Bimanual Psychomotor Performance in Neurosurgical Resident Applicants Assessed Using NeuroTouch, a Virtual Reality Simulator

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OBJECTIVE: Current selection methods for neurosurgical residents fail to include objective measurements of bimanual psychomotor performance. Advancements in computer-based simulation provide opportunities to assess cognitive and psychomotor skills in surgically naive populations during complex simulated neurosurgical tasks in risk-free environments. This pilot study was designed to answer 3 questions: (1) What are the differences in bimanual psychomotor performance among neurosurgical residency applicants using NeuroTouch? (2) Are there exceptionally skilled medical students in the applicant cohort? and (3) Is there an influence of previous surgical exposure on surgical performance?

DESIGN: Participants were instructed to remove 3 simulated brain tumors with identical visual appearance, stiffness, and random bleeding points. Validated tier 1, tier 2, and advanced tier 2 metrics were used to assess bimanual psychomotor performance. Demographic data included weeks of neurosurgical elective and prior operative exposure.

SETTING: This pilot study was carried out at the McGill Neurosurgical Simulation Research and Training Center immediately following neurosurgical residency interviews at McGill University, Montreal, Canada.

PARTICIPANTS: All 17 medical students interviewed were asked to participate, of which 16 agreed.

RESULTS: Performances were clustered in definable top, middle, and bottom groups with significant differences for all metrics. Increased time spent playing music, increased applicant self-evaluated technical skills, high self-ratings of confidence, and increased skin closures statistically influenced performance on univariate analysis. A trend for both self-rated increased operating room confidence and increased weeks of neurosurgical exposure to increased blood loss was seen in multivariate analysis.

CONCLUSIONS: Simulation technology identifies neurosurgical residency applicants with differing levels of technical ability. These results provide information for studies being developed for longitudinal studies on the acquisition, development, and maintenance of psychomotor skills. Technical abilities customized training programs that maximize individual resident bimanual psychomotor

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training dependant on continuously updated and validated metrics from virtual reality simulation studies should be explored. (J Surg Ed 73:942-953.

KEY WORDS: medical student neurosurgical applicants, interview, NeuroTouch/NeuroVR, virtual reality simulator, bimanual psychomotor performance, technical abilities customized training (TACT)

COMPETENCIES: Practice-Based Learning and Improvement, Patient Care, Medical Knowledge

INTRODUCTION

Resident selection remains a highly subjective process. In surgical residency programs, methods for applicant selection lack specific validated technical aptitude testing and rely predominately on interviews and other information, despite evidence that suboptimal operative performance causes significant patient morbidity.[1] The field of neurosurgery has yet to incorporate reproducible, objective measures of bimanual psychomotor performance in the selection of applicants and the evaluation, assessment, and training of residents in neurosurgical programs. Advances in technology have led to the development of increasingly complex virtual reality simulators that have been incorporated in the selection and training of aviation personnel.[2] The Association for Surgical Education Simulation Committee[3,4] as well as the American College of Surgeons[5] have stressed the importance of research in the role of simulation in applicant selection and evaluation. Although few evaluative bodies, most notably the Royal College of Surgeons in Ireland[6] incorporate simulation in the selection of surgery residency applicants, these practices are not widespread and lack long-term validation. Objective assessments of performance are of increasing importance as residency training programs shift toward a competency-based curriculum. The development of high-fidelity neurosurgical virtual reality simulators[6] such as the NeuroTouch have made it possible to study neurosurgical performance in surgically naive populations.[7-15]

This pilot study was designed to answer 3 questions: (1) What are the differences in bimanual psychomotor performance among neurosurgical residency applicants using NeuroTouch? (2) Are there medical students with exceptional psychomotor skills in an applicant cohort? and (3) Is there an influence of previous surgical exposure on surgical performance?

MATERIALS AND METHODS

Subjects

A total of 22 medical students from Canadian universities applied for the 16 positions available in the 11 Canadian neurosurgical residency programs accepting residents in 2015.[16] In all, 17 applicants were interviewed. These applicants had no knowledge that they would be asked to participate in this study before their interviews so that this request would not influence their interview performance. Immediately following completion of their interviews, each of the 17 students was asked by the McGill neurosurgical resident coauthors of the study to participate in the trial. These residents informed potential participants that all data collected would be kept anonymous and would not be provided in any form to the residency selection committee. There was no financial or other compensation offered for participation in the study. All participants in the study signed an approved McGill University Ethical Review Board consent.

Questionnaires

Basic demographic data, video game and music exposure, weeks of neurosurgery elective undertaken, and prior operative exposure were obtained. Participants were also asked to rate their technical ability, how confident they consider themselves in the operating room, and whether they feel simulators should be used in candidate selection on a 10-point Likert scale. The short form of the State-Trait Anxiety Inventory (STAI) questionnaire was completed before, and following the virtual reality task as previously described.[10] The STAI questionnaire consisted of 6 items (calm, tense, upset, relaxed, content, and worried) as adapted for surgical trials measured on a 4-point Likert scale. Higher scores imply greater anxiety perception with the maximum achievable STAI score being 24, whereas the minimum score is 6.

NeuroTouch Simulator

The previously described NeuroTouch (now called NeuroVR) platform was used to conduct this study.[7-15]

Simulation Task

To address the study questions, 3 simulated brain tumors with identical visual appearance, stiffness, and random bleeding points used in a previous study by our group (Fig. 1A).[10] These spherical tumors had a simulated glioma-like brain tumor appearance and stiffness (Young's modulus = 9 kPa) differentiating them from surrounding simulated cortical surface (Young's modulus = 3 kPa) and surrounding white matter–like tissue (Young's modulus = 3 kPa) providing a distinct tumor border interface (Young's modulus = 3 kPa).[10] To increase operative realism, an audible heartbeat of 60 per minute was incorporated into each of the scenarios. Participants were instructed with both verbal and written information that the goal of the procedure was to remove as much tumor as possible in a specified time

