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ORIGINAL ARTICLE - NEUROSURGERY TRAINING

Filling the gap between the OR and virtual simulation: a European study on a basic neurosurgical procedure

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Abstract

Background Currently available simulators are supposed to allow young neurosurgeons to hone their technical skills in a safe environment, without causing any unnecessary harm to their patients caused by their inexperience. For this training method to be largely accepted in neurosurgery, it is necessary to prove simulation efficacy by means of large-scale clinical validation studies.
Methods We correlated and analysed the performance at a simulator and the actual operative skills of different neurosurgeons (construct validity). We conducted a study involving 92 residents and attending neurosurgeons from different European Centres; each participant had to perform a virtual task, namely the placement of an external ventricular drain (EVD) at a neurosurgical simulator (ImmersiveTouch). The number of attempts needed to reach the ventricles and the accuracy in positioning the catheter were assessed.
Results Data suggests a positive correlation between subjects who placed more EVDs in the previous year and those who get better scores at the simulator ($p = .008$) (fewer attempts and better surgical accuracy). The number of attempts to reach the ventricle was also analysed; senior residents needed fewer attempts (mean = 2.26; SD = 1.11) than junior residents (mean = 3.12; SD = 1.05) ($p = .007$) and staff neurosurgeons (mean = 2.89, SD = 1.23). Scoring results were compared by using the Fisher's test, for the analysis of the variances, and the Student's T test. Surprisingly, having a wider surgical experience overall does not correlate with the best performance at the simulator.
Conclusion The performance of an EVD placement on a simulator correlates with the density of the neurosurgical experience for that specific task performed in the OR, suggesting that simulators are able to differentiate neurosurgeons according to their surgical ability. Namely this suggests that the simulation performance reflects the surgeons' consistency in placing EVDs in the last year.

Keywords Simulation · EVD placement · Residency training · Construct validity · Patient's safety

Abbreviations

ACGME	Accreditation Council of Medical Education
CT	Computed tomography
EVD	External ventricular drain
ENSSG	European Neurosurgery Simulation Study Group
EWTD	European Working Time Directive
OR	Operative room
PGY	Post graduate year

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Introduction

The reduction of resident work hours established by the Accreditation Council of Medical Education (ACGME) in 2003 and by the European Working Time Directive (EWTD) issued in 1993 by the European Union [1] resulted in the reduction of surgical caseload for neurosurgical residents; with the increasing focus on patient safety, it has become evident that simulation could play a decisive role in neurosurgical education [2, 3]. Placing an external ventricular drain (EVD) is a "simple", although not trivial surgical procedure, where complications may arise, leading to potentially devastating outcomes. In this regard, virtual reality simulators—with haptic feedback technology—might be able to create a realistic and safe environment, where both residents and surgeons could train and practice, in order to perform this procedure better and more safely [4]. To date, it has not been clearly demonstrated if training with simulation determines a better neurosurgical performance; this is a very difficult question to answer, since many factors contribute to the final outcome [5].

The first important step is to assess how simulation can be useful as a training tool by substantiating its construct validity, which is defined as the simulator's ability to differentiate between less and more experienced surgeons [6]. If validated, simulation could be adopted to teach junior neurosurgeons, and to assess their level of competency before they perform a real operation on patients [7]. Content validity has been demonstrated for some neurosurgical simulation exercises [8–10], but construct validity has been more difficult to establish. Data comparing neurosurgical experience and simulation performances is less reported in the literature, in which all the reported studies are on single-centre experiences with very small numbers of participants [4]. The purpose of this study is to assess whether it is possible to find a correlation between the *real* neurosurgical experience and *virtual* performance, when performing a ventriculostomy and placing an external ventricular catheter.

Methods

This study was conducted during the National Congress of the Italian Society of Neurosurgeons (Vicenza, Italy, 2014), during the XVII Italian Hands-On Microsurgery Course (L'Aquila, Italy, 2014), during the "Skull-Base Workshop: Posterior Fossa Approaches, (Naples, Italy, 2014) and during the EANS training courses in Sofia (Bulgaria, 2016) and Vilnius (Lithuania, 2017).

Based on data from existing literature and from collected unpublished data, we hypothesised an effect size $f = 0.35$, with similar variance between groups. Considering $\alpha = 0.05$, a sample size equal to 90 was appropriate to obtain a power $(1-\beta) = 85\%$.

