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Original article

Applying an immersive tutorial in virtual reality to learning a new technique

Appliquer un tutoriel immersif en réalité virtuelle dans l'apprentissage d'une nouvelle technique

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ABSTRACT

Objective. – The medical world is continuously evolving, with techniques being created or improved almost daily. Immersive virtual reality (VR) is a technology that could be harnessed to develop tools that meet the educational challenges of this changing environment. We previously described the immersive tutorial, a 3D video (filmed from the first-person point of view), displayed on a VR application. This tool offers access to supplementary educational data in addition to the video. Here we attempt to assess improvement in learning a technique using this new educational format.
Material and methods. – We selected a single neurosurgical technique for the study: external ventricular drainage. We wrote a technical note describing this procedure and produced the corresponding immersive tutorial. We conducted a prospective randomized comparative study with students. All participants read the technical note, and one group used the immersive tutorial as a teaching supplement. The students completed a multiple-choice questionnaire immediately after the training and again at six months.
Results. – One hundred seventy-six fourth-year medical students participated in the study; 173 were included in assessing the immediate learning outcomes and 72 were included at the six-month follow-up. The VR group demonstrated significantly better short-term results than the control group ($P = 0.01$). The same trend was seen at six months.
Conclusion. – To our knowledge, this study presents one of the largest cohorts for VR. The use of the immersive tutorial could enable a large number of healthcare professionals to be trained without the need for expensive equipment.

Mots clés :
Réalité virtuelle
Formation chirurgicale
Neurochirurgie
Simulation
Apprentissage basé sur la vidéo
Apprentissage expérientiel

RÉSUMÉ

Objectifs. – Le monde médical ne cesse d'évoluer avec notamment une multiplication des techniques de soins. La réalité virtuelle immersive (VR), pourrait permettre le développement d'outils qui répondent aux enjeux pédagogiques. Nous avions préalablement décrit le tutoriel immersif. Il s'agit d'une vidéo 3D (filmée en point de vue à la première personne), projetée dans une application VR. Cet outil offre en supplément du film, un accès à d'autres données pédagogiques. L'objectif de notre étude est d'évaluer l'amélioration de la mémorisation d'une technique en utilisant ce nouveau format pédagogique.
Matériel et méthode. – Nous avons sélectionné une technique opératoire neurochirurgicale : la dérivation ventriculaire externe. Nous avons rédigé une note technique décrivant cette procédure et avons produit le tutoriel immersif correspondant. Une étude randomisée prospective comparative a été réalisée auprès

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d'étudiants. Tous ont lu la note technique, un groupe utilisait en supplément pédagogique le tutoriel immersif. Les étudiants ont rempli un questionnaire à choix multiple immédiatement après la formation et à six mois.

Résultats. – Cent soixante seize étudiants en quatrième année de médecine ont participé à l'étude, 173 ont été inclus pour évaluer la restitution immédiate des connaissances. Ils étaient 72 à six mois. Le groupe VR a significativement apporté de meilleures réponses à court terme par rapport au groupe contrôle ($p = 0{,}01$), La même tendance est retrouvée à six mois.

Conclusion. – À notre connaissance, ce travail présente l'une des plus grandes cohortes étudiant la VR. L'utilisation du tutoriel immersif pourrait permettre, sans équipements onéreux, de former en grand nombre des professionnels de santé.

1. Introduction

The revival of virtual reality (VR) in its immersive form occurred in 2012 with the incorporation of the Oculus Company.

VR systems, at first non-immersive (i.e., used without a headset), have been used in the medical field since the 1990s. The first applications were educational tools designed to help users understand autistic behavior [1]. In training situations, VR was first used by pilots [2]. Now, there are many various applications, and the number of articles on VR published on the website of the US National Library of Medicine (pubmed.gov) is growing exponentially. Our immersive tutorial in VR is a mobile application to showcase a technical procedure [3]. The tutorial comprises a main screen where a movie is projected, with content on each side. Creating the tutorial involves three steps. First, the surgical procedure is recorded in 3D from the expert's point of view (using the equipment worn by the surgeon performing the procedure). Second, the movie is organized into chapters corresponding to the different steps of the surgery (with calibration and synchronization of the two videos). Finally, clinical, imaging and drawing data are incorporated into the tutorial. This immersive tutorial in VR uses different pedagogical features that have independently proven their efficacy in improving learning. Firstly, the use of immersive VR itself provides an experience close to reality, instead of just watching a scene. The 3D experience adds depth, lending even more realism to the scene. According to Fowler [4], immersion provides a feeling of presence (the user feels as if he or she were in the environment) and of copresence (the user feels as if other people were part of this environment), which are the best criteria for a successful 3D VR learning environment. The first-person point of view has been shown to improve the learning of new gestures. Mirror neurons are usually activated [5] when the learner sees someone else performing a procedure. If this procedure is viewed from a first-person perspective, cognitive load is lower [6], and trainees are more able to replicate the procedure. Finally, the possibility of interacting with pedagogical data is inspired by e-learning methodology: having everything available to enable understanding [7], as a blended learning tool.