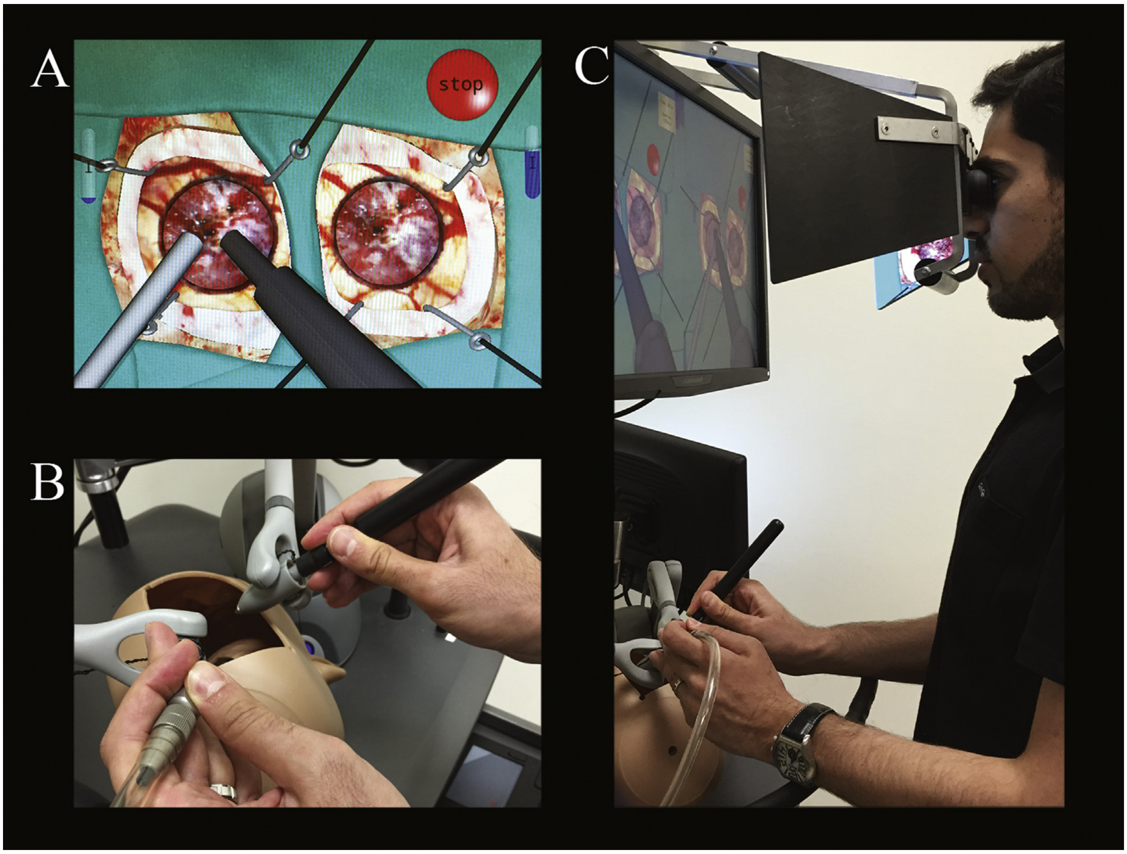

FIGURE 1. (A) Operator view of 2 of the 3 tumors to be resected with a sucker in nondominant hand and ultrasonic aspirator in dominant hand. (B) Haptic instruments used by participants. (C) Model performing task.

(2 min) while not compromising the "normal" surrounding tissue. Tumor removal was accomplished with a virtual ultrasonic aspirator held in the participant's dominant hand and activated via foot pedal and a suction device in the nondominant hand (Fig. 1B and C).[10]

Metrics

Validated tier 1, tier 2, and advanced tier 2 metrics were used to assess bimanual psychomotor performance as previously described.[7,9,14,15] Tier 1 metrics include blood loss, tumor percentage resected, and simulated "normal" brain volume removed. Tier 2 metrics are total tip path length, maximum and sum of forces used by instruments. Advanced tier 2 metrics are efficiency index, coordination index, ultrasonic aspirator path length index, and ultrasonic aspirator bimanual forces ratio.

Statistical Analysis

We report descriptive statistics as counts and percentages for categorical variables. For continuous variables, means and standard deviations are used. Participants were categorized according to quartiles of bimanual psychomotor performance into 3 groups: the top group (first quartile), a middle group (second and third quartiles), and a bottom group (fourth quartile) adapted from models described in previous studies.[1,17] Analysis of variance method with post hoc testing using the Bonferroni correction was performed to assess statistical differences among the 3 groups.[18] As each participant performed 3 operations on identical tumors, the repeated measures from each individual were considered to be correlated. We therefore adopted linear mixed-effects model to analyze such correlated data.[18] Box-Cox transformation to normality was applied to the outcome variables to satisfy the normality assumption of the linear models. The linear mixed-effects model analysis was used to compare the performance of each candidate with known postgraduate year 1 to 3 resident performance on the same 3 tumors.[10] Results were considered statistically significant when $p < 0.05$.

RESULTS

Demographics and STAI

A total of 15 Canadian (representing 68% of the national applicant pool), along with one foreign neurosurgical applicants agreed to participate in the study and were provided with a random identification number. Demographic, STAI,

TABLE 1. Characteristics of Participants

	n = 16
Mean age (SD*)	26.6 (3.2)
Men/women	12/4
Right handed/left handed	14/2
Video game, h/wk	
0	10
<1	4
2-10	1
>10	1
Musical instrument, h/wk	
0	12
<1	4
Mean neurosurgery elective weeks	11.2 (4.6) (range: 4-22)
Mean number of surgical skin closures	10.9 (6.3) (range: 1-25)
Used simulator previously, yes/no	7/9
Felt monitored by colleague during task, yes/no	8/5
Missing	3
Likert scale self-rating aptitude in manual dexterity	7.4 (1.0)
Likert scale confidence in the operating room	7.4 (1.0)
Self-rating among medical school peers	
Top 5%	5
Top 10%	5
Top 20%	3
Top 50%	3
Likert scale simulator use in applicant selection	6.7 (2.9)
State-Trait Anxiety Inventory Scale	
Pretrial	10.6 (2.2)
Posttrial	11.3 (2.8)

* = Standard Deviation.

and other participant data can be seen in Table 1. Participants showed no statistically significant increase in mean STAI score when pretrial value 10.6 (standard deviation, 2.2) and posttrial value 11.3 (2.8) were compared.

