simulator. Once the participant felt comfortable in the simulated environment, the competition task was launched. The exercise automatically ended at 150 s or earlier if the participant felt he/she had completed the task. At the end of the simulation, a window outlining the score in each of the subcategories was provided to each participant as immediate feedback on their performance. Finally, each participant was asked to note their impression of the training exercise and the technology through a 5-point Likert scale.

Statistical analysis

Results were analyzed using SPSS 20.0 (IBM Corp., NY, USA) according to the participants' level of training, gender, age and handedness. Covariates included the number of meningiomas operated on, and hours/week playing a musical instrument or video games. Multivariate ANOVAs were conducted on each factor. ANCOVAs were computed to adjust for different covariates. Post hoc analyses were computed with Tukey test. Results were considered significant at $p < 0.05$.

Table 1 Participant demographics

	N (%)
Gender	
Male	64 (88.9)
Female	8 (11.1)
Age	
Mean ± SD	30.8 ± 4
Handedness	
Right	66 (90.3)
Left	5 (7.9)
Ambidextrous	1 (1.4)
Video games	
Player	30 (41.7)
Hours/week (mean ± SD)	2 ± 4.4
Musical instrument	
Player	11 (15.3)
Hours/week (mean ± SD)	0.4 ± 1.1
Meningioma cases	
Mean ± SD	17.4 ± 21.1
Training level	
Medical student	10 (13.9)
Junior resident (PGY 1–3)	18 (25)
Senior resident (PGY 4 or +)	44 (61.1)

Results

A total of 72 participants were enrolled in the study: 10 medical students, 18 junior residents (PGY 1–3) and 44 senior residents (PGY 4 or above). The majority of the participants were male (89 %) and right handed (92 %) (Table 1). Video games were played by 42 % of participants with a mean of 2 h/week and only 15 % of participants played musical instruments (Table 1).

All participants used the allotted 150 s to complete the task. Therefore, the time to perform the task was not used in the analysis. In the multivariate analyses, there was no statistically significant influence of age, gender or handedness on the different performance metrics assessed. However, the level of training was associated with significant differences in task performances in multivariate and univariate analyses (Tables 2, 3). Post hoc analyses showed significant differences in the percentage of tumor removed depending on the level of training between the medical students and junior residents ($p = 0.034$) and between the medical students and the senior residents ($p = 0.002$). There was no significant difference between junior and senior residents in the percentage of tumor removed (Table 3). The efficiency measure of the ultrasonic aspirator demonstrated that medical students (mean = 48.7 %) underperformed when compared to junior residents (mean = 65.2 %, $p = 0.006$) or senior residents (mean = 62.1 %, $p = 0.013$). There was no significant difference between the junior and senior residents in this metric of performance. The total path lengths, durations of excessive force and normal brain removed were not significantly different when the groups were compared (Table 3). On assessing individual results (Fig. 3), three outliers who performed extremely well in the efficiency metric were identified in the junior resident group (circle). Our data did not allow us to define an explanation for this excellent performance but raises the question that a subgroup of individuals may possess enhanced hand-eye coordination skills allowing them to excel in the defined technical tasks assessed in this study. Correcting the results for the level of training effect with the number of meningioma cases operated on rendered the multivariate analysis nonsignificant ($p = 0.094$). The expected high correlation between the level of training and the number of meningioma cases operated on was also apparent ($r = 0.654$, $p < 0.001$). Adjusting the data for the number of hours of video games and musical instrument played/week was not associated with any significant changes in the results.