The simulated task consisted of performing an EVD placement using a high-resolution and high-performance virtual reality platform with haptic feedback technology (ImmersiveTouch Inc., University of Illinois at Chicago Medical Center, Chicago, IL, USA). The platform includes a library of different cases built from patients' data provided by the University of Illinois at the Chicago Medical Center. The data was pre-segmented and assembled from a CT DICOM data set, after removing patients' personal information. We evaluated the number of attempts needed to reach the ventricle with the catheter; the case we used for all the participants was "Case A", with a normal ventricle size (see Fig. 1d, e). Moreover, the accuracy of a simulated ventriculostomy catheter placement was evaluated by measuring the distance (in millimetres) between the tip of the catheter and the Foramen of Monro: this distance represents the score—namely a lower score indicates a more accurate performance. Before entering the study, all participants signed an informed consent form. Once the task was completed, the participants filled out a questionnaire about their surgical career and a content validity questionnaire about the simulator and the specific simulated task (Fig. 1). Results were analysed using Microsoft Excel 2013 (Microsoft, Redmond, WA, USA) SPSS 20.0 (IBM Corp., Armonk, NY, USA), (Analyst Soft Inc., Walnut, CA, USA) and Jasp (University of Amsterdam, Amsterdam, NL) according to the participants' level of training, years of experience and number of EVDs placed throughout careers. Scoring results were compared by using the Fisher's test, for the analysis of the variances, and the Student's *T* test. Results were considered significant at a *p* value lower than 5%.

Results

Ninety-two participants [47 males and 45 females; average age of 32 years old (min 26; max 53); 25 junior residents (PGY1–3), 49 senior residents (PGY 4–6) and 18 staff neurosurgeons] from different European countries were involved in the study. We measured whether the right frontal ventricle was reached (yes/no) by the catheter at the simulator and the number of attempts needed to do so (the candidate had a maximum of three attempts to reach the ventricle). If the catheter was inside the ventricle, we recorded the distance from the tip of the tool to the homolateral foramen of Monro. We correlated each participant's performance at the simulator with their surgical experience in regard to EVD placement; this was measured with the overall number of EVDs placed (throughout their career) and with the number of EVDs positioned during the last year (Table 1).

First, we analysed the performance at the simulator when positioning an EVD according to the candidates' *curricula*: mean number of attempts to reach the ventricle was 2.62 (SD = 1.18); we correlated this parameter with the number of EVDs positioned by the candidate throughout his/her career but no statistical correlation was found ($p = .079$) (Fig. 2a). On the other hand, a negative correlation was shown when comparing the number of attempts to reach the ventricle at the simulator and the number of EVDs placed during the last year ($p = .008$) (Fig. 2b).

We then divided all the participants into three groups, according to their level of training. Based on the retrieved data, junior residents (PGY 1–3) placed an average of 20.3 EVDs overall during their neurosurgical training (max = 100; min =