Bimanual Psychomotor Performance Among Participant Groups

For every metric assessed, there was a definable top-, middle-, and bottom-performing group. These groups segregated into 1 top quartile ($n = 4$), 2 middle quartiles ($n = 8$), and 1 bottom quartile ($n = 4$) as outlined in previous surgical studies.[1,17] Significant differences were found between these 3 groups for tier 1, tier 2, and advanced tier 2 metrics (Figs. 2-4). For all 13 metrics assessed, significant differences were found between the top- and bottom-performing groups (Figs. 2-4); whereas for the 4 advanced tier 2 metrics, significant differences were found between all the 3 groups (Fig. 4). As each participant was assigned the same random number, their individual positions in the top, middle, and bottom groups for each of the 11 metrics assessed can be followed. For tier 1 metrics, the 4 individuals in the bottom group with regard to tumor removal were also in the bottom group for the least "normal" brain volume. In the tier 2 metrics, a number of individuals consistently appear in either the bottom or top groups especially in the sum of forces used and maximum force applied. In the advanced tier 2 metrics, 2 applicants (1 and 14) appeared consistently in the top group in 3 out of 4 metrics. A total of 3 applicants (4, 5, and 12) demonstrated consistently lower performance in the advanced tier 2 metrics studied. Although these patterns were evident, some participants do appear in different groups based on the specific metrics assessed and further studies are necessary to understand the linkages among the 11 different metrics assessed.

A demonstration of top-performing participant 14 (left) and bottom-performing participant 5 (right) resecting 2 virtual tumors is shown in a Supplementary video. Participant 5 lacks bimanual coordination and exhibits poor control of nondominant hand (sucker) while using ultrasonic aspirator (Video, Supplementary Figure S1, http://links.lww.com/NEU/A708 Playback time 200%.

Comparison of Applicant Bimanual Psychomotor Performance With Neurosurgical Residents

A linear mixed-effects model analysis was conducted comparing individual applicant bimanual psychomotor performance with the mean performance of 6 postgraduate year 1 to 3 neurosurgical residents assessed in a previous study.[10] Significant differences in tier 1, tier 2, and advanced tier 2 performance between applicants and junior residents were identified. For tier 1 metrics, 4 applicants removed less tumor, 1 applicant had increased blood loss, whereas another had decreased blood loss (Fig. 5). For tier 2 metrics, 1 applicant had increased sucker total tip path length and increased ultrasonic aspirator total tip path length (Fig. 6). For advanced tier 2 metrics, 6 applicants had a decreased ultrasonic aspirator path length index, 3 applicants had a decreased ultrasonic aspirator bimanual forces ratio, and 1 applicant had a decreased efficiency index (Fig. 7). Only 1 applicant (applicant 1) demonstrated higher bimanual psychomotor performance with respect to the resident control group (approaching significance: efficiency index, $p = 0.07$; path length index, $p = 0.07$).

Interestingly, the 2 applicants (1 and 14) who demonstrated consistently higher (and approaching significance) bimanual psychomotor performance compared to residents were also in the top group compared with their peers. Thus, these applicants can be considered to be high performers not just compared with their peers, but with junior residents as well.

Factors Influencing Applicant Bimanual Psychomotor Performance

Applicant factors that significantly influenced the performance metrics are displayed in Table 2. Age, sex, handedness, video game exposure, and prior simulator use had no

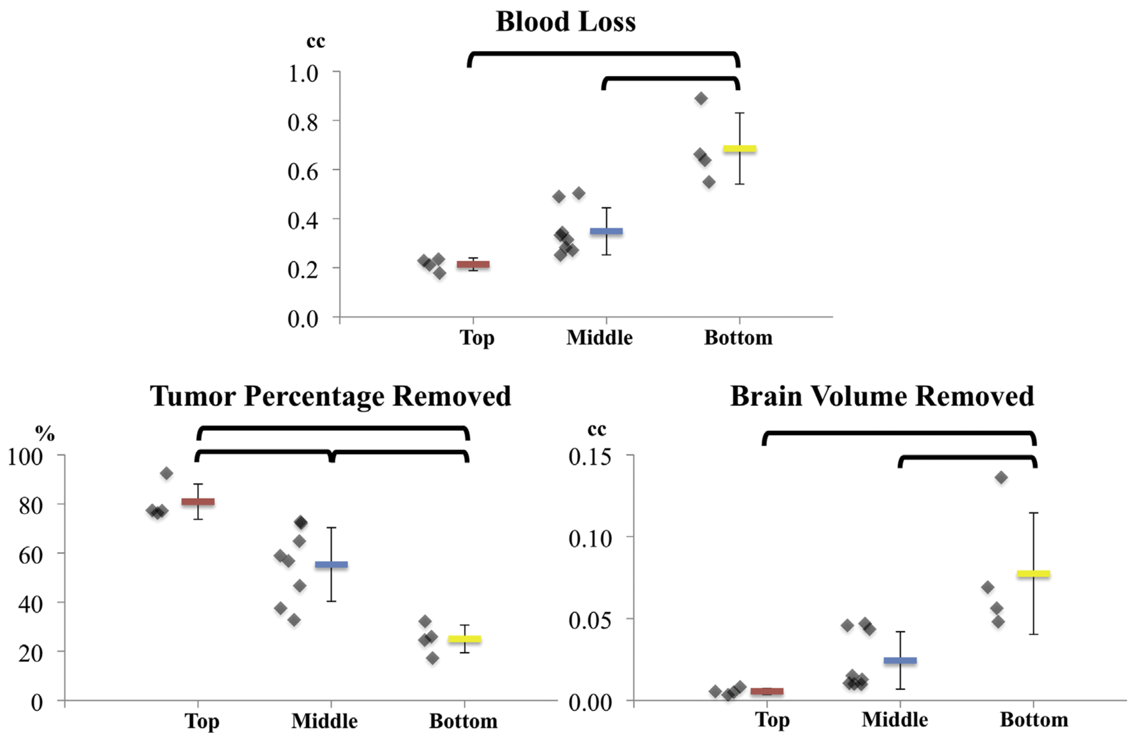

FIGURE 2. Tier 1 metrics of neurosurgical applicants. Tier 1 means (±SD) in cubic centimeters (cc) organized into top, middle, and bottom groups along with individual medical student ($n = 16$) values. Bar represents $p < 0.05$ between 2 indicated groups. Red color bars indicate individuals in top-performing group, blue bars indicate individuals in middle-performing group, and yellow bars indicate individuals in bottom-performing group. SD, standard deviation.

statistically significant influence on the metrics studied on univariate and multivariate analyses.