The most two common ways to create VR content are computer-generated images (CGI) and 360° videos [8]. In a previous study, we described another method: 180° videos with first person point of view (FPPoV) [3]. The idea of this user interface is to provide a new way to learn a technical note. We detailed our step-by-step method and showed that our concept was interesting for healthcare professionals: they were willing to adopt it, saying they understood better and would learn faster. In a very first step, to understand the interest of this 180° FPPoV method, we wanted to assess knowledge acquisition of a technical note. Virtual Reality literature combined different VR approaches, different protocols with different ways to assess efficiency (knowledge test versus transfer test). Regarding knowledge acquisition, 360° video has demonstrated significantly higher engagement but not higher retention [9], and CGI has not shown superiority [10]. Here, we wanted to determine whether this type of VR experience (180° FPPoV) could improve memorization of a medical procedure in addition to a standard note. We selected a simple short surgical intervention. In the neurosurgical field, the positioning of a drain in the brain's ventricular system is usually quickly learned, but neurosurgical trainees must fulfill certain prerequisites before they are able to perform the procedure safely and optimally. The acquisition of these prerequisites by young medical students, before entering residency, is evaluated.

2. Material and methods

The procedure presented here was external ventricular drainage (EVD). We described the main surgical points in a technical note and designed a specific immersive tutorial.

We wrote a technical note with two senior surgeons of the neurosurgery department. This note described the way EVD is usually taught in different hospitals. The first part of the note concerned general indications and pathophysiology. Then, each step was precisely described: patient positioning, preparation, opening, approach, draining, drain fixation, and closing.

For the immersive tutorial, first, the 3D movie was recorded using the Revinax® method (device worn by the surgeon to record his or her point of view). The movie was edited and divided into 4 chapters: preparation, approach, puncture, fixation/closure. Then, on the left side of the screen, we added the preoperative CT-scan showing ventricular dilatation due to subarachnoid hemorrhage. On the right side, we added the 3D model obtained from the post-operative CT-scan showing the skull and trajectory of the drain through the ventricles (Fig. 1). We recorded a voice-over to explain the different steps. The comments corresponded to the practical description of the technical note.

A survey was developed by two senior surgeons in the neurosurgical department of the University Hospital of Montpellier, and checked by two other specialists: a specialist in medical simulation and another in education sciences at the University of Montpellier. This survey was composed of 10 questions (Appendix). The first question was whether the respondent had already been involved in this procedure in an operating room. The next questions were multiple-choice (5 per question). The questions concerned indications, patient management, and preparation until the incision. The second part of the survey focused on the technical aspect of the procedure.

The study was performed in the Medical Simulation Center of the Montpellier Medical School. This work was approved by the institutional review board of the Collège de Neurochirurgie (*Comité d'éthique de la recherche en neurochirurgie* – IRB 00011687). The students involved were in their 4th year of medical studies (2 years before residency). The entire group joined the study at the end of their lessons. The students were informed about the study, its design and aims, and gave their consent before starting. They were