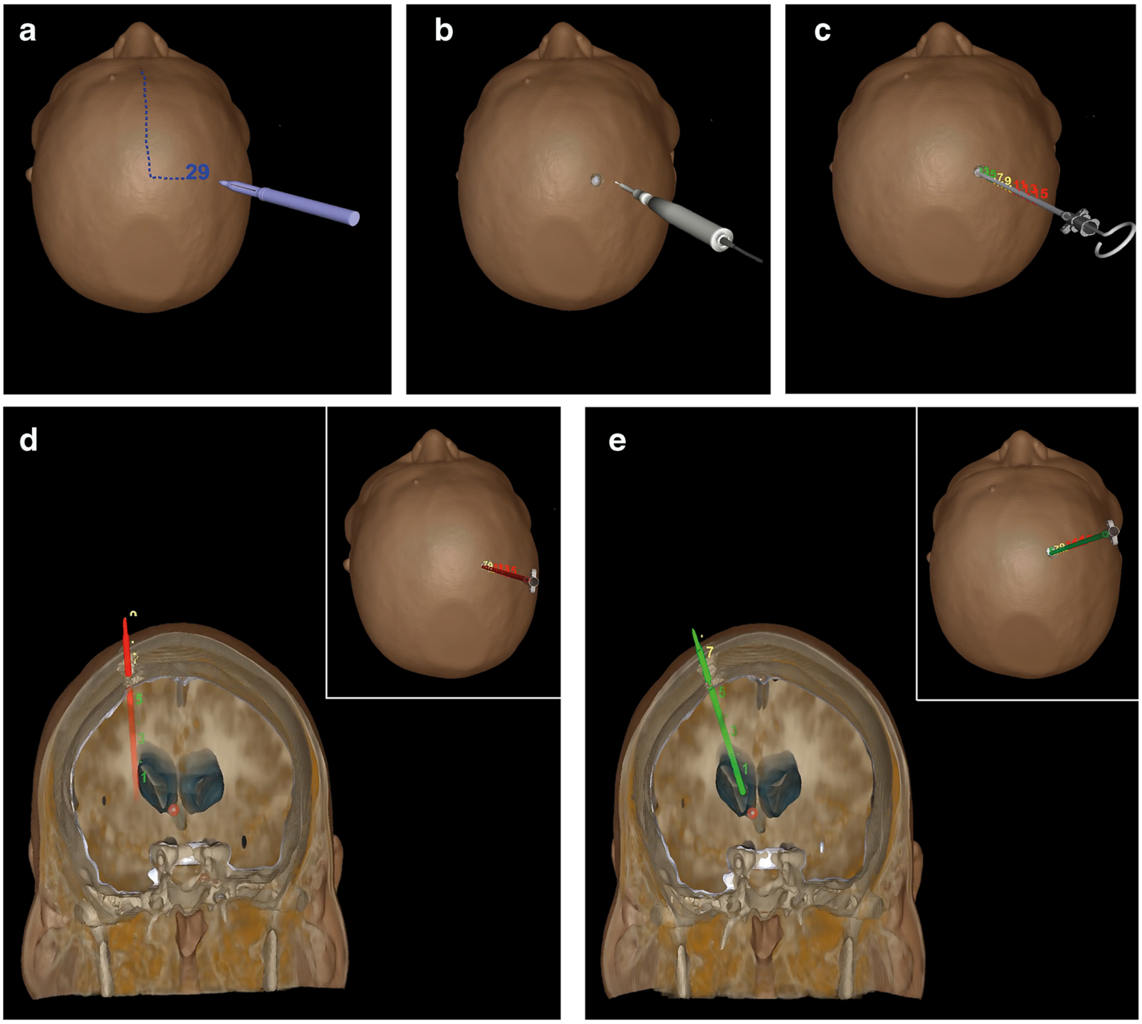

Fig. 1 Simulated EVD Task. **a** Identification of the Kocher point. The virtual head can be rotated in any direction by pressing the button on the haptic device. This helps identify important landmarks and understand the anatomy. The marker tool allows the trainee to take exact measurements on the skin (in millimetres). **b** Drilling the bone in order to expose the dura mater. Please note that the drilling tool is endowed with haptic feedback, so it reproduces the feeling and vibrations of a real driller. **c** Inserting the catheter. The catheter is inserted through the burr hole, aiming at the Monro's foramen. Thanks to haptic feedback, the trainee can have the feeling of passing through different structures (dura mater, brain parenchyma, ependymal layer). **d** Ventricle missed. The candidate positioned the catheter too laterally and far away from the Monro's foramen (red sphere). The red colour tells the candidate he/she failed. **e** Ventricle reached. The candidate positioned the catheter inside the ventricle, close to the Monro's foramen (red sphere). The green colour of the catheter indicates to the candidate that the procedure was successful

5; SD = 20.01); senior residents (PGY 4–6) 54.0 (max = 200; min = 5; SD = 41.84), whereas staff neurosurgeons positioned 104.7 EVDs throughout their careers (max = 250; min = 20; SD = 70.90) (Fig. 3a), confirming that the cumulative number of positioned EVDs will increase during the career of a neurosurgeon (Fig. 3a).

The number of attempts to reach the ventricle was also analysed; senior residents needed fewer attempts (mean = 2.26; SD = 1.11) than junior residents (mean = 3.12; SD = 1.05) ($p = .007$) and staff neurosurgeons (mean = 2.89, SD = 1.23) (Fig. 3b).

We focused on the density of experience, looking at the number of EVDs that were positioned by the study participants during the last year of their practice; junior residents had a mean EVD/year ratio of 8.1 (max = 13.33; min = 0; SD = 6.49), senior residents 12.7 (max = 33; min = 1; SD = 7.26) and staff neurosurgeons 8.1 (max = 25; min = 0; SD = 5.95) respectively (Fig. 3c). Senior residents are those who have the highest number of EVDs per year, indicating that the best results at the simulator were recorded among those residents who placed more EVDs/year (Fig. 3b, c). This is also confirmed by the fact that—regardless of any subgroup analysis—having positioned more EVDs during the last year of surgical activity correlates with a better performance at the simulator for any study participant (Fig. 2b). This result was also confirmed by the fact that those participants who reached the ventricle at the simulator (regardless of the number of attempts) where those who positioned more

Table 1 The European Neurosurgery Simulation Study Group participants' features and performance at simulator when positioning a virtual right frontal EVD. Junior and senior residents, along with staff neurosurgeons, had a maximum of three attempts to position an EVD; the distance between the tip of the catheter and the foramen of Monro was measured; results were correlated to the participant's neurosurgical experience—measured as the number of EVDs positioned during the entire career and during the last year, along with the amount of time spent playing a musical instrument or video-games (hours/week)