Univariate analysis demonstrated that increased time spent playing musical instruments was associated with a statistically significant increase in efficiency index, an assessment of the time spent by instruments in direct contact with the tumor. Increase in self-rating aptitude in manual dexterity and increased number of skin closures were associated with significantly less ultrasonic aspirator total tip path length that is a measure of improved ability to use this instrument. High self-ratings of confidence in the operating room were associated with a significant decrease in suction coordination index and trends for decreased tumor removal, efficiency, and ultrasonic aspirator path length index.

When multivariate analysis was used, there was a trend for both increased operating room confidence and increased weeks of neurosurgical exposure to increase blood loss.

DISCUSSION

In this pilot study, 16 of 17 applicants who were interviewed for the neurosurgery residency program at McGill University agreed to have their bimanual psychomotor performance assessed on the NeuroTouch virtual reality neurosurgical simulator. The study was designed to answer a number of questions including the variation in bimanual psychomotor technical skill within this cohort, whether there are applicants with exceptional psychomotor skills and to characterize the influence of applicant-specific factors on performance. This study is unique in using previously validated metrics in a neurosurgery resident applicant population.

Variability in Applicant Bimanual Psychomotor Performance

We have demonstrated wide variability in performance within this neurosurgical applicant group in all performance metrics assessed. Applicant performance in this cohort segregated into top, middle, and bottom groups suggesting that the bimanual metrics assessed in this study may not be distributed normally. In a study involving neurosurgery resident applicants, composite performance scores using the ImmersiveTouch virtual reality system followed a bell curve distribution, with few high- and low-performing outliers.[19] No significant differences between first year medical students, neurosurgical applicants, or neurosurgical residents were found in this study.[19] The reasons for the disparity with the present study is unclear but may be related to differences in the virtual reality simulators and the complex validated metrics used in this study, which allowed for a more complete assessment of bimanual psychomotor

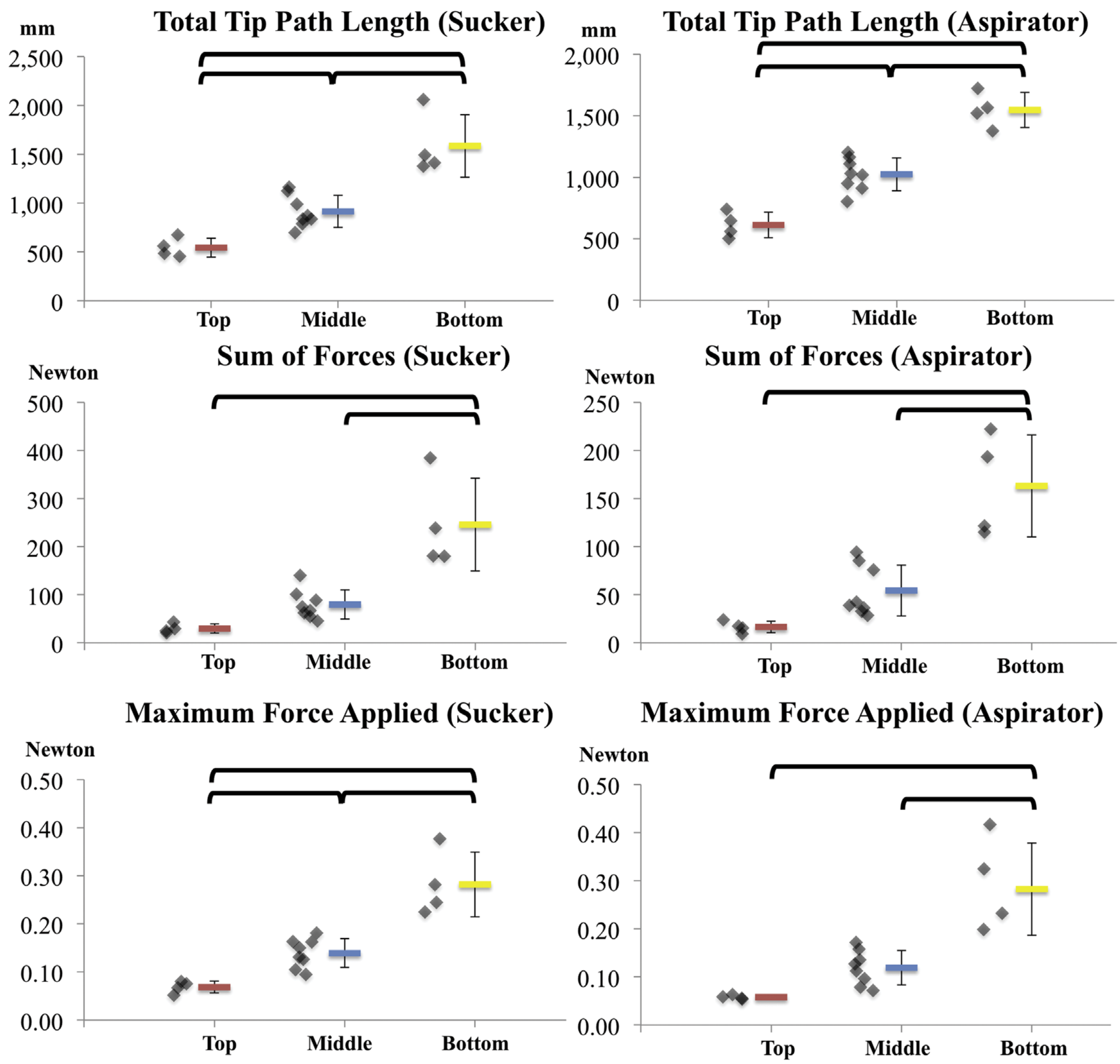

FIGURE 3. Tier 2 metrics of neurosurgical applicants. Tier 2 means (±SD) in millimeters (mm) for total path length and in Newtons for forces organized into top, middle, and bottom groups along with individual medical student ($n = 16$) values. Bar represents $p < 0.05$ between 2 indicated groups. Red color bars indicate individuals in top-performing group, blue bars indicate individuals in middle-performing group, and yellow bars indicate individuals in bottom-performing group. SD, standard deviation.