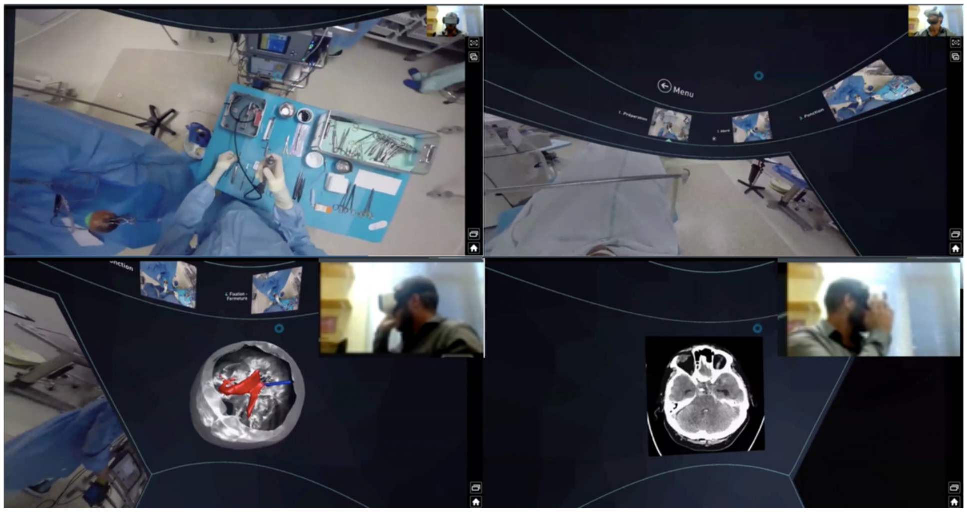

Fig. 1. User experience of the EVD immersive tutorial. User interface for the experience created for this study. Straight ahead: the main screen is playing a 3D video from a first-person point of view (upper picture). On the right side of the main screen: other pedagogical content (here, a 3D model) is displayed. Users can rotate the content (lower left picture). On the left side of the main screen: other content (here, a CT-scan) is displayed. User can switch different slides (lower right picture).

randomly divided into two groups. Group A had 7 minutes to read the printed technical note for the EVD procedure. Group B had the same amount of time to read the note; they then went through the immersive experience. The immersive experience was displayed on a Samsung® Gear VR (Samsung Electronics, Seoul, South Korea) and lasted 7 minutes.

Then, each group had to complete the survey. Students who had already seen this procedure in the operating room were excluded. The remaining students received 1 point if they answered correctly. If they made one mistake, they received 0.5 points; those students who made two mistakes received 0 points.

Six months later, the same form was sent to students by e-mail to analyze medium-term difference. Those who had been involved in an EVD between the first and second test were excluded.

Statistical analysis used a Wilcoxon rank-sum test with continuity correction (statistical department of Montpellier university hospital). A P-value < 0.05 was considered a significant difference.

3. Results

One hundred seventy-six students participated in the study (Fig. 2). Three were excluded because they had already participated in an actual EVD inside an operating room. Of the remaining 173 participants, 88 belonged to Group A (51% female, 49% male). The students in this group received a technical note. Group B (which trained using VR) consisted of 85 students (54% female, 46% male).

The detailed results are shown in Table 1, and final results in Fig. 3. Group B had significantly better results ($P = 0.01$) in answering the questionnaire, with a mean score of 5.17 [SD ± 1.29] and a median score of 5 (95% CI: 4.5–6), compared to Group A with a mean score of 4.59 [SD ± 1.4] and a median score of 5 (95% CI: 3.5–5.5).

Group B better answered questions more specifically related to operative technique (i.e., gestures), with significant differences for questions 6 ($P = 0.017$) and 10 ($P = 0.02$). A similar trend could be seen for question 7, although the difference was not significant ($P = 0.07$).

Six months later, 80 students replied to the survey. Eight were excluded because they had participated in an actual EVD in the operating room between the first and the second survey. Thirty-five belonged to group A and 37 to group B.

The results showed similar trends at six months, but without significant difference ($P = 0.19$). Mean score for Group A was 3.19 [SD ± 1.44] with a median of 3 (95% CI: 2–4); for group B the mean score was 3.57 [SD ± 1.35] with a median of 3.5 (95% CI: 3–4.5).

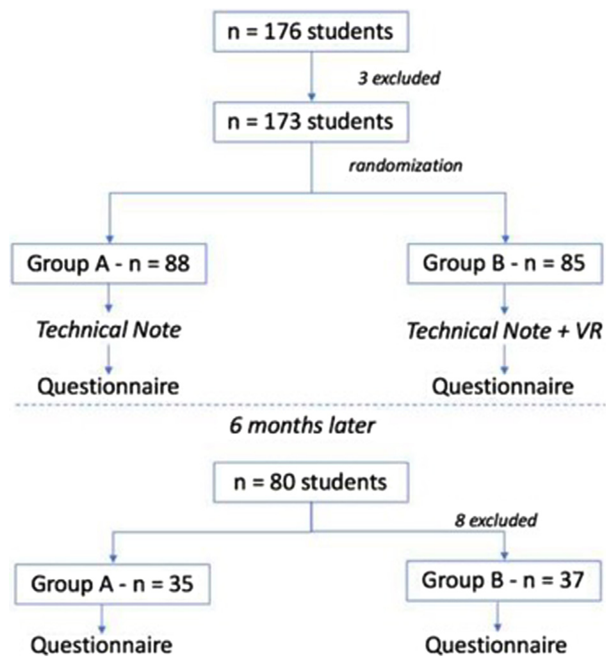

Fig. 2. Study flowchart.