	Participant	Ventricle reached?	No. attempts	Distance from Monro (in mm)	Sex	Age	PGY	No. EVDs overall	No. EVDs/last year[a]	Musical instruments (h/week)	Video games (h/week)
Junior residents	#1	Yes	1	10.8	F	27	1	10	10	0	0
	#2	Yes	1	47.8	M	28	3	15	5	2	0
	#3	Yes	2	8.4	M	27	2	5	2	10	0
	#4	Yes	2	18.6	M	26	1	10	10	0	5
	#5	Yes	2	12.2	M	26	3	40	13	6	20
	#6	Yes	2	26.5	M	33	3	100	25	0	0
	#7	Yes	2	18.4	M	28	2	20	7	0	4
	#8	Yes	2	34.5	F	27	3	10	2	0	0
	#9	Yes	3	17.0	M	26	0	10	10	2	6
	#10	Yes	3	34.0	M	27	2	7	4	0	0
	#11	Yes	3	14.1	F	27	1	10	10	0	0
	#12	Yes	3	31.9	M	27	2	10	5	12	0
	#13	Yes	3	22.4	F	27	1	10	10	0	0
	#14	No	Ø	/	M	28	2	10	5	0	0
	#15	No	Ø	/	M	28	3	12	4	0	0
	#16	No	Ø	/	M	27	3	45	15	6	10
	#17	No	Ø	/	M	27	2	10	5	0	0
	#18	No	Ø	/	M	29	2	25	13	3	10
	#19	No	Ø	/	M	29	0	40	13	10	2
	#20	No	Ø	/	F	30	2	25	13	0	2
	#21	No	Ø	/	M	28	3	20	7	2	0
	#22	No	Ø	/	M	27	2	30	10	0	0
	#23	No	Ø	/	F	29	3	8	0	0	1
	#24	No	Ø	/	F	28	3	15	3	6	10
	#25	No	Ø	/	F	28	3	11	2	0	0
Senior residents	#26	Yes	1	20.4	M	29	5	50	10	0	5
	#27	Yes	1	26.6	F	28	4	26	7	0	0
	#28	Yes	1	27.0	F	29	5	50	12	0	0
	#29	Yes	1	20.1	M	27	4	87	23	1	0.5
	#30	Yes	1	20.7	M	29	4	70	20	0	4
	#31	Yes	1	24.5	M	31	5	30	6	0	1
	#32	Yes	1	32.1	M	29	4	10	3	3	0
	#33	Yes	1	22.8	M	28	5	45	10	2	0
	#34	Yes	1	27.2	M	31	6	198	36	0	0
	#35	Yes	1	14.2	M	36	4	50	13	3	0
	#36	Yes	1	29.4	M	34	6	82	21	0	0
	#37	Yes	1	33.6	F	30	5	15	3	0	0
	#38	Yes	1	25.5	M	29	4	50	20	0	0
	#39	Yes	1	10.9	M	34	5	50	15	3	0
	#40	Yes	2	19.5	M	31	6	200	33	5	2
	#41	Yes	2	27.5	M	33	4	100	25	0	2
	#42	Yes	2	22.3	F	29	4	12	3	0	0
	#43	Yes	2	26.9	F	31	6	70	20	3	0
	#44	Yes	2	23.7	F	31	6	40	10	0	0
	#45	Yes	2	36.3	F	39	4	60	15	1	1
	#46	Yes	2	26.8	M	33	5	70	30	0	0
	#47	Yes	2	41.0	F	33	5	50	10	0	0
	#48	Yes	2	28.5	F	30	6	100	20	0	0

Table 1 (continued)