performance and more accurate segregation into distinct groups.[7,15] In our study, applicant performance was similar or significantly worse than the mean of a group of junior resident controls depending on the metric assessed. A study by Holloway et al.[20] involving medical students and residents failed to demonstrate significant differences in performance in brain volume removed, tumor volume removed, force applied, and instrument path length. Gelinas-Phaneuf et al. demonstrated significant differences in percentage tumor removed and efficiency measure (calculated as ultrasonic aspirator length divided by tumor percentage removed).[7,15] Advanced tier 2 metrics have been found to reliably outline significant differences in the levels of neurosurgery residency training in 2 previous studies carried out by our group.[7,15] In the present study, advanced tier 2 metrics were also the most useful in discriminating bimanual psychomotor performance among the applicants with ultrasonic aspirator path length index being the most reliable metric in discerning individual applicant performance from junior resident performance.

Applicants With Exceptional Psychomotor Skills

In one of our previous studies, 3 high-performing junior resident outliers were noted, though no cause was found for their top performance.[7,15] Similarly, in a small bowel anastomosis task, 5 out of 36 senior medical students were classified as having "super manual dexterity," by attaining optimum performance at the second session as opposed to by the eighth for the group as a whole.[21] In this study, 2 individuals (applicants 1 and 14) were consistently among the top performers on advanced tier 2 metrics compared

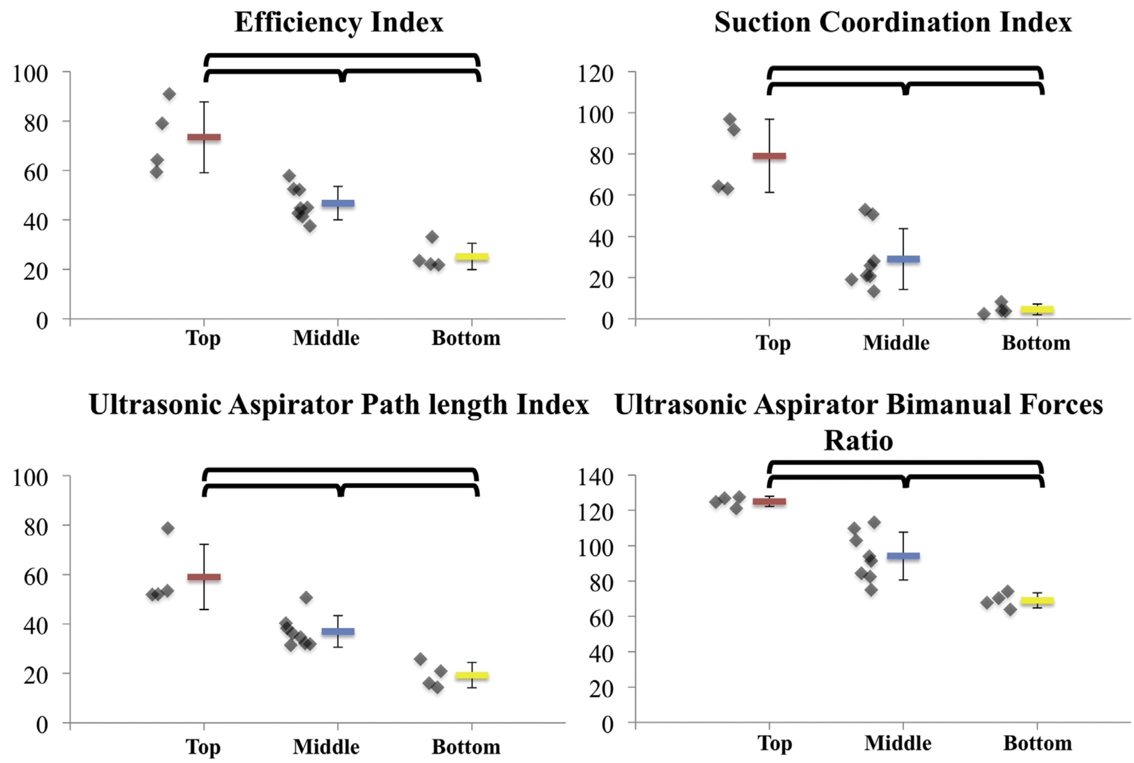

FIGURE 4. Advanced tier 2 metrics of neurosurgical applicants. Advanced tier 2 means (±SD) organized into top, middle, and bottom groups along with individual medical student ($n = 16$) values. Bar represents $p < 0.05$ between 2 indicated groups. Red color bars indicate individuals in top-performing group, blue bars indicate individuals in middle-performing group, and yellow bars indicate individuals in bottom-performing group. SD, standard deviation.

