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Simulation to become a better neurosurgeon. An international prospective controlled trial: The Passion study

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ABSTRACT

Introduction: Surgical training traditionally adheres to the apprenticeship paradigm, potentially exposing trainees to an increased risk of complications stemming from their limited experience. To mitigate this risk, augmented and virtual reality have been considered, though their effectiveness is difficult to assess.

Research question: The PASSION study seeks to investigate the improvement of manual dexterity following intensive training with neurosurgical simulators and to discern how surgeons' psychometric characteristics may influence their learning process and surgical performance.

Material and methods: Seventy-two residents were randomized into the simulation group (SG) and control group (CG). The course spanned five days, commencing with assessment of technical skills in basic procedures within a wet-lab setting on day 1. Over the subsequent core days, the SG engaged in simulated procedures, while the CG carried out routine activities in an OR. On day 5, all residents' technical competencies were evaluated. Psychometric measures of all participants were subjected to analysis.

Results: The SG demonstrated superior performance ($p < 0.0001$) in the brain tumour removal compared to the CG. Positive learning curves were evident in the SG across the three days of simulator-based training for all tumour removal tasks (all p-values <0.05). No significant differences were noted in other tasks, and no meaningful correlations were observed between performance and any psychometric parameters.

Discussion and conclusion: A brief and intensive training regimen utilizing 3D virtual reality simulators enhances residents' microsurgical proficiency in brain tumour removal models. Simulators emerge as a viable tool to expedite the learning curve of in-training neurosurgeons.

1. Introduction

The professional journey of each surgeon involves a continuous process of learning through the analysis and correction of mistakes, a phenomenon particularly prominent in the specialized field of neurosurgery. The age-old adage "see one, do one, teach one" inherently recognizes that our educational paths are significantly influenced by a

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regrettable frequency of errors, often resulting in injuries or fatalities among patients (Meling and Meling, 2021; Perin et al., 2021a, 2022).

Abbreviations:

PASSION	Psychological Assessment and Skills Training by Simulation in Neurosurgery
BNSC	Besta NeuroSim Center
AR	Augmented Reality
VR	Virtual Reality
SG	Study Group
CG	Control Group
PGY	Postgraduate year of training
EVD	External Ventricular Drainage
RPM	Raven's Progressive Matrices
APM	Advanced Progressive Matrices
OR	Operating Room

Possessing extensive theoretical knowledge does not automatically translate into surgical brilliance (Perin et al., 2021b) and conventional training methods, such as cadaver dissection and purposeful practice, may inadequately bridge this gap (Hinkle and Pontone, 2021). This realization emphasizes the necessity to explore and adopt innovative educational strategies within the domain of surgical training.

Over recent decades, there has been a growing interest in virtual reality (VR), augmented reality (AR) and mixed reality as potential tools to expedite the learning process for both novice and experienced surgeons, aiming to elevate proficiency levels while reducing the occurrence of critical errors (Spreen and Strauss, 1998; Ribeiro de Oliveira et al., 2016; Choudhury et al., 2013; Kohn et al., 2000). However, these technologies have yet to gain widespread adoption due to cost implications and a lack of robust clinical evidence supporting their efficacy (Jena et al., 2011; Meling and Meling, 2021).

The Besta NeuroSim Center (BNSC) is dedicated to neurosurgical training, equipped with state-of-the-art neurosurgical 3D VR simulators and rehearsal devices, complemented by unique physical brain models. This infrastructure allows residents and neurosurgeons to engage in practice within a risk-free environment (Benet et al., 2014; Aboud et al., 2002; Park, 2022). The BNSC has demonstrated a strong commitment to training, collaborating extensively with the European Association of Neurosurgical Societies (EANS) in recent years (Błaszczyk et al., 2021).

Within this framework, we have developed a prospective, randomized, controlled, and international study to assess, for the first time, the tangible impact of high-tech simulator training on neurosurgical performance. Simultaneously, we conducted a comprehensive psychometric analysis of neurosurgery residents to potentially elucidate correlations between their learning curves, technical proficiency, cognitive performance, and personality profiles (PASSION: Psychological Assessment and Skills Training by Simulation in Neurosurgery). The outcomes of this study hold the promise of offering a prospective evaluation of the influence of simulation on neurosurgical performance, coupled with insights into the relevance of psychometric profiling for neurosurgical residents.

2. Materials and methods

2.1. Design of the study

The study started in March and ended in September 2019 and it took place at the BNSC, IRCCS Istituto Neurologico Carlo Besta in Milan. Residents in Neurosurgery from all over the world were recruited to join the PASSION Study (IRB No 20/2015) over a period of twenty-four months (from January 2017 to January 2019). To apply, candidates had to answer a questionnaire about personal data, hobbies and surgical experience, and the 16-Personality Factors. To prevent any potential impact on the outcomes, individuals with prior exposure to neurosurgical simulators, specifically residents, were excluded from participation in the study.

Based on data collected during previous courses, we calculated a total sample size of 68 participants, considering an effect size of 0.8 and alpha error of 0.05. Ninety residents were asked to participate and were randomized with 1:1 ratio by Postgraduate year of training (PGY) and training country in two groups: the *Simulation Group (*SG*)*, assigned to an intensive training with the neurosurgical simulators, and a *Control Group (*CG*)* assigned to ordinary activities of the traditional apprenticeship. The randomization by year and country sought to establish two homogeneous groups based on surgical experience (PGY) and country where the residency program was conducted.