	Participant	Ventricle reached?	No. attempts	Distance from Monro (in mm)	Sex	Age	PGY	No. EVDs overall	No. EVDs/last year[a]	Musical instruments (h/week)	Video games (h/week)
	#49	Yes	2	13.8	F	30	6	50	8	0.5	0.5
	#50	Yes	2	19.0	M	34	4	40	10	0	0.5
	#51	Yes	2	33.1	M	34	6	50	13	0	0
	#52	Yes	2	20.4	M	31	4	20	5	0	1
	#53	Yes	2	20.4	F	32	5	40	8	0	2
	#54	Yes	2	20.5	F	30	4	12	4	0	0
	#55	Yes	3	18.6	F	29	4	40	10	0	0
	#56	Yes	3	18.0	F	31	5	30	6	0	0
	#57	Yes	3	29.1	M	29	4	75	25	0	3
	#58	Yes	3	31.2	F	37	5	100	20	0	0
	#59	Yes	3	27.8	F	33	7	150	21	0	0
	#60	Yes	3	29.7	F	33	6	50	20	0	0
	#61	No	Ø	/	M	32	4	30	5	0	0
	#62	No	Ø	/	F	29	5	40	10	0	2
	#63	No	Ø	/	M	29	4	20	5	2	0
	#64	No	Ø	/	M	40	5	30	7	2	2
	#65	No	Ø	/	F	28	4	40	10	0	0
	#66	No	Ø	/	M	30	5	10	2	0	0
	#67	No	Ø	/	M	31	4	30	8	0	5
	#68	No	Ø	/	M	35	4	45	11	0	0
	#69	No	Ø	/	M	34	4	20	5	2	6
	#70	No	Ø	/	M	30	5	5	1	6	6
	#71	No	Ø	/	F	30	5	30	6	0	0
	#72	No	Ø	/	M	30	5	30	6	0	0
	#73	No	Ø	/	M	31	6	100	20	1	0
	#74	No	Ø	/	F	28	4	45	11	1	0
Staff	#75	Yes	1	24.7	M	31	N/A	20	10	0	0
	#76	Yes	1	27.3	F	47	N/A		0	0	0
	#77	Yes	1	35.2	F	53	N/A	250	5	0	0
	#78	Yes	1	26.5	F	39	N/A	50	10	0	0
	#79	Yes	2	25.1	F	39	N/A	200	25	0	3
	#80	Yes	2	34.9	F	35	N/A	60	6	0	3
	#81	Yes	3	28.5	M	39	N/A	200	14	0	0
	#82	Yes	3	25.4	F	43	N/A	100	10	0	0
	#83	Yes	3	29.1	F	52	N/A	150	1	0	0
	#84	Yes	3	22.7	F	43	N/A	200	15	0	0
	#85	No	Ø	/	F	45	N/A	100	5	0	0
	#86	No	Ø	/	F	44	N/A	120	7	0	0
	#87	No	Ø	/	F	35	N/A	50	5	0	0
	#88	No	Ø	/	F	33	N/A	50	7	0	0
	#89	No	Ø	/	F	36	N/A	50	5	0	0
	#90	No	Ø	/	F	36	N/A	50	6	0	0
	#91	No	Ø	/	F	46	N/A	30	2	0	0
	#92	No	Ø	/	F	33	N/A	100	13	0	0

Ø Please note that these subjects did not reach the ventricle after three attempts

[a] Approximated to the nearest whole number

EVDs during the last year of their career ($p < .001$) (Fig. 3d).

Moreover, the outcomes were analysed according to their video-game and instrument playing habits: all the analyses showed no statistically significant correlation between those who play videogames habitually or those who play any musical instrument.

At the end, each participant completed a post-simulation survey with a 5-item Likert scale questionnaire. The participants found that the difficulty (2.9/5.0) and realism (3.3/5.0) of the task were acceptable; the sensory realism with the haptic feedback technology was found to be appropriate (3.4/5.0). Overall, the participants were satisfied with the experience