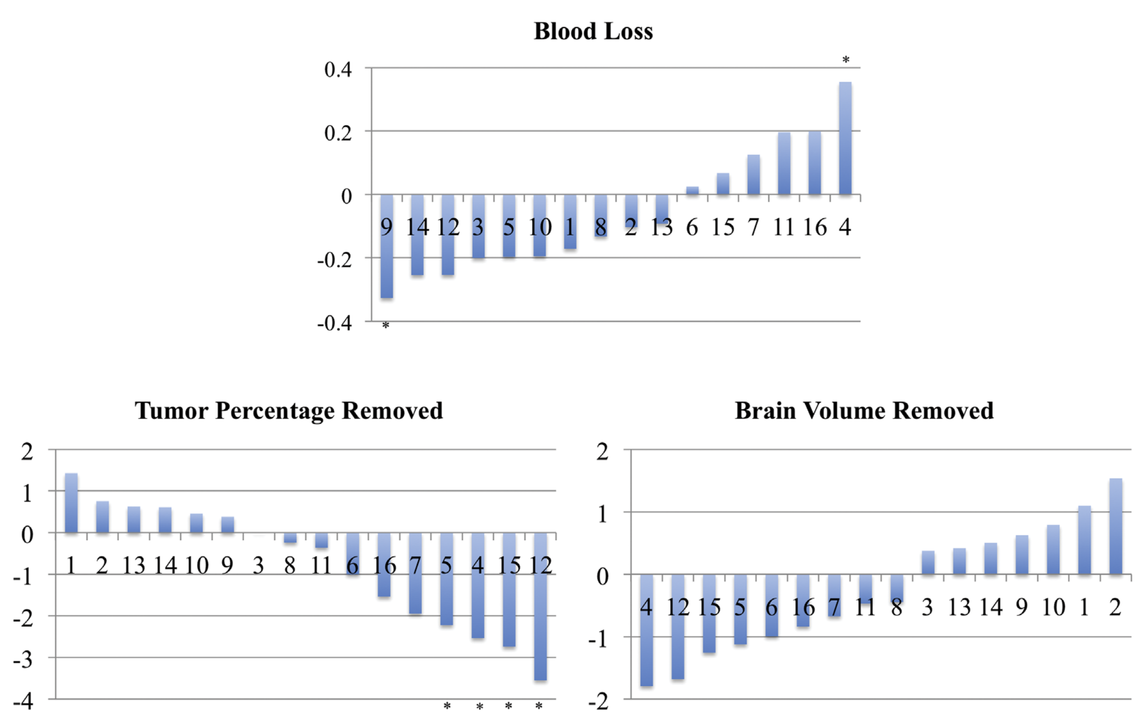

FIGURE 5. Tier 1 metrics comparison of applicant and resident groups. A waterfall plot in which the y-axis represents normalized mean tier 1 data in cubic centimeters from 6 reference PGY 1 to 3 residents with individual applicant tier 1 values represented as blue bars with *$p < 0.05$ indicating significant difference from the PGY 1 to 3 groups. PGY, postgraduate year.

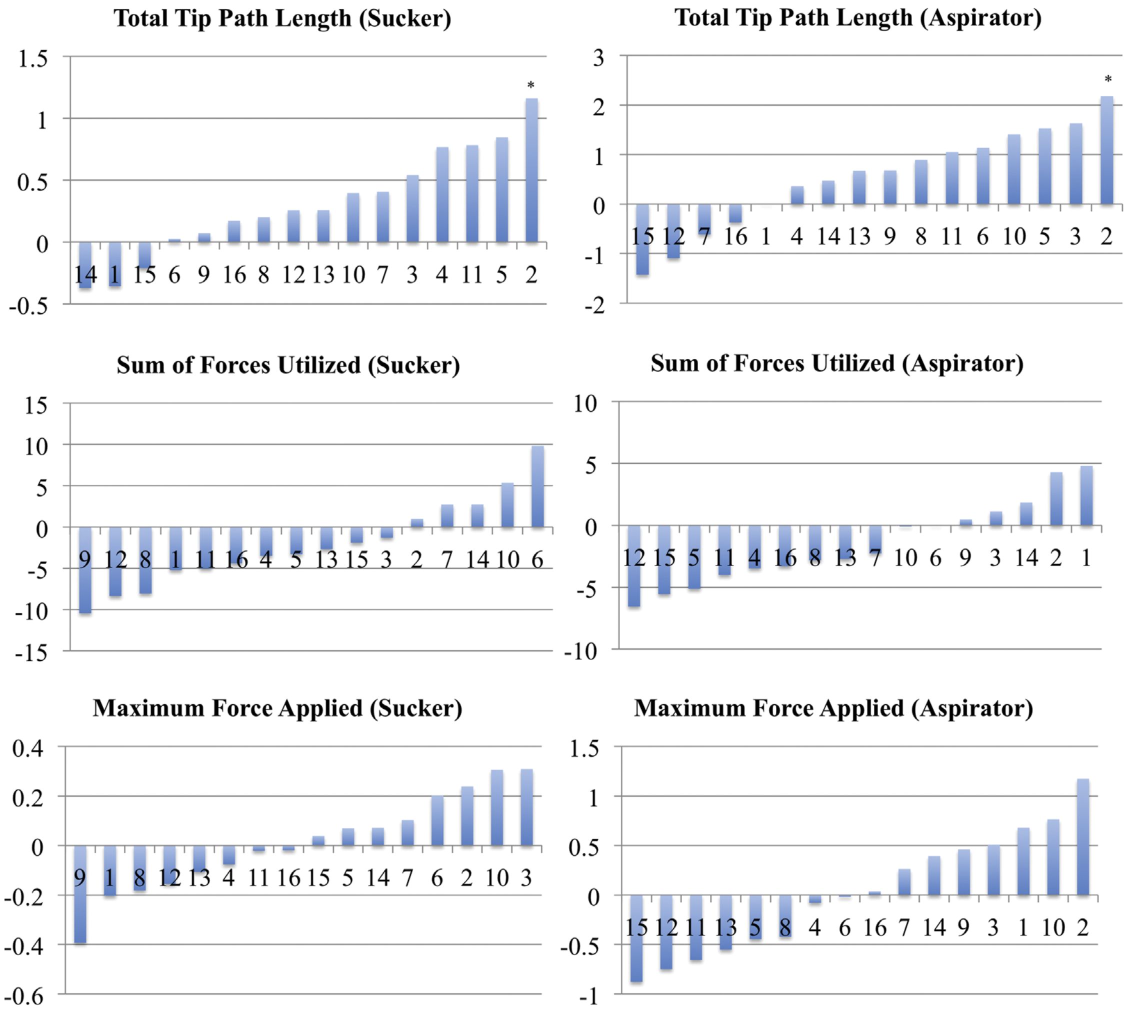

FIGURE 6. Tier 2 metrics comparison of applicant and resident groups. A waterfall plot in which the y-axis represents normalized mean tier 2 data in millimeters for total path length and in Newtons for forces from 6 reference PGY 1 to 3 residents with individual applicant tier 2 values represented as blue bars with $*p < 0.05$ indicating significant difference from the PGY 1 to 3 groups. PGY, postgraduate year.