The study was performed over 5 days and the participants were grouped in sessions of 4–6 people. During the initial day (Pre-Training), residents' proficiency in common neurosurgical procedures was evaluated using specific experimental models provided by the BNSC staff. Subsequently, during the main training period (days 2–4), the SG underwent intensive training with neurosurgical simulators for 8 h each day. At the same time, the Control Group (CG) engaged in regular training activities in a neurosurgical ward and participated to ordinary neurosurgical activities either in the O.R. or on the ward. On the fifth day, we re-evaluated the surgical skills of all participants (post-training), comparing them to the assessments conducted during the Pre-Training phase. Finally, the participants were tested for bi-manual dexterity and psychometric abilities, such as fluid intelligence and spatial ability, with standard and validated exams (see below – *subgraph 2.3*). The study design is shown in Fig. 1. Throughout the entire duration of their stay in Milan, participants had their accommodation and lunch expenses covered by the study organizers.

All data was collected in a database using Excel 2013 (Microsoft®, USA) and the results were analysed using SPSS 20.0® (IBM Corp., NY, USA) and Prism 8® (GraphPad Software, 2018). Non-parametric tests were used for the analysis of quantitative variables, in particular the Mann-Whitney *U* test for independent samples and the Wilcoxon test for dependent samples. Results with $p < 0.05$ were considered statistically significant.

2.2. Pre and Post Training surgical tasks

Lumbar Puncture. All participants performed lumbar puncture on a mannequin (Supplementary Materials Fig. 1). The score was calculated as the average of three attempts (Supplementary Materials Table 1).

EVD placement. All participants had to place a right frontal EVD on NeuroVR Neurosurgical Simulator (CAE Healthcare). Each of the residents performed three attempts and the score was calculated as the average of the distance (in millimetres) between the catheter tip from the Monro foramen (BurrHole Selection). Moreover, the BNSC staff recreated a simple and reproducible model of EVD placement consisting in a box with a hole on top, used for aiming a pen at the centre of coloured trajectories. (Supplementary Materials Fig. 2, EVD Training Box). The mean score of the three attempts was calculated, as shown in the Supplementary Materials Table 2.

Aneurysm clipping. Using the vascular simulator from Surgical Theater™ [Surgical Theater, LLC- Mayfield, Ohio (OH), USA], participants were tasked with clipping a left middle cerebral artery aneurysm, simulating the skin incision, the craniotomy, and the aneurysm clipping, as previously described by Perin et al., 2021a, 2021b, 2022 Mean score was calculated considering the position and trajectory of the clip (compared to a *gold standard* clip positioned by the vascular surgeon during surgery), residual aneurysm, vessel occlusion or stenosis and the appropriateness of the clip chosen (Supplementary Materials Table 3).