Each of the 72 participants completed the post-simulation surveys with above average scores for each of the items (for example with: 5 = high agreement, 3 = agreement, 1 = do not agree). The participants thought that the difficulty of the

Table 2 Multivariate analysis of the effect of specific factors on performance

	F	df	df error	p
Age	0.954	21	178.6	0.52
Gender	1.643	7	64	0.14
Level of training	1.995	14	126	0.02
Handedness[a]	0.503	7	63	0.83

[a] The one ambidextrous individual was not included in these results

Table 3 Effect of level of training on various performance metrics

	Medical students[a]	Junior residents (PGY 1–3)[a]	Senior residents (PGY 4 or +)[a]	p
Percentage of tumor removed	53.4 ± 13.6	65.7 ± 11.2	68.8 ± 12.1	0.002
Volume of normal brain removed (mm^3)	124.2 ± 95.2	186.0 ± 199.1	218.6 ± 201.2	0.357
Path length of suction (mm)	1,175.4 ± 463.2	996.2 ± 302.4	958.4 ± 314.7	0.188
Path length of ultrasonic aspirator (mm)	1,661.6 ± 315.0	1,582.7 ± 432.1	1,753.8 ± 489.3	0.397
Duration of excessive force of ultrasonic aspirator (s)	1.9 ± 2.6	2.7 ± 4.0	2.4 ± 3.8	0.863
Duration of excessive force of suction (s)	5.3 ± 10.6	1.2 ± 1.8	2.2 ± 7.7	0.357
Ultrasonic aspirator efficiency measure (%)	48.7 ± 10.7	65.2 ± 15.3	61.5 ± 13.1	0.008

[a] Values represent means ± SD

exercise and the associated measures of performance were appropriate (at, respectively, 3.5 and 3.8). The visual and sensory realism of the exercise was found to be acceptable, with the visual aspect (at 3.3) being ranked higher than that of the sensory (at 2.9). The participants were satisfied with the technology as a whole (at 3.7). The strongest response to the items in the Likert scale was that the users expressed wanting to use the system for training if it were made available in their current programs (at 3.9). The results of the post-task survey can be seen in Table 4. The survey also contained open-ended questions regarding improvements related to any component of the simulator (i.e., the exercise, hardware or scoring).

Discussion

Objective evaluation of performance in competitive environments has demonstrated the usefulness of simulation. This study showed that assessing performance in a VR environment can differentiate participants by their training level. In other studies specific to neurosurgery, Banerjee et al. [22] showed that the ImmersiveTouch ventriculostomy simulator was also accurate and realistic in a competitive setting but not able to differentiate various level of training in terms of performance. By increasing the difficulty of the task (i.e., performance of a VR ventriculostomy with shifted ventricles), repetition improved performance [29]. Task repetition has also been shown to improve the position of inserted thoracic pedicle screws after one session of practice on a VR simulator [23]. In this current study, medical students and neurosurgical residents using the NeuroTouch simulator thought that the system was pertinent and realistic. As well, the simulated tumor resection exercise was able to discriminate between the different levels of training of the participants through significantly different performance scores.

Various surgical specialties have developed and validated VR simulators for laparoscopic, gynecological, ophthalmological and sinus surgery [30–34]. A number of specific factors have been found to impact trainees' performance on simulators, but the studies have shown conflicting results [35–37]. Age, years of postgraduate training and visual perception were associated with a set of defined laparoscopic skills [38]. Gender, handedness and being a video game player were associated with fewer errors and unnecessary movements in VR laparoscopic tasks [39]. Visual spatial skills, computer gaming experience and gender were associated with better performances using a VR colonoscopy simulator [40].

A number of studies have shown an influence of video gaming on the task performance using simulators [39–46]. This topic has been reviewed, and the results suggest that video game playing may enhance initial endoscopic/laparoscopic performances but more complex tasks such as knot-tying are not improved by exposure to this activity [47]. We did not find that the amount of video games played/week significantly improved performance during a simulated neurosurgical exercise on the NeuroTouch platform.

Our study is also consistent with the results of Madan et al. [48] which demonstrated that playing a musical instrument did not significantly influence performance in endoscopic surgery. However, scores of a simple task on a sinus simulator were higher in participants who played a musical instrument for more than 10 years, but this effect was lost when the task became more complex [49]. The present VR task