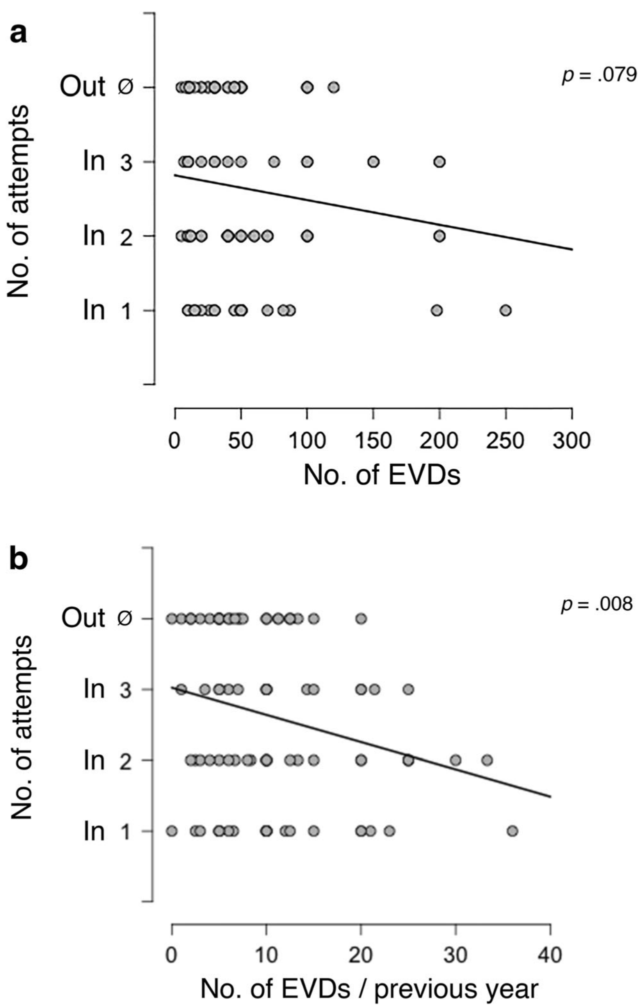

Fig. 2 **a** Correlation between the number of attempts needed to reach the ventricle (In = catheter that reached and stayed inside the ventricle; Out = catheter outside the ventricle) and number of EVDs placed during the entire career of a resident/neurosurgeon; having placed more EVDs overall does not correlate with fewer attempts when positioning a virtual EVD at the simulator. **b** Correlation between the number of attempts needed to reach the ventricle and number of EVDs placed during the previous year of practice of a resident/neurosurgeon; having placed more EVDs in the last year of time correlates with fewer attempts when positioning a virtual EVD at the simulator

(3.3/5.0) and they agreed that this type of simulation would be truly useful if made available at their institution (3.7/5.0); 82 participants out of 92 would implement this kind of simulation within their own department.

Discussion

After implementing resident work hour restrictions [11], medical errors have not decreased and patient safety has not increased [12–14]. Besides, a decrease in surgical caseload and surgical exposure might negatively impact neurosurgical residents [3] and the continuity of care [15]. Hence, a plausible support to better train junior residents has been found in simulation; in fact, there are several reports on the possible utility of simulation in training neurosurgeons with fewer risks for the patients [2, 16, 17]. Unfortunately, at this moment, data on the construct validity of neurosurgical simulators is inconsistent.

Therefore, we focused on the relationship between the real surgical experience level and the performance when doing a ventriculostomy at a simulator. Our hypothesis was that the older (and more experienced) the neurosurgeon, the better the performance would have been. Interestingly, the results showed that the most experienced neurosurgeons did not get the best scores at the simulator. As a matter of fact, PGY 4–6 residents performed better (Fig. 3b). Data showed that the participants who positioned more EVDs in the most recent period were those who needed fewer attempts to reach the ventricle at the simulator (Fig. 2b). A possible explanation for this lies in the fact that senior neurosurgeons may be offset because they tend to perform this procedure less frequently than residents, even though they have placed more EVDs throughout their careers, as if senior neurosurgeons were deskilled for this specific task.

It would be important to correlate the data we collected with each participant's success rate when positioning a real EVD in the OR; unfortunately, in order to obtain this information, it would be necessary to follow every neurosurgeon during their practice and record the number of attempts anytime an EVD is inserted, along with the ventricles' size, the presence of brain shift and haemorrhage at the preoperative CT scan. This would demand a more complex study, which is beyond the goal of this research.

In a recent systematic review [4] that analysed six previously published simulated ventriculostomy studies with outcome data, five using ImmersiveTouch [8, 18–21] and one using the EasyGuide Neuronavigation System [22], the relationship between experience and performance was reported and analysed. In some cases, there were no differences in the performances according to the participants' year of practice [8]; in others, optimal performances were obtained from beginning or mid-residency students [21]. This is in line with what Kang et al. found in different surgical specialties: their