Dura mater closure. To assess bi-manual coordination, we recreated a

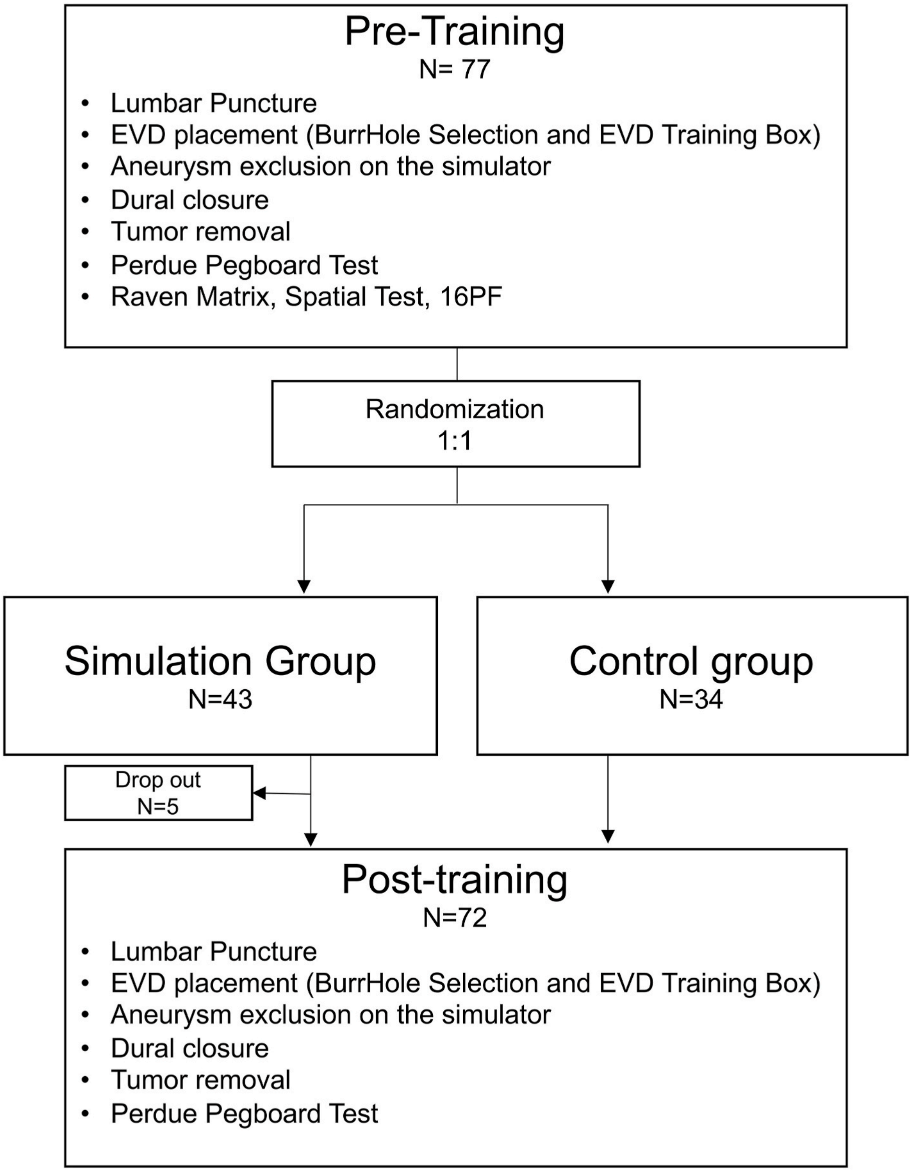

Fig. 1. Flow chart showing the study design. Randomization was based on the PGY and the country of neurosurgery residency. The duration of the course was 5 days. On the Pre-Training day, the participants' abilities were tested on experimental models. During the Training days, the simulation group SG) did intensive simulation training, while the control group (CG) observed surgeries in the OR and did general activities on the neurosurgery ward and OR. During the Post-Training day, residents' abilities were retested using the same models used during the Pre-Training. Because of technical problems with simulators, data about 5 participants was not analysed because they were not uniform.

model of dura closure and tumour removal. Latex-free white gloves were used to reproduce the aspect and elasticity of the dura mater. The glove was inserted on an Integra dura support device and a linear or a C-shaped line was drawn (Supplementary Materials Fig. 3). Using a microscope, the participants had to open and close the dura following the lines, first using the dominant hand and then using the non-dominant hand, for a total of four tasks each. The participants were given 15 min to complete the tasks. A scalpel, scissors, forceps, and a 4.0 suture (Vicryl, Ethicon, by Johnson&Johnson) were provided. All the procedures were recorded and evaluated by a neurosurgeon with at least 10 years of experience, following the criteria shown in Table 4 of the Supplementary Materials.

Tumour removal. The ability to remove an intra-parenchymal tumour was assessed using a brain tumour model created by Soering®, GmBH, Germany (Supplementary Materials Fig. 4). The model's characteristics, in terms of the difference in colour and texture between its two components (tumour vs brain parenchyma), provide a quite realistic prototype for this task. Under microscopic view, the participants used an ultrasonic aspirator, a dissector and microforceps to complete the task. The performance was recorded and evaluated by an expert neurosurgeon considering objective and subjective criteria in a single-blinded fashion (Supplementary Materials Table 5).

2.3. *Psychometric assessment*

Bimanual dexterity. The Purdue Pegboard Test® (Lafayette Instrument Company, Indiana, USA) provides a measure of dexterity and bimanual coordination (Hinkle and Pontone, 2021). The participants were given 30 s to insert pegs into the holes of the pegboard. This task was repeated with the dominant and non-dominant hand three times. Later, we assessed the bi-manual dexterity by asking them to insert the pins with both hands simultaneously in 30 s. Finally, the ability to assemble the "stud-wheel-disk-wheel" was evaluated by alternating the right and left hand in 60 s ("assembly task"). For each test, a score was calculated by giving one point for each element positioned (Supplementary Materials Table 6). We tested bi-manual dexterity during the Pre-Training and Post-Training to assess a possible improvement in the SG.

Fluid intelligence. Raven's Progressive Matrices (RPM) is a non-verbal test used to measure abstract reasoning and estimate fluid intelligence (Spreen and Strauss, 1998). It is a sequence of geometric figures to be completed by choosing one out of eight. We administered the advanced form of the test, Advanced Progressive Matrices (APM), which consists of 48 elements presented as a set of 12 (set I) and another of 36 (set II), characterized by increasing complexity of the questions. The maximum score is 48.

2.4. *Simulation training session*

The *Simulation Group* (SG) underwent an intensive three-day simulation training program (from day 2 until day 4). This training involved simulating various scenarios, including EVD placements, lumbar punctures on different anatomical spines (ImmersiveTouch® Inc., University of Illinois at Chicago Medical Center, Chicago, IL, USA), and various types of tumor removal using NeuroVR™ (CAE healthcare, developed by the National Research Council Canada). These modern technology simulators are endowed with haptic feedback and able to detect the position of the instrument's tip and discriminating the different tissue resistance (Ribeiro de Oliveira et al., 2016; Choudhury et al., 2013). Participants were asked to remove two meningiomas - a Low Bleeding case (Low-BM) and a High Bleeding case (High-BM) - and a glioma. Each task had a maximum time limit of 15 min and was carried out twice daily. Learning curves were acquired by comparing all the candidate's performances. The final score was assessed by the simulator, considering the percentage of tumour volume removed, of healthy tissue removed, total blood loss, and achievement of haemostasis (Supplementary Materials Table 7).