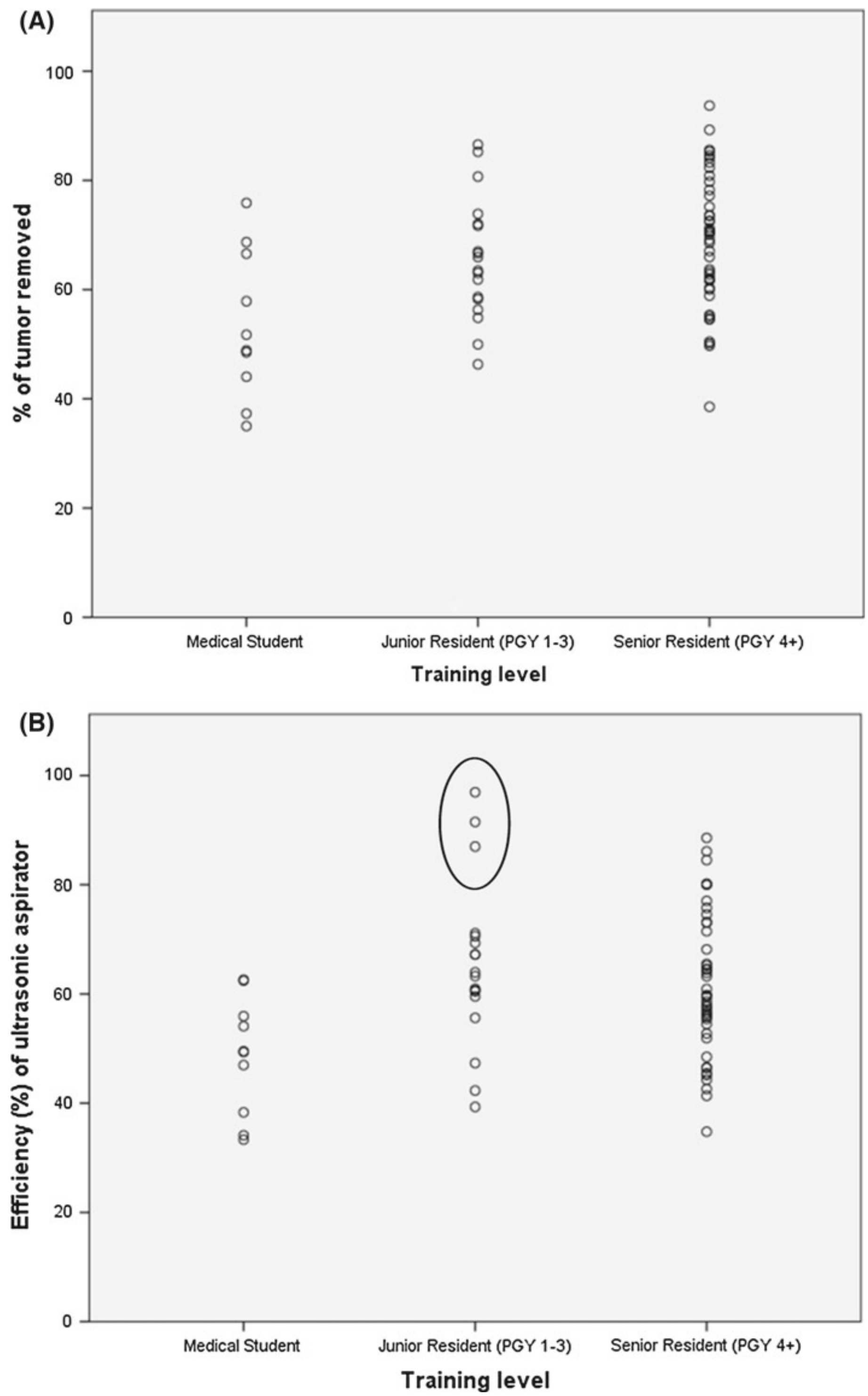

Fig. 3 **a** Distribution of scores by training level for the percentage of tumor removed. **b** Distribution of scores by training levels for the ultrasonic aspirator efficiency (a higher score denotes improved ultrasonic aspirator effectiveness). Note the *circled outliers*

involving the bimanual removal of a three dimensional simulated brain tumor with simulated bleeding and continuous haptic feedback is substantially more complex than simple peg transfers and other simulated surgical procedures. This increased task complexity may involve different visuospatial abilities than those used during video gaming or playing a musical instrument, and therefore, these activities do not significantly improve performance during our defined task. This conclusion is supported in our present study by the importance of the number of meningioma cases performed rather than the level of training. Our results support the concept that one's surgical experience in a similar task is more important than the amount of time spent in a training program and reinforces the idea that other assessment models could be more