4. Discussion

We showed that an immersive VR tutorial improved retention of knowledge. Short-term acquisition was better in the VR group. Another recent study [11], using VR for nursing skills, found no difference between the group using VR and the group receiving conventional training. The authors reported the same postinterventional improvements and lower retention scores at six months, and concluded that VR was at least as good as conventional training. We agree with their conclusion that best practices need to be defined: assessing the correct use of VR in training is crucial.

What remains challenging to establish clear guidelines for VR use concerns the wide variety of and different intentions for how

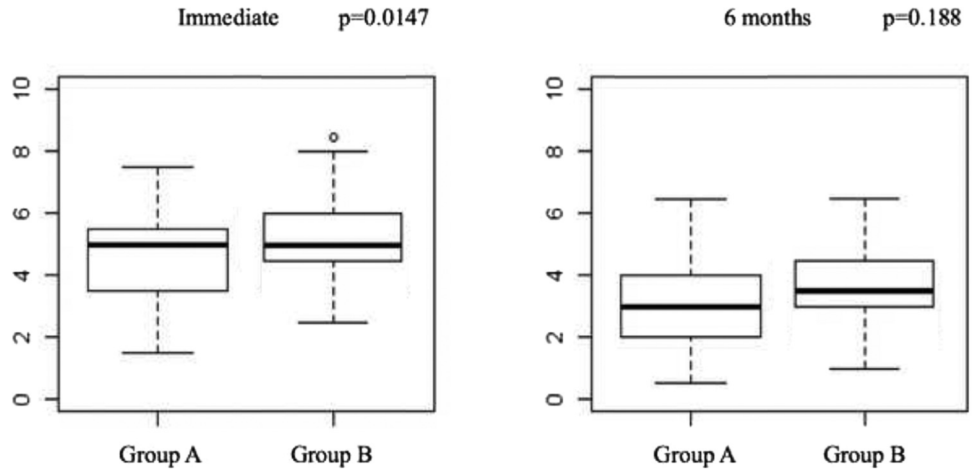

Fig. 3. Immediate and mid-term results (Wilcoxon rank-sum test): Group B had significantly better results immediately after; same trend at six months.

VR environments are implemented within a given curriculum. Which VR studies are consistent, reliable and comparable in best addressing the issue of standardizing key factors for using VR in best pedagogical practices for educating the next generation of learners? It may very well depend on the type of VR that is studied (e.g., CGI, 360° video, 180° video, etc.), since the pedagogical objectives (i.e., theoretical, procedural, practical knowledge, etc.), what they are compared against (e.g., books, videos, lectures, physical simulation, etc.) and what type of assessment is used may lead to confusing indications between declarative knowledge, skills and competency, which do not involve the same psychological resources. Here we decided to focus on one type of VR content, and understanding step-by-step what could be its indications.

We do not think VR can replace traditional education, but VR is probably valuable as a supplementary tool. If people can understand better and faster thanks to this tool, it could save time compared to regular training, enabling more people to be trained. Designing the best practice involves understanding when VR should be used: before, during or after a formal lesson. In a study on mastoidectomy, Andersen et al. [12] showed that using VR before a training course increased benefit and subsequently achieved better results.

How can VR improve retention? VR probably helps the user to understand better and may thus optimize the benefit of a lesson. Various studies focusing on the use of VR in different learning contexts, with different kinds of content (360° video [9]/CGI [13]/FPPoV Videos [3]) were unanimous that learners are more involved and say they understand better. These benefits may come from reducing “task-unrelated images or thoughts” [9] thanks to the immersive characteristic of these experiences. Indeed, blinding students to the actual environment increases their focus.