with their peers as well as with the junior residents, whereas 3 applicants (4, 5, and 12) had consistently lower performance. As the number of skin closures on univariate analysis significantly influenced ultrasonic aspirator total tip path length and as there was a trend for the number of weeks of neurosurgical exposure to influence blood loss on multivariate analysis, we explored whether these factors could explain the individual top performance of applicants 1 and 14 and the lower performance of applicants 4, 5, and 12. These factors do not completely explain the individual differences between applicants as top-performing applicant 14 had only 5 skin closures (11 other applicants had greater than 5) as compared with lower-performing applicants 4, 5, and 12 with 20, 8, and 15, respectively. Applicants 1 and 14 had 14 and 12 weeks of neurosurgical exposure, respectively, whereas the poor-performing applicant 4 had 16 weeks of neurosurgical exposure greater than all but 2 other applicants. Other factors including intrinsic bimanual technical performance may need to be further explored as reasons for these differences. Recent studies by Zatorre and colleagues involving newly learned auditory-motor associations may relate directly to the question of psychomotor intrinsic talent.[21] Pre- and post-functional magnetic resonance imaging studies following a 6-week piano-training protocol dissociated learning-related patterns of neural activity from pretraining activity that predicts learning rates. These studies confirm that there are specific brain regions that account for individual talent that are distinct from brain areas activated by training and are consistent with the concept that in auditory-motor learning predisposition plays an essential role that is clearly distinguished from training-related plasticity.

Factors Influencing Performance

Applicants did not know that they would be asked to participate in this study before their interviews to prevent this information from influencing their interview performance. In an attempt to lessen participant stress after their

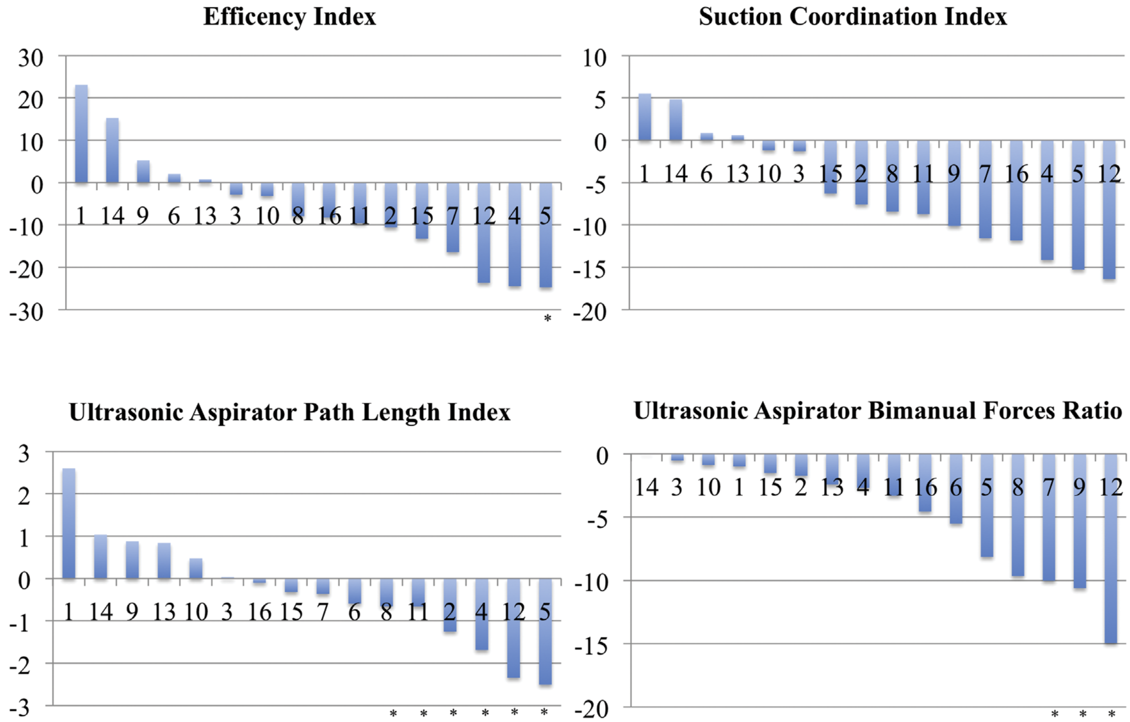

FIGURE 7. Advance tier 2 metrics comparison of applicant and resident groups. A waterfall plot in which the y-axis represents normalized mean advanced tier 2 data for 6 reference PGY 1 to 3 residents with individual applicant tier 2 values represented as blue bars with *$p < 0.05$ indicating significant difference from the PGY 1 to 3 groups. PGY, postgraduate year.

interviews, only residents involved in the study asked the applicants to participate. No neurosurgeons interacted with the participants at any time during the trial. Applicants' STAI scores were higher but not significantly higher when compared to a previous medical student group assessed at our research centre 10.6 (2.2) versus 8.3 (1.9) indicating that increased baseline stress may have been a factor in influencing performance.[21] This may be explained by the timing of the trial. The trial scenario itself did not induce a significant increase in stress levels in the participants when pretrial and posttrial scores were compared.

On univariate analysis, various applicant factors including exposure to music, self-rating of manual dexterity, self-rating of operating room confidence, and number of skin

TABLE 2. Univariate and Multivariate Regression Analysis of Applicant Factors With Performance Metrics