3. Results

3.1. *Demography*

90 international residents were enrolled; of these, 77 participated, while 13 candidates could not join the study because of logistic and bureaucratic issues. Data related to five participants were not included in the final analysis because of data loss while performing the study. Participants came from different geographical areas (35% from Western Europe, 22% from Eastern Europe, 28% from China, 8% from North Africa and 7% from Arabia and Turkey). The study sample constituted 73% men and 27% women.

93% were right-handed, 6% were left-handed, and only 1 was ambidextrous (1%). Eleven were PGY 1 (15%), 11 were PGY 2 (15%), 19 were PGY 3 (26%), 21 were PGY 4 (29%), and 10 were PGY 5 (13%). For the analysis, PGY 1–3 were considered as Junior residents (for a total of 41 participants) and PGY 4–5 as Senior residents (for a total of 31). Demographic data along with residents' surgical experience are summarized in Table 1.

3.2. *Pre and Post Training assessment*

Dura mater closure. There were no differences between the groups in the linear dura closure with either the dominant or non-dominant hand ($p = 0.34$ vs $p = 0.35$ respectively). We assessed an improvement in the performance of the SG for the C-shaped dura closure ($p = 0.01$); we could not measure any difference in the C-shaped dura closure with the non-dominant hand ($p = 0.1$). The results are shown in Fig. 5 of the Supplementary Materials.

Tumour removal. Candidates in the SG showed an improvement in Post-Training tumour removal performance ($p < 0.0001$); this was not observed in the CG [Fig. 2]. Learning curves on the simulator were compared for the different tasks across the SG participants and we recorded a significant improvement in the tumour removal performance over the three days of training (Fig. 3). In particular, the improvement was more substantial in the removal of the most difficult tumours, the High Bleeding meningioma (High-BM) and the glioma, as shown in Fig. 3c and e ($p < 0.005$ and $p < 0.05$, respectively). Furthermore, we examined how tumour removal performance varied across tumour types among senior and junior residents. We observed a partial improvement of senior vs. junior neurosurgeons during the second and third day of training, even if the difference is not significant ($p = 0.3$ and $p = 0.5$, respectively [Fig. 3b and d]. We did not find any differences between the two groups (SG vs CG) when analysing the lumbar puncture on the mannequin, the EVD placement tasks, and the aneurysm exclusion simulation. The average score and the Pearson coefficient are shown in Table 8 of the Supplementary Materials (see Fig. 4).

3.3. *Psychometric results*

No correlation between the psychometric tests and the manual performances in both groups were discovered. Both groups improved the dexterity with the Pegboard Perdue, but no difference was assessed between the control and the simulation group (Table 6 of the Supplementary Materials). The 16 PF qualitative data are illustrated in the Supplementary Materials.

4. Discussion

The presumption that every surgeon learns from mistakes involves recognizing that errors are an inherent part of the medical profession. On the other hand, the impact of mistakes is significant and research indicates that in the USA, there are over 150 deaths annually attributed to errors, with 40% of them arising from surgical mistakes (Kohn et al., 2000). This is even more pronounced in neurosurgery, which is the medical specialty most prone to litigation (Jena et al., 2011). While complete error avoidance may be unattainable, and acknowledging their instructive role is equitable, there exists a distinct benefit in mitigating the incidence of errors attributable to deficiencies in foundational surgical skills during the nascent phases of the surgical training process.

Various learning approaches have been proposed in a safe and patient-free environment. Cadaveric or animal laboratories are highly valuable for their accurate anatomical representation and realistic tactile feedback. However, their widespread accessibility is impeded by substantial costs and inherent ethical concerns, rendering them a less straightforward option for aspiring surgeons in training (Benet et al., 2014; Aboud et al., 2002; Park, 2022; Błaszczyk et al., 2021). In recent times, alternative approaches involve the utilization of physical models, including silicone tubes for microsurgical vascular simulation and 3D models for anatomical learning and tumour resection (McGuire et al., 2021). These models afford advantages in terms of cost-effectiveness, reproducibility, and efficacy for surgical training. However, their disposability is a common characteristic, and despite persistent efforts aimed at enhancing realism, they have not yet attained optimal realism (Ratinam et al., 2019). The other major set of tools is represented by simulators that exploits augmented/virtual/mixed reality. Simulators have been shown to be a valid, consistent, realistic and repeatable option in other surgical domains, with some studies providing evidence for their usefulness (Chaer et al., 2006; Seymour et al., 2002; Ahlberg et al., 2007; Meling and Meling, 2021).

In neurosurgery, many simulators have been introduced to simulate different procedures and numerous reports, mainly monocentric and not randomized, have validated the utility of these neurosurgical simulators, but the impact of simulation on neurosurgical performance in the OR has never been studied (Alaraj et al., 2013; Coelho et al., 2014; Delorme et al., 2012; Holloway et al., 2015; Tagaytayan et al., 2018; Meling and Meling, 2021). Instead, we focused on this aspect and, comparing the control group with the study group, we found a clear improvement when

Table 1

The PASSION Study Group participants' features and surgical experience as mean surgeon are shown. Residents were randomized by PGY and country of neurosurgery residency.