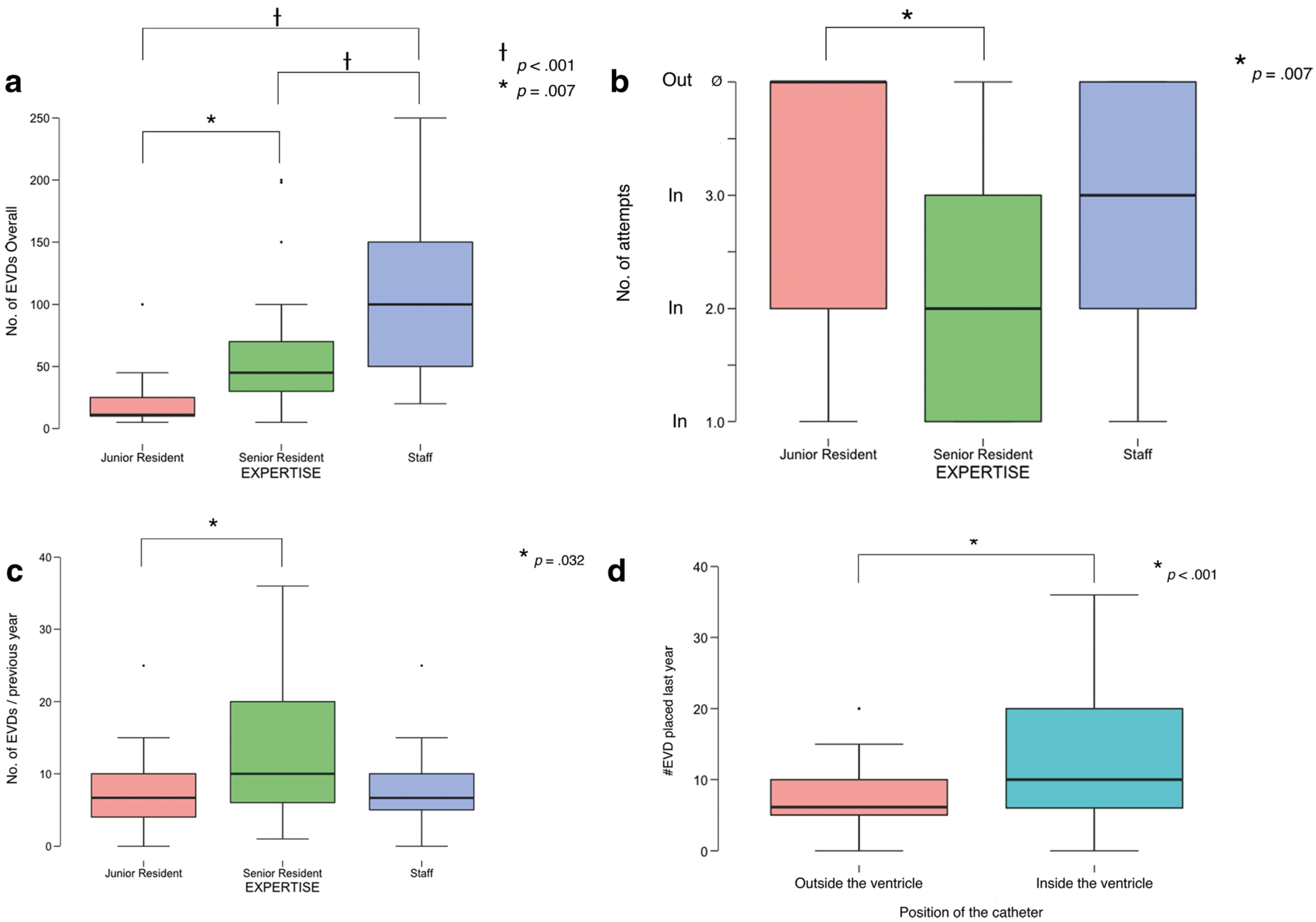

Fig. 3 **a** Overall number of EVDs placed. Participants were divided into junior residents (PGY 1–3), senior residents (PGY 4–6) and staff (attending neurosurgeons). Groups were statistically different, with the older surgeons having placed more EVDs compared to both senior and junior residents. **b** Number of attempts needed to reach the ventricle while positioning a virtual EVD. Note that senior residents performed better compared to junior residents and to attending neurosurgeons (staff). **c** Number of EVDs placed during the last year according to participants' experience. Please note that senior residents positioned more EVDs compared to their junior colleagues. **d** Number of EVDs placed in the last year and access to the lateral ventricle. Note that if you have put more EVDs during the previous year, it is easier to reach the ventricle with a catheter at the simulator

results concurred with ours as they too demonstrated how only a precise and continuous training scheme would permit the finest acquisition of all quintessential neurosurgical skills [23]. In line with our findings, the mixed-reality ventriculostomy simulator described by Hooten et al. demonstrated a strong relationship between the scores and the participant's level of training [24]. However, our study differs from the others in literature since it presents the largest series of neurosurgeons (both staff and residents) who practiced and were assessed at a virtual reality simulator: all the existing studies in this field were conducted in a single institution or on very small cohorts of residents/attending neurosurgeons [4]. The present study analysed a large group of participants coming from different European countries, residency programs and hospitals, and with different ways of performing this neurosurgical procedure: on the one hand, this population's heterogeneity represents a plus because it allows us to extend the validity of these results to a wider community; on the other hand, it limits the power of the study since it increases the inter-individual variability.

This is the only multi-centric study that correlates European neurosurgeons'—both residents and attending—experience in positioning an EVD (measured as PGY, total number of EVD placed during their career and number of EVD positioned during the last year of practice) with their performance at a simulator. All the existing literature in the field has never measured the impact of practice density (No. of EVD/last year of practice) on performance [4]. Yudkozsky et al. attempted to correlate simulator performance with OR performance for this surgical task [21]; in this prospective/interventional single-center study, they enrolled only 16 residents (no attending neurosurgeon) at different levels of training within a 7-year program in the USA. Only 12 residents provided partial data about the EVD success rate in the OR (no data about patients' ventricle size, pre-existing brain swelling/hematoma/shift on the CT scan, to weight their performance) [21]. Unfortunately, the small study population and the existing biases hamper the scientific relevance of their findings, so that a large prospective study is needed to answer this important question.