		Univariate Analysis			Multivariate Analysis		
Variable	**Metric**	**Estimate**	**95% CI**	**p**	**Estimate**	**95% CI**	**p**
Music	Efficiency index	3.52	0.31∼6.73	0.03	4.76	−6.74∼16.27	0.28
Likert scale self-rating aptitude in manual dexterity	Total tip path length by ultrasonic aspirator	−1.70	−3.33∼−0.07	0.04	0.002	−0.33∼0.34	0.98
Likert scale confidence in the operating room	Blood loss	−1.03	−1.80∼−0.25	0.19	0.25	−0.005∼0.52	0.05
	Tumor percentage removed	−1.20	−2.46∼0.01	0.05	−1.58	−8.66∼5.50	0.53
	Efficiency index	−1.30	−2.79∼0.15	0.07	−1.55	−8.36∼5.26	0.52
	Suction coordination index	−10.20	−17.6∼−2.7	0.01	−12.63	−42.2∼16.94	0.27
	Ultrasonic aspirator path length index	−0.70	−1.5∼0.06	0.07	−0.46	−4.30∼3.39	0.73
Weeks of neurosurgery	Blood loss	−0.001	−0.03∼0.02	0.93	0.03	−0.001∼0.06	0.05
Number of skin closure	Total tip path length of ultrasonic aspirator	−0.30	−0.50∼−0.10	0.01	−0.32	−0.83∼0.19	0.14

closures significantly influenced performance, whereas age, handedness, video game exposure, and previous virtual reality simulator experience did not. The literature has conflicting information regarding the degree to which these factors influence performance. Gelinas-Phaneuf's study using medical students on a NeuroTouch simulator prototype demonstrated no influence of musical instrument exposure.[13] Other studies using virtual reality laparoscopic tasks have shown differences according to handedness[22] and gender,[23] whereas previous internship rotation had no influence on performance.[23] A positive effect of video game exposure on virtual reality performance has been previously documented.[24] On multivariate analysis, only self-rating of operating room confidence and weeks of neurosurgery elective demonstrated a trend ($p = 0.05$) to increased blood loss.

Responses of self-ratings of manual dexterity and confidence in the operating room mirrored each other, both with means of 7.4 (1.0). One explanation may be that applicants are unlikely to feel comfortable in the operating room if they do not have confidence in their manual dexterity. In previous studies, medical students who did not feel confident about their manual dexterity skills took longer time to complete a virtual reality laparoscopic bead-sorting task,[25] whereas greater levels of self-assessed dexterity evaluation correlated with improved instrument-handling scores in a laparoscopic virtual reality environment.[23] However, an unexpected finding in this study was the inverse relationship between self-ratings of operating room confidence and performance. Applicants who judged themselves as more confident had statistically inferior performance on suction-coordinating index and trends to decreased performance on a number of other metrics assessed on univariate analysis, though this did not reach significance on multivariate analysis. Only increased blood loss trended toward significance with increasing operating room confidence and increasing weeks of neurosurgery. Candidates who had exposure to more neurosurgery may feel more confident; however, lack the skills necessary to achieve a desirable surgical outcome. This finding is inconsistent with previous data, which demonstrates that self-assessed ratings of performance accurately reflect performance in simulation scenarios.[23] The reason for these differences remains unclear and need further evaluation; however, our results suggest that applicants who judge themselves very confident may display poorer bimanual performance than their peers.

Strengths and Limitations

Although this pilot study may have implications for residency applicant technical skills screening, the results must be interpreted with caution. Long-term follow-up data is needed to correlate simulator scores on admission to a residency program with subsequent performance on the same simulator, psychomotor performance during residency, and the performance of residents when they become practicing neurosurgeons before applying simulation technology to screen applicants. Applying this type of screening before data on long-term follow-up is available would not be appropriate. To address this issue, the information from this pilot study is being incorporated into a global multicenter longitudinal study that will follow neurosurgical resident applicants through their resident training and during their practice as independent neurosurgeons. Multiple issues including which scenarios to employ, which simulators to adopt, the best validated metrics, emphasizing patient safety, to assess and which proficiency-based benchmarks to use need to be resolved. The results of this longitudinal study should provide data that relates directly to the question as to whether selecting neurosurgery residency applicants using information from simulation studies is a reasonable strategy. A more pragmatic approach to simulation technology may be in the training, as opposed to selection of residents. The findings of this pilot study suggest that "personalized residency technical skills training programs" could be explored, which maximize trainee bimanual psychomotor training dependant on initial and ongoing information from simulation studies. We propose that this conceptual framework be referred to as "Technical Abilities Customized Training" (TACT). Neurosurgical TACT programs could focus on accelerating top performers, improving areas of weakness in average performers and early identification of trainees with poor performance, while initiating multiple validated methods to enhance and to maintain the bimanual performance of all groups.

This study was focused on the assessment of psychomotor bimanual performance of applicants to a neurosurgical program at a Canadian University and may not be representative of neurosurgical applicants in other localities. A total of 15 of the 22 students (68%) from Canadian medical schools are included in this study, all of which indicated that a neurosurgery residency was their first choice.[16] Other 2 applicants from Canadian medical schools were not interviewed for the McGill position and therefore were not available for this study. The authors believe that this study includes a reasonable representation of Canadian medical students applying to neurosurgery in Canada. Although the weeks of applicant neurosurgical exposure is a very accurate value, data on the number of skin closures are based on memory and are less reliable. The number of applicants studied, quality, difficulty, types of metrics, and short duration task scenario assessed in this study may not adequately discriminate performance among the medical students studied. These metrics are being assessed by other surgical specialties and may aid in determining the universality of their usefulness in assessing medical student applicants to other surgical areas.[26,27]

The strength of this study is the use of a high-fidelity platform with previously validated metrics. It is among the first studies to reveal the variation of neurosurgical applicant psychomotor performance. Having objective measurements of individual bimanual psychomotor performance along with proficiency performance benchmarks would allow residency programs to not only implement simulation-based training curricula but to tailor their surgical education to the skill sets of individual trainees and form the basis for longitudinal studies to assess the use of these curricula.[7-10,14]

CONCLUSIONS

The results of our pilot study outline that simulation technology identifies neurosurgical residency applicants with varying levels of technical ability. This information would be useful to develop longitudinal studies on the acquisition, development, and maintenance of psychomotor skills. TACT programs that maximize individual resident bimanual psychomotor training dependant on continuously updated and validated metrics from virtual reality simulation studies should be explored.

ETHICAL STANDARDS

All procedures followed were in accordance with the ethical standards of the responsible committee on human experimentation (institutional and national) and with the Helsinki Declaration of 1975, as revised in 2008.

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SUPPLEMENTARY INFORMATION

Supplementary data associated with this article can be found in the online version at http://dx.doi.org/10.1016/j.jsurg.2016.04.013.

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