There are different ways of creating and thinking about an immersive experience: the instructional design of the VR experience is essential. We proposed tutorials, not direct interaction, except for additional data depicted in the environment. One of the main advantages of the immersive tutorial is that it enables the user to experience from a first-person point of view: to learn through “the expert's own eyes”. An interesting study by Fiorella et al. [14] compared learning a procedure from a first-person point of view versus learning from the opposite side. Compared to the FPPoV group, “learning from the opposite side” led to 50% more mistakes in reproducing the assembly of an electronic system. These results may be explained by the way mirror neurons [5] work with less “cognitive load” [6].

We not only used 3D videos but also added some relevant pedagogical data (CT-scan and the corresponding 3D model) in the rest of the virtual environment. In surgical education, learning begins with the study of anatomy. The possibility offered by VR of taking an “anatomic journey”, rotating and entering into a 3D organ to become familiar with the environment, is interesting. VR is not only a fun way to learn; it improves understanding, as it is possible to see an environment from various angles. Concerning neuroanatomy, Ekstrand et al. [15] found no difference in effectiveness between VR and books as learning tools; VR prevented “neurophobia” in 175 students, and the authors stated that the results were encouraging. In cardiac anatomy, Maresky et al. [13] found improvements in results after learning through VR; VR helped students to have a better understanding of the organ itself and its functioning. In the present study, the 3D model was a reconstruction of the skull with transparent parts showing the location of the ventricular system and the trajectory of the drain. In our immersive experience, the students could play with the model. They could move and rotate the model as many times as necessary to optimize understanding of the drain's trajectory.

Experiencing it in VR gives a better understanding of a situation or context. Another approach to teaching is empathy: this emotion can be used to understand the patient's experience. Dyer et al. [16], for example, focused on the possibility of feeling what older people feel: the empathy approach can help students better understand their patients or a situation. In our study, we did not separate questions about cognitive knowledge from the ones about psychomotor skills. The number of questions that students were asked may have been too small to achieve discrimination. In a subsequent study, we could also think about a new way to present indications by showing a patient (or an actor) in context, instead of putting them in a paper note.

So far, only some students have tried VR, and this can lead to two biases. The first one is the motivation to participate in the study: students were disappointed when they were randomly assigned to the non-VR group. Noticing this in our preliminary study, we decreased this bias by offering a VR experience to students from the non-VR group once they finished their exercise. Conversely, some students belonging to the VR group discovered VR for the first time in beginning the study; they were at first distracted and looking all around before starting the learning experience, after which they were much more focused than the non-VR group. However, here again, we could have another bias: what happens behind the mask? Is the student actively watching? Suppose they had their eyes closed during the whole experience? The quality of VR continues to improve, but some people still feel dizziness. Sometimes, this is not actual motion sickness but just an uneasiness that occurs when using VR for the first time. During our study, no one asked

Table 1
Detailed immediate and mid-term results.

