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Immersive virtual reality for cognitive mapping in awake brain surgery: a scoping review

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***Abstract*—*During Awake Brain Surgery (ABS), cognitive functions are monitored with neuropsychological tests, which have to be done during electrical stimulation. Language is the most tested domain. Limitations in assessing other higher cognitive functions are due to the difficulties in adapting neuropsychological tasks to awake surgery conditions. Virtual Reality (VR) can combine the realism of stimulus with the experimental control required during cognitive mapping, offering new possibilities of new procedures for complex cognitive functions. This scoping review aims to examine the state of the literature regarding the use of VR for cognitive mapping in ABS.*

***Keywords*—*awake brain surgery, virtual reality, cognitive mapping.*

I. Introduction

During ABS, cognitive functions are monitored by cognitive tests. Its administration is done while a brain area receives direct electrical stimulation to block its function. As such, the presentation time of stimuli must be short, and the answer should be given in 5 seconds [1]. This procedure is expected to result in a more extensive resection and fewer neurological deficits. However, the majority of ABS, although demonstrated to be well tolerated by patients [2], has been performed almost exclusively in lesions involving language areas [3], [4]. Mapping non-language functions has received much less attention, mainly due to difficulties adapting cognitive tasks to ABS [5]. Only recently, ABS started being done in patients in areas different than language. Brandling-Bennett and colleagues (2012) performed awake-intraoperative memory testing using electrical stimulation to identify the fornix' white matter tracts involved in memory function [6]. Coello and colleagues (2013) presented an overview of different tasks that can be used intraoperatively, enhancing the importance of adapting them to the patient and assuring its postoperative functionality [7]. In 2013, Duffau & Mandonnet (2013) studied the importance of the "onco-functional balance", the compromise between achieving maximum tumor resection and preserving maximum functionality [8].

VR applications in healthcare have increased over the past years. Its utility has expanded from a training tool to a highly reliable neuro-technology assistant in multiple fields, including neurosurgery. VR seems to be an ideal candidate to implement novel cognitive mapping paradigms since it is a cost-effective and comprehensive tool that easily integrates other technologies such as eye-tracking [9]. This scoping review aims to summarize the state of the literature regarding the use of VR for cognitive mapping in ABS and will focus on (1) which cognitive mapping tasks and domains are being implemented in VR (2) which technologies are used for presentation and interaction in these VR tasks, (3) how are these VR cognitive mapping tasks being clinically validated.

II. Methods

A systematic search of the existing literature was performed using four digital databases: PubMed, Web of Science, ACM and IEEE. The search focused on ABS for tumor resection studies that use VR for improving the cognitive mapping phase, published in English in peer-reviewed journals and conferences. The search was performed using the following keywords targeting titles and abstracts: 'virtual reality' AND 'awake brain surgery'. Articles were excluded if they were systematic reviews or meta-analyses.

III. Results

We have identified 96 papers through database searching, 93 after duplicates removal. In the first screening based on titles and abstracts, 88 were removed, as they did not involve the application of VR to ABS (most studies were about VR training in neurosurgical care). In total, five full-text articles were assessed for eligibility, being that we have excluded one for being a review (Table 1).

TABLE I. Cognitive mapping through VR in ABS

Author	VR task	Domain	VR device
Mazerand (2017)	Esterman test based luminous stimuli	Optical radiations	Oculus DK1 and DK2
Bernard (2018)	vTime app: VR social network	Social cognition	Samsung Gear VR with a Samsung S7 smartphone
Delion (2019)	Naming task (DO 80)	Language	Samsung Gear VR with a Samsung S7 smartphone
Casanova (2021)	VR environment with animated avatars	Nonverbal language, empathy, and theory of mind	HTC VIVE with Tobii Pro VR Integration

The first work is from Mazerand and colleagues (2017), who developed the Functions' Explorer based on a VR headset (FEX-VRH) to overcome the difficulties of testing the visual field intraoperatively. In this proof of concept study, with a right-eye blind patient presenting a left parieto-temporal

glioblastoma, while the neurosurgeon performed direct electrostimulation, the operator provided luminous stimuli on the screen of the headset (an Oculus). On a computer screen, the operator selected the points among those proposed by the modified Esterman test. Each stimulus was presented in the patient's screen for a few milliseconds, and he needed to inform the operator whether or not he could see the luminous stimulus. The FEX-VHR was found to be a promising approach to map the optical radiation and prevent permanent visual field defects [10].

Bernard and colleagues (2018) used a VR social network (VTime app) to map social cognition to explore patients' interactions with the neuropsychologist's avatar in virtual locations. The vTime app allows interaction with several avatars and positional control in different virtual environments. The avatar can point anywhere within the scene and produce gestural expressions such as OK, Thumbs Up, Clap, Thumbs Down, Blow Kiss, etc. The authors performed a single-center, prospective, unblinded trial with three patients. Different VR experiences with a VR headset (Samsung Gear VR headset combined with a Samsung S7 smartphone with headphones) were proposed during wound closure. Despite some limitations, the neuropsychologist, as an avatar, could communicate with the participants and explore gesture communication while wearing a VR headset [11].

Delion and colleagues (2019) evaluated a VR headset's tolerance and safety in 30 patients with a brain tumor near the language area. This study was performed using a Samsung Gear VR headset combined with a Samsung S7 smartphone and headphones. The authors performed language mapping was performed with a naming task (DO 80), presented on a digital tablet, then in 2D and 3D through a VR headset. During the wound closure, different VR experiences (such as Ocean Rift and Zen Parade) were proposed to the patient, offering different types of interaction with an avatar piloted by a neuropsychologist. From the 30 patients, no one reported cybersickness, and only two could not use the VR headset due to technical issues. Also, 20 patients agreed to look at the VR experiences while the wound was being closed; for 12 of them, no further analgesia was needed [12].

Finally, Casanova and colleagues (2021) evaluated the feasibility and safety of a VR headset with incorporated eye-tracking (a Tobii Pro VR Integration, an eye-tracking retrofitted HTC VIVE) to present a visuospatial and social VR experience to 15 patients with brain tumors near language and/or motor areas. The VR task was developed with animated avatars to explore nonverbal language, empathy, and theory of mind. None of the patients experienced VR sickness, and the eye-tracking was functional, enabling the clinicians to analyze the patients' attention and exploration of the visual field [13].

IV. Discussion and conclusions

These results demonstrate that it is possible to immerse the patients in VR and interact with them, opening the field of new brain mapping procedures for complex cognitive functions, namely: calculation, praxis, gnosias, attention, executive functions and social cognition, among others. Consequently, it will promote knowledge advances on the anatomo-functional connectivity, conveying the possibility of understanding functional and eloquent areas to be preserved. This might also help detect and understand functional shifts and potentiate them for rehabilitative purposes. However, several issues need to be solved, namely the hardware installation in an operating room. In the reviewed studies, the headset was maintained in front of the patient's eyes by the assessor, which may cause trepidation and affect the field of view. Also, in order to be more comprehensive, future VR cognitive mapping systems should include cognitive prescreening, intraoperative cognition mapping, and postsurgical cognitive assessment and rehabilitation.

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