Participant	Group	Sex	Age	PGY	Nationality	Dominant Hand	Hospital surgical procedures	No. EVDs overall	No. EVDs last year	No. Meningiomas overall	No. Meningiomas last year	No. Gliomas overall	No. Gliomas last year
#1	Simulation	M	33	3	Algerian	Right	1258	25	10	0	0	1	0
#2	Simulation	M	32	5	Albanian	Right	1200	25	3	36	30	70	43
#3	Simulation	F	27	3	Spanish	Right	400	4	3	0	0	0	0
#4	Control	M	30	3	Bulgarian	Right	650	6	3	2	1	3	1
#5	Simulation	M	26	2	Lithuanian	Right	2500	12	6	0	0	0	0
#6	Control	M	29	3	Lithuanian	Right	3000	34	20	2	2	5	5
#7	Simulation	F	30	4	Algerian	Right	1000	20	5	50	15	100	20
#8	Simulation	M	29	4	French	Right	2500	30	8	5	5	6	6
#9	Simulation	F	34	3	Algerian	Right	95	8	0	0	0	0	0
#10	Simulation	M	35	2	Austrian	Right	1500	3	3	1	1	0	0
#11	Control	M	33	5	Bosnian	Right	300	10	3	3	1	2	1
#12	Simulation	M	30	3	Algerian	Right	1000	40	10	20	0	0	0
#13	Control	F	28	4	Moroccan	Right	500	48	15	3	3	2	2
#14	Control	M	29	4	Serbian	Ambidextrous	800	50	15	3	2	8	3
#15	Control	M	31	5	Belgian	Right	1000	150	50	1	1	2	2
#16	Simulation	F	30	3	Italian	Right	600	30	10	2	1	0	0
#17	Control	M	28	4	Lithuanian	Right	3000	45	19	3	3	4	4
#18	Simulation	M	31	5	Serbian	Right	500	10	4	3	2	2	1
#19	Simulation	M	32	3	Albanian	Right	1200	7	5	13	7	21	9
#20	Control	M	31	5	Serbian	Right	800	30	10	4	2	2	2
#21	Simulation	M	27	2	Egyptian	Right	300	21	10	11	11	10	10
#22	Simulation	M	30	5	Algerian	Right	1258	143	32	56	12	79	17
#23	Simulation	M	25	1	Serbian	Right	750	3	3	0	0	0	0
#24	Simulation	F	29	4	Spanish	Right	300	25	6	1	1	1	1
#25	Simulation	F	32	4	German	Right	500	40	12	0	0	2	1
#26	Simulation	M	26	2	Belgian	Right	3000	10	2	4	1	6	0
#27	Simulation	F	30	2	Polish	Left	1200	30	15	5	4	5	3
#28	Control	F	26	1	Italian	Right	900	4	4	0	0	0	0
#29	Simulation	F	32	4	German	Right	1700	16	4	0	0	0	0
#30	Control	F	28	2	Italian	Left	650	13	5	0	0	0	0
#31	Simulation	M	29	3	Austrian	Right	1000	14	6	0	0	1	1
#32	Control	M	24	3	Ukrainian	Right	1000	15	7	2	1	2	1
#33	Control	F	26	2	Arabic	Right	1000	10	4	0	0	0	0
#34	Control	M	32	4	Chinese	Right	3000	30	15	15	5	40	15
#35	Control	M	35	4	Chinese	Right	3000	50	9	150	30	200	85
#36	Simulation	M	34	3	Chinese	Right	3600	30	10	2	1	5	2
#37	Simulation	F	27	1	Italian	Right	1700	10	10	0	0	0	0
#38	Control	M	29	3	Italian	Right	1700	60	20	3	2	2	1
#39	Simulation	M	35	4	Chinese	Right	1500	100	30	5	4	5	3
#40	Control	M	34	4	Chinese	Right	3000	40	10	100	13	300	15
#41	Simulation	F	27	1	Italian	Right	600	5	5	0	0	0	0
#42	Simulation	M	33	3	Chinese	Right	3000	30	15	0	0	0	0
#43	Control	F	26	1	Italian	Right	550	8	8	0	0	0	0
#44	Simulation	M	27	1	Italian	Right	600	3	3	3	0	0	0
#45	Control	F	29	3	Turkish	Right	1500	10	3	6	3	4	2
#46	Control	F	33	6	Italian	Left	3000	20	1	1	0	0	0
#47	Control	M	33	5	Chinese	Right	2250	75	20	10	5	10	5
#48	Simulation	M	31	3	Chinese	Right	1500	30	15	180	80	170	10
#49	Control	M	30	1	Chinese	Right	1000	20	10	70	15	100	20
#50	Simulation	M	27	1	Chinese	Right	3200	20	8	1	1	0	0
#51	Control	M	31	2	Chinese	Right	3000	50	10	30	10	20	5
#52	Simulation	M	31	5	Chinese	Right	3000	80	20	10	2	3	1
#53	Control	M	29	4	Chinese	Right	3000	50	10	30	10	20	5

(*continued on next page*)

Table 1 (*continued*)