Table 4 Evaluation of the simulator (5 point Likert scale, higher is more satisfied/in agreement)

	Mean (±SD)
Difficulty of the challenge	3.5 ± 0.94
Visual realism	3.3 ± 1.0
Sensory realism	2.9 ± 1.05
Overall satisfaction	3.7 ± 0.94
Appropriate metrics	3.8 ± 0.99
Would use simulator if available in training program?	3.9 ± 1.2

accurate in measuring technical skills competency than the level of training of the trainee.

The posttest survey does not completely establish face and content validity since the participants could not be considered experts in the field. The results, however, do suggest that the simulator looked and felt realistic and that the resident participants would like to expand its use in their training. Similar results were obtained in a bariatric VR simulator [11]. NeuroTouch undergoes face and content validity through a review panel of neurosurgeons and medical education experts twice a year [7]. This aids development of specific neurosurgical VR tasks but further research is needed to ensure appropriate validation of the NeuroTouch simulator.

The results of the current study should be interpreted with caution. First, the study population was small and biased toward senior residents and only a limited number of medical students participated. This is understandable given the context of the meeting and the competition. Second, the competitive setting itself could influence results. Medical students were not eligible for prizes and may not have given their optimal effort. Third, the short duration of the task and its level of difficulty might not have been able to discriminate levels of performance among participants. In real-life settings, no defined time limits are imposed on the resection of meningiomas. No significant difference was found between the groups in either measures of error (normal brain removed or excessive forces applied) suggesting that the task was not difficult enough to discriminate among these metrics.

The expanded use of VR simulation technology could play a number of roles in the future of neurosurgery [4,5]. These systems may allow focused research into the visual, tactile and other clues that neurosurgeons use during a variety of operative procedures helping us to understand how neurosurgeons actually perform surgery. Medical students expressing an interest in neurosurgery as a career could assess their technical abilities needed for this specialty. This could improve the quality of the selection process by allowing students and selection committees more validated information related to technical aspects needed to perform well in a neurosurgical program. Resident technical teaching could be optimized based on defined validated competence levels rather than years in a program. The development of a curriculum based on national and international simulation programs should improve the quality of neurosurgical teaching in a worldwide context. In 2010, a national boot camp for PGY-1 neurosurgery was implemented [50,51]. In 2012, the latest version of the NeuroTouch simulator was piloted at one of the six regional sites. A more advanced NeuroTouch simulator (as developments are ongoing) will be assessed at a forthcoming PGY-2 and PGY-3 boot camp. Continued resident rehearsal of operative and other procedures in a safe but realistic environment should lessen errors and improve patient safety. As has occurred with the continuous assessment of airplane pilots [52], the ability to assess and hopefully improve a neurosurgeons technical abilities throughout one's neurosurgical career would seem to be a realistic goal for validated simulation programs.

Conclusions

This study demonstrated that different levels of competency in neurosurgery can be assessed by a haptic feedback-enhanced VR simulator. Advanced level of training was associated with improved results on a tumor resection task using the NeuroTouch simulator. The impact of the number of meningioma cases done was significant and needs to be analyzed in future studies. Interestingly, being a video game player or a musician did not affect the performance on the simulator as has been described in other surgical specialties.

In this pilot study, face, content and construct validity was established in competitive setting with medical students and neurosurgical residents. Based on these results, future study designs will be improved by incorporating expert participants and assuring noncompetitive settings. We are currently carrying out a series of studies assessing medical students, junior and senior residents, neurosurgical fellows and neurosurgical staff to further define and improve validity of the training exercises in the NeuroTouch platform. Further studies using VR simulation technology utilizing a variety of operative scenarios are essential for the neurosurgical community to integrate these technologies into the education and the evaluation of neurosurgeons throughout their training and career.

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Conflict of interest The authors declare no conflict of interest.

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