	Cluster without VR (A)	Cluster with VR (B)	*P*-value
Q2			0.347
0	12 (7%)	14 (8%)	
0.5	33 (19%)	25 (14%)	
1	40 (23%)	49 (28%)	
Q3			0.791
0	18 (10%)	21 (12%)	
0.5	44 (25%)	41 (24%)	
1	23 (13%)	26 (15%)	
Q4			0.455
0	2 (1%)	5 (3%)	
0.5	2 (1%)	1 (1%)	
1	81 (47%)	82 (47%)	
Q5			0.356
0	16 (9%)	19 (11%)	
0.5	29 (17%)	37 (21%)	
1	40 (23%)	32 (18%)	
Q6			0.017
0	25 (14%)	44 (25%)	
0.5	26 (15%)	16 (9%)	
1	34 (20%)	28 (16%)	
Q7			0.07
0	30 (17%)	33 (19%)	
0.5	21 (12%)	33 (19%)	
1	34 (20%)	22 (13%)	
Q8			0.343
0	49 (28%)	53 (31%)	
0.5	21 (12%)	26 (15%)	
1	15 (9%)	9 (5%)	
Q9			0.474
0	21 (12%)	22 (13%)	
0.5	30 (17%)	38 (22%)	
1	34 (20%)	28 (16%)	
Q10			0.002
0	34 (20%)	55 (32%)	
0.5	31 (18%)	27 (16%)	
1	20 (12%)	6 (3%)	
Total – immediate	**4.59 ± 1.4** **5 [3.5; 5.5]**	**5.17 ± 1.29** **5 [4.5; 6]**	**0.0146**
Q2.6			0.347
0	11 (15%)	9 (12%)	
0.5	11 (15%)	16 (22%)	
1	15 (21%)	10 (14%)	
Q3.6			0.505
0	7 (10%)	8 (11%)	
0.5	22 (31%)	23 (32%)	
1	8 (11%)	4 (6%)	
Q4.6			0.125
0	15 (21%)	22 (31%)	
0.5	1 (1%)	0 (0%)	
1	21 (29%)	13 (18%)	
Q5.6			0.292
0	19 (26%)	20 (28%)	
0.5	13 (18%)	7 (10%)	
1	5 (7%)	8 (11%)	
Q6.6			0.389
0	17 (24%)	19 (26%)	
0.5	15 (21%)	9 (12%)	
1	5 (7%)	7 (10%)	
Q7.6			0.357
0	23 (32%)	16 (22%)	
0.5	11 (15%)	14 (19%)	
1	3 (4%)	5 (7%)	
Q8.6			0.367
0	19 (26%)	23 (32%)	
0.5	13 (18%)	10 (14%)	
1	5 (7%)	2 (3%)	
Q9.6			0.105
0	17 (24%)	19 (26%)	
0.5	7 (10%)	11 (15%)	
1	13 (18%)	5 (7%)	
Q10.6			0.256
0	19 (26%)	12 (17%)	
0.5	15 (21%)	21 (29%)	
1	3 (4%)	2 (3%)	
Total – 6 months	**3.19 ± 1.44** **3 [2; 4]**	**3.57 ± 1.35** **3.5 [3; 4.5]**	**0.1858**

Immediate and mid-term detailed results: questions (Q) were multiple-choices (5 choices per question). Students received 1 point if they answered correctly. If they made one mistake, they received 0.5 points; students who made two mistakes received 0 points.

to remove the headset. Maybe some did not want to say anything in front of the group, and therefore kept their eyes closed. Eye-tracking devices could help to avoid this bias.

The present study required at least 100 people to obtain significant results. The trend in favor of better results was still present at six months but was no longer significant. Even though the response rate was more than one-third at six months, we did not succeed in reaching cutoff. In the next study, we should also try to have another session three months after the first one, to repeat VR exposure and see if it reinforces learning and if we can maintain retention, as certain authors mentioned a dose-response relationship with number of exposures [12]. Thus, it would be interesting to compare iterative VR exposure with the present findings, to see if the difference is maintained or not.

The present study is very much just a first step toward understanding the potential of VR, and especially the immersive tutorial. Here we wanted to assess memorization. Group B did best in questions which were more specifically related to operative technique (questions 6, 7 and 10). In our approach, VR appeared to be more relevant to practical knowledge than theory. We chose as a first step a specialized surgical procedure, to be sure the students tested did not already know this process. As we were studying the learning effects of this new tool, we could not take the risk of negative learning affecting students' memorization of a crucial method they would have to know. We decided to implement VR first in addition to a technical note, as a complementary tool. To complete our understanding, future studies will have to compare VR with lectures, video and physical simulators. The next crucial step will be to assess knowledge transfer, with an assessment based on a Script Concordance Test and with a procedural hands-on evaluation method. In this way, other items apart from memorization could be included (psychometric considerations, procedure duration, etc.). The present study does not claim to show that VR trainees perform the procedure better, but they are able to remember the steps better. Thus, VR could be used as a tool for better understanding, or to refresh before performing a procedure. Description of the learning journey is part of designing best practices.

Another promising application of VR is preoperative surgical planning. VR has been shown to improve the accuracy of surgical gestures [17] for a spine procedure. We can imagine in the future operating first in VR, acquiring the perfect gesture. Before being able to achieve this, we can at least learn better and review a technique more efficiently.

Limitations for using VR usually concern content creation cost, development time, the cost of dedicated hardware (i.e., headsets and computers), and the time needed to train people on how to set and use the headset. There are several attempts to facilitate content creation and reduce cost (a CGI surgical simulator may cost more than $ 100,000) [18]. Choosing video-based content accelerates creation. Deployment through a mobile/autonomous head-mounted display makes facilitates implementation.

One of the values of VR immersive tutorials is that they aim to be affordable, easy to share, and efficient; these benefits can address the problems reported by WHO concerning surgical training in any part of the world [19]. Not everyone can afford to have access to a laboratory or a simulation training center.