Participant	Group	Sex	Age	PGY	Nationality	Dominant Hand	Hospital surgical procedures	No. EVDs overall	No. EVDs last year	No. Meningiomas overall	No. Meningiomas last year	No. Gliomas overall	No. Gliomas last year
#54	Simulation	M	29	4	Czech	Right	3000	46	28	1	1	2	2
#55	Control	M	35	4	Chinese	Right	360	10	4	2	2	4	2
#56	Control	M	27	3	Chinese	Right	500	8	3	2	1	0	0
#57	Simulation	M	30	4	Chinese	Right	8000	100	60	13	10	15	5
#58	Control	M	30	4	Italian	Right	3000	60	5	2	1	3	2
#59	Control	M	32	5	Italian	Right	3000	100	5	10	3	10	1
#60	Simulation	M	37	4	Chinese	Right	3500	15	5	2	1	0	0
#61	Control	M	34	3	Chinese	Right	2000	20	10	20	10	0	0
#62	Control	M	36	4	Chinese	Right	3800	300	67	nd	nd	nd	nd
#63	Simulation	M	29	3	Chinese	Right	3000	15	10	15	8	13	7
#64	Control	M	27	1	England	Right	1500	5	5	2	2	5	5
#65	Simulation	M	26	1	Croatian	Left	3000	4	4	0	0	0	0
#66	Simulation	M	30	4	Italian	Right	2500	31	10	2	2	0	0
#67	Control	M	30	3	Turkish	Right	1750	30	8	5	3	6	3
#68	Control	M	30	2	Turkish	Right	1750	15	5	1	1	0	0
#69	Control	M	26	1	Italian	Right	3000	7	7	0	0	0	0
#70	Simulation	F	26	2	Arabic	Right	206	5	2	0	0	0	0
#71	Control	F	27	2	German	Right	1500	25	25	0	0	0	0
#72	Simulation	M	28	4	Italian	Right	1000	50	12	1	1	0	0

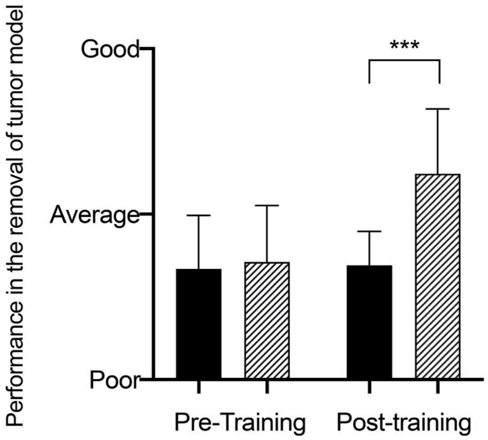

Fig. 2. The graph shows the residents' performance in the removal of tumour model tumour during the Pre-Training and the Post training. It illustrates the improvement of Post Training performance in the Simulation Group (SG) ($p < 0.0001$) compared to the Control Group (CG) ($p > 0.99$). *$p < 0.05$, **$p < 0.005$, ***$p < 0.0005$. CG = Control Group. SG = Simulation Group.

performing the tumour removal task in the group that received intensive training, demonstrating the advantage of simulators on surgical performance. This result is supported by the remarkable progress seen in the tumour removal task with the NeuroVR® simulator (Fig. 3) It is reasonable to assume that intensive training and numerous repetitions determine the acquisition of new technical skills which, when translated into clinical practice, lead to better performance, but this remains to be convincingly demonstrated (Meling and Meling, 2021).

Another salient observation relates to a general improvement in suturing proficiency across all participants. Remarkably, the difference between the Simulation Group (SG) and Control Group (CG) was notably conspicuous in the test involving suturing a C-shaped dura incision with the dominant hand. The significance of this observation stems from the fact that this task is not formulated as a mirrored learning test in the simulators. Consequently, in theory, neither the SG nor the CG had the chance to specifically practice suturing for this task. This may be interpreted as a transversal effectiveness of the simulators, facilitating training of bimanual skills and dexterity that can subsequently be applied across diverse scenarios. Consequently, these findings may be attributed to the impact of simulator-based practice, potentially resulting in heightened concentration, attention, and precision during the execution of microsurgical tasks (Hedman and Felländer-Tsai, 2020).

Regarding the second endpoint of the PASSION study, i.e. to identify psychological characteristics that facilitate the learning process, improve performance in the OR, and possibly reduce errors in the OR (Bajunaid et al., 2017; Alotaibi et al., 2015), we could not appreciate any correlation between the psychometric tests and practical performance. Nevertheless, the qualitative data analysis revealed some interesting and unprecedented data about the neurosurgery residents. Extroversion does not seem to be a characteristic trait of the participants, in contrast to the typical personality profile conventionally attributed to surgeons (Lourinho et al., 2017; McGreevy and Wiebe, 2002). These data could be due to the development of a stability between introverted and extroverted behaviours, which can be implemented from medical school and continue throughout the training program (Davidson et al., 2015; Khan et al., 2021). This element could also explain the average level of anxiety of the cohort, which, as a result of adapting to the constant demands of the surgical environment, has low levels of neuroticism, greater emotional resilience, and effective coping mechanisms, which contrast the profiles delineated in various studies involving samples of medical students (Wetzel et al., 2006; McManus et al., 2004). This hypothesis could be confirmed by many who perceive stress not as a productive stimulant but as a counterproductive element, enabling individuals to