We have not noticed a positive correlation between video-games and/or musical instrument habits with the performance at a virtual reality simulator; this is not in line with the existing literature [4]. Most likely, playing video-games and musical instruments does not improve the skills of a neurosurgeon, since psychomotor skill development is very task-dependent, as indicated by the fact that attending neurosurgeons seem to have "lost" their fine ability to perform an EVD, even though they can conduct more sophisticated procedures [25]. Younger participants (who incidentally are more likely to play video-games) usually consider surgical simulators more seriously than senior attending surgeons, due to their self-motivated need to learn, and enthusiasm for new technologies. Besides, it is worth mentioning that the simulator does not allow you to firmly place the non-dominant hand over the patient's head while the catheter is being introduced with the dominant hand. In real life, this two-handed technique provides the operator with a good idea of the 3D spatial relationship between the patient's anatomy (on the one hand) and the catheter (on the other hand). If the candidate is not fully familiar or comfortable enough with the simulated depth perception provided by the stereo monitor, it might hamper the performance at the simulator (since the surgeon has already learnt to perform this procedure following that by-manual approach on real patients).

In the future, the use of virtual reality simulation might be more widespread in neurosurgery [26, 27], particularly in the realm of education. This idea is further supported by the first introduction in 2010 of a national simulation boot camp for PGY-1 neurosurgical trainees [28, 29]. Simulation could also be useful for medical students interested in pursuing neurosurgery as a career in order to better understand if they are fit for this specialty: thanks to this technology, they could comprehend which key technical skills are required for this discipline [29]. For neurosurgeons, as in the field of aviation, where airplane pilots are continuously assessed by means of different simulation scenarios [30], simulation could become the mean of evaluation of all neurosurgeons, with the ultimate goal of assessing and refining technical abilities throughout one's career and potentially reducing the risks of committing errors during neurosurgical procedures.

However, future developments in technology may renovate the way in which surgery is taught to young residents: detailed immersive 3D pre-surgical planning or simulated surgery could possibly improve the surgeon's performance and thus patient care. While it is difficult to assign a statistically proven value to the benefit of this technology, more studies are necessary to further assess the usefulness of this approach in order to standardise and make neurosurgical training safer.

In the near future, we would like to conduct a large, prospective, controlled, randomised trial with all European neurosurgery residents who are interested in simulation to define the impact of an intense, standardised virtual reality neurosurgery training on residents' surgical skills compared to a more traditional "apprenticeship" surgical training.

Conclusion

This is the first transnational European study on simulation in neurosurgery. ImmersiveTouch, a virtual reality platform with haptic feedback technology, has already demonstrated to improve EVD placement skills. Our data suggests that the scores obtained by assessing a ventriculostomy in this virtual reality environment could differentiate participants by their actual skills' level. Results do not correlate with the operator's general experience in this type of procedure or with their level of training but with one's daily practice of this surgical procedure, therefore suggesting that the habitual practice of EVD placement is what makes a neurosurgeon's EVD performance better. This study adds a relevant portion to the construct validity of simulated ventriculostomy with the ImmersiveTouch platform, enforcing its value as a possible assessing and training tool. Starting from medical school and throughout a neurosurgeon's career, this simulator could be used to reduce surgical risks and thereby improve patient's outcome. Further research studies are necessary to eliminate some of the current biases and to better understand the real relationship between virtual and real OR. In the future, virtual reality platforms may be regarded as an important and valuable tool to standardise medical education, neurosurgical assessment and training, possibly improving surgical skills and clinical outcomes.

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Compliance with ethical standards

Conflict of interest All authors certify that they have no affiliations with or involvement in any organisation or entity with any financial interest (such as honoraria; educational grants; participation in speakers' bureaus; membership, employment, consultancies, stock ownership or other equity interest; and expert testimony or patent-licencing arrangements), or non-financial interest (such as personal or professional relationships, affiliations, knowledge or beliefs) in the subject matter or materials discussed in this manuscript.

Ethical approval All procedures performed in studies involving human participants were in accordance with the ethical standards of the institutional and/or national research committee and with the 1964 Helsinki declaration and its later amendments or comparable ethical standards.

Informed consent Informed consent was obtained from all individual participants included in the study.

Appendix

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