We showed that our immersive VR tutorial can improve memorization (a theoretical assessment). Further studies will explore subsequent performance of gestures (practical assessment).

5. Conclusion

We attempted to combine VR (to make subjects more involved by providing an immersive experience), a first-person point of view (to change the usual way of learning a procedure), and interactive data. Our results showed a significant improvement after the students had this experience. We can already affirm that VR immersive tutorials would be a good way to refresh one's surgical skills just before performing a procedure.

Human and animal rights

The authors declare that the work described has been carried out in accordance with the Declaration of Helsinki of the World Medical Association revised in 2013 for experiments involving humans as well as in accordance with the EU Directive 2010/63/EU for animal experiments.

Informed consent and patient details

The authors declare that this report does not contain any personal information that could lead to the identification of the patient(s) and/or volunteers.

Disclosure of interest

Dr Maxime ROS is a neurosurgeon. He was practicing at the Montpellier University Hospital before founding Revinax®, the company that developed and created the methodology for the immersive first person POV tutorials as described herein. The other authors declare that they have no competing interest.

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Author contributions

All authors attest that they meet the current International Committee of Medical Journal Editors (ICMJE) criteria for Authorship.

Appendix A. Appendix

QUESTIONNAIRE:
1/Have you ever attended an external ventricular drainage procedure? Yes - No
2/The EVD procedure is:
A/a neurosurgical procedure,
B/performed under the same conditions as lumbar puncture,
C/used to treat an acute increase in ventricular volume,
D/an iterative treatment for hydrocephalus,
E/the indication is based on a clinical triad and brain scan should not delay implementation.
3/The EVD procedure is performed:
A/at the patient's bedside because of its urgent nature,
B/under maximum sterile conditions,
C/in the operating room under local anesthesia,
D/systematically due to acute hydrocephalus secondary to a CSF production disorder,
E/in the operating room after the development of a small skull flap.
4/During EVD, the patient is positioned:
A/prone, head in the axis,
B/supine, head in left rotation,
C/supine, head in the axis,
D/in left lateral decubitus,
E/supine, head hyperextended.
5/Important markers that allow one to perform an EVD safely:
A/the mid-pupillary axis and the median line are indispensable markers,
B/the implantation of the catheter is on an orthogonal trajectory to the skull,
C/the approach is usually on the right,
D/the coronal suture is not one of the markers,
E/the mastoid is a useful marker for ventricular puncture.
6/Opening the skull:
A/is not essential for a simple EVD,
B/is performed with a trocar and hammer,
C/requires the use of a drill,
D/is concomitant with the opening of the dura mater,
E/is performed by directing a tool in an oblique axis towards the pupillary mark.
7/Concerning the introduction of the catheter into the brain:
A/this is done according to a precise axis with cranial markers,
B/the catheter is always orthogonal to the bone,
C/the procedure takes as reference the pupillary axis and the mastoid,
D/the procedure involves moving toward the contralateral medial canthus,
E/there is no sensation until 7 cm of the catheter has been introduced.
8/Regarding collection of cerebrospinal fluid (CSF):
A/the CSF is obtained after at least 7 cm of the catheter has been introduced,
B/the collection of CSF is not systematic immediately after puncture,
C/when CSF is flowing, the guide has to be removed,
D/in case of failure, the puncture is made on the contralateral ventricle,
E/it may be necessary to lower the end of the catheter to obtain a flow.
9/In the absence of immediate collection of CSF:
A/this is a frequent situation, and should not change the process,
B/it is necessary to continue the introduction of the catheter until it is 10 cm from the skull,
C/it is necessary to leave the catheter in position and modify the trajectory,
D/after three failures, it may be necessary to control positioning on CT,
E/it is necessary to introduce a second catheter to puncture the contralateral ventricle.
10/After obtaining the CSF, you must:
A/remove the guide immediately, taking care not to mobilize the catheter,
B/immediately close the incision on the catheter to fix it,
C/take a sample for systematic analysis,
D/introduce 1 cm of the catheter after removing the guide so that the catheter is in the middle of the ventricle,
E/tunnel the catheter away from the incision and then fix it to the skin so that it does not move.

Appendix B. Supplementary data

Supplementary data associated with this article can be found, in the online version at: https://doi.org/10.1016/j.neuchi.2020.05.006.

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