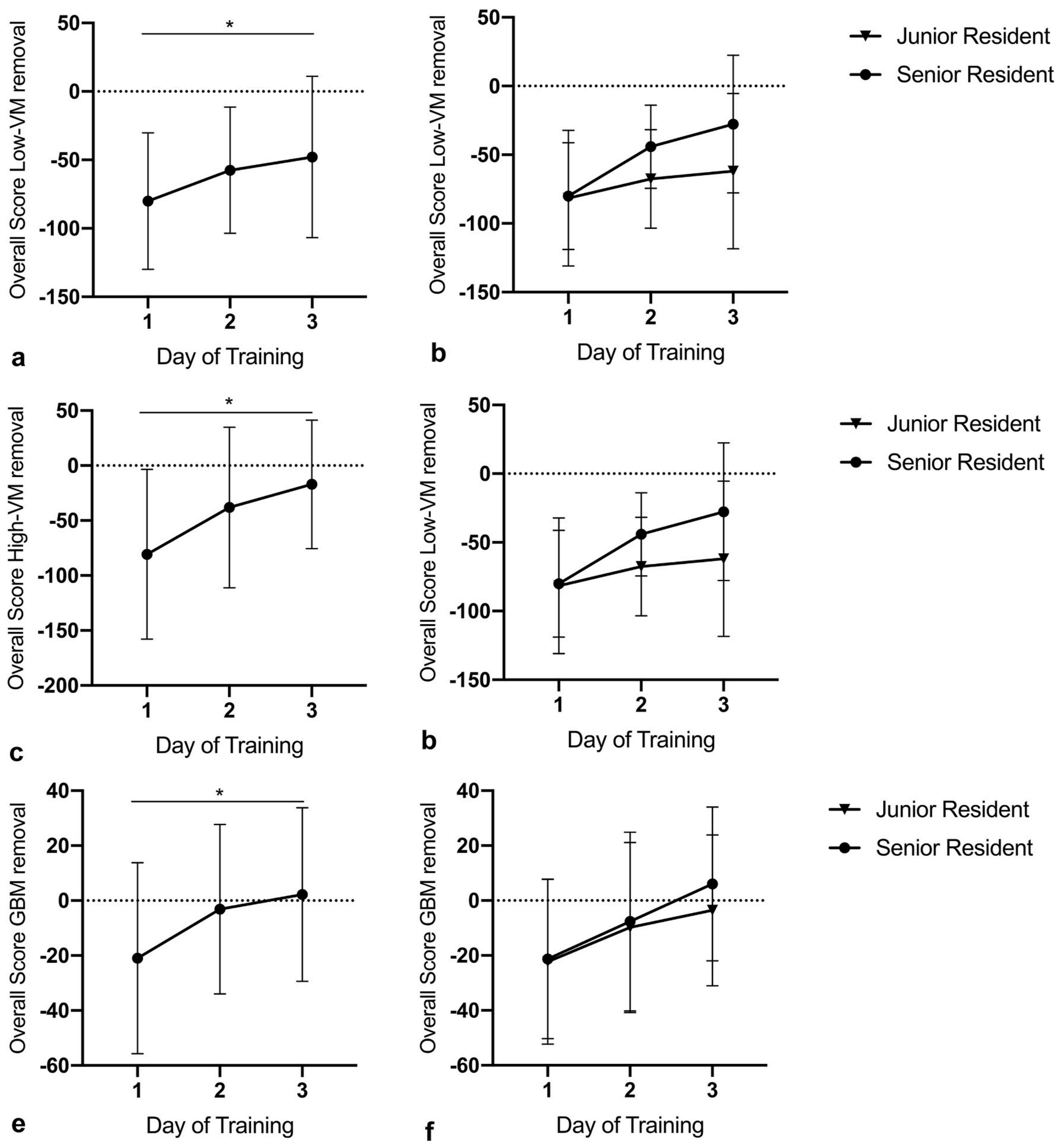

Fig. 3. The picture shows the results of tumour removal using the neurosurgical simulator. **a** It is notable the improvement over the three days of training in the removal of the Low Bleeding meningioma ($p = 0.02$). **b** The different performances of seniors and juniors in the Low Bleeding Meningioma removal. The first day score was the same but during the second and the third day of training the seniors performed better but there is no statistical difference ($p = 0.35$). **c** There is a sharp improvement in the removal of High-Bleeding Meningioma ($p = 0.001$). **d** Even if the seniors residents performed better than the juniors there is no difference between the groups ($p = 0.5$). **e** The performance in glioma removal increased markedly ($p = 0.001$). **f** There is no difference in the performance of the glioma removal between senior and junior residents ($p = 0,7$). Low-BM = Low-Bleeding meningioma, High-BM=High Bleeding meningioma, $^*p < 0.05$, $^{**}p < 0.005$, $^{***}p < 0.0005$.

resist pressures that might adversely impact performance (Gadjradj et al., 2021; Zaed et al., 2020). Therefore, average levels of anxiety could be consistent with a tendency to underestimate the role of stress in surgical practice or in the development of control over the ability to make it effective. Consistent with numerous reports, our study population also exhibits a balance in traits such as independence and self-control, qualities conducive to collaborative teamwork and the prevention of conflict and attrition among colleagues. This is noteworthy because surgeons displaying antagonistic behaviour tend to encounter difficulties in interpersonal relationships with colleagues, an increased frequency of malpractice complaints, and even a higher incidence of divorce (Drosdeck et al., 2015).

However, notwithstanding its strengths, the methodology employed in this study has certain limitations. Firstly, in order to have a large, international study population, we had legal and ethical limitations that did not allow us to bring the control group to the OR, in order to continue with their regular surgical training. Secondly, as the primary emphasis of this study is on training, the initial study design intended to include only residents in their first to third postgraduate years (PGY 1–3). However, difficulties arose in recruiting a sufficient number of junior residents (PGY 1–3) due to bureaucratic, economic, and legal complexities across various hospitals and countries. Consequently, we broadened the inclusion criteria to encompass residents in their first to fifth postgraduate years (PGY 1–5). Lastly, the duration of the study for each participant was constrained to five days rather than a more significant period, primarily to control costs and ensure the feasibility of

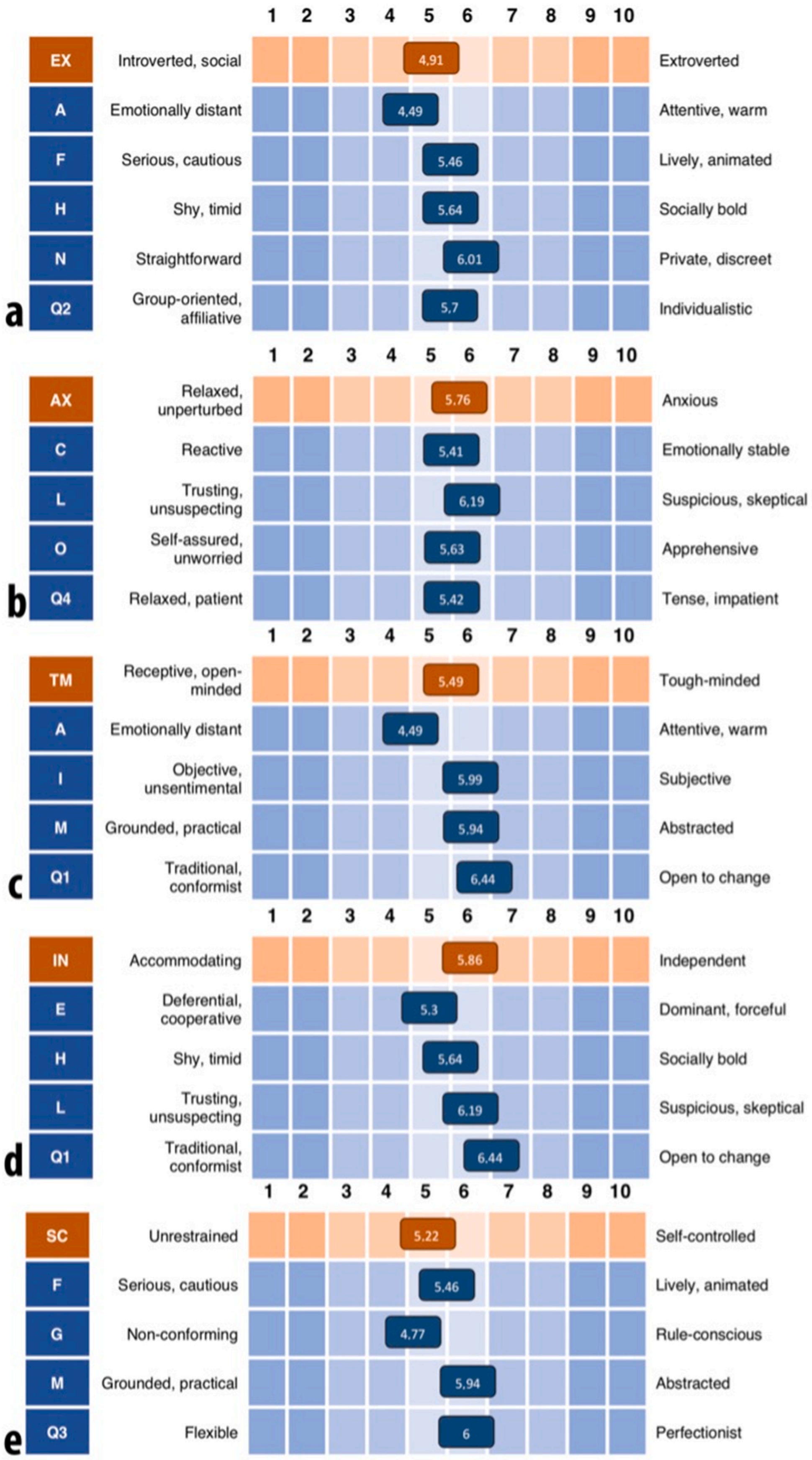

Fig. 4. 16 Personality factor data. **a** Extroversion. **b** Anxiety. **c** Hardness. **d** Introversion. **e** Self-control.

the study. This allocation included three days dedicated to training, with an additional day each for pre-training assessment and post-training assessment.

5. Conclusions

A short and intense training with VR simulators improves neurosurgeons' performance both in simple and complex tasks, such as dura closure and brain tumour removal. This evidence may be important in paving the way to a new structured training program for future neurosurgeons, where surgical skills must be acquired in a patient-free environment before performing operations on humans.

The results of this study were presented during the following congress

−69th SINch (Italian Society of Neurosurgery) @ONLINElikeONSITE, short communication.
- eEANS 2020 Beyond Borders Virtual Congress, short communication.

Declaration of competing interest

The authors declare that they have no known competing financial interests or personal relationships that could have appeared to influence the work reported in this paper.

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Appendix A. Supplementary data

Supplementary data to this article can be found online at https://doi.org/10.1016/j.bas.2024.102829.

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