Patient Feedback during an Awake Craniotomy Using Virtual Reality

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***Abstract*—The goal of this work in progress project is to provide an improvement to the currently used procedure of physician-patient interaction during the awake craniotomy using Virtual Reality (VR) technology. The proposed procedure will evaluate the patient's response to the visual and auditory stimuli, provided via a VR device. We will highlight the functionality of the setup, its advantages and shortcomings, and discuss possible risks of the used technology. Our approach provides a complete virtual environment, including situations and combinations of stimuli that can test complex reactions of the patient, and, on the other hand, is completely under control of the neuropsychologist. We conclude by showing that the benefits of the approach significantly outweigh the downsides, so that the presented technology is not only a new opportunity, but also the future.**

Keywords-Virtual Reality; Awake Craniotomy; Patient Feedback.

I. INTRODUCTION

For some patients, awake surgery is the best way to avoid the risk of surgical neurological deficits [1]. “The main advantage of awake craniotomy is to allow for intraoperative electrocorticography and cortical mapping to identify eloquent brain areas” [2]. This advantage also outweighs the psychological disadvantages that can arise from this method. For this reason, awake surgery is used more and more frequently [1]. Current brain mapping, for example, uses images that the patient has to recognize and name or texts that the patient has to read aloud [3].

We propose an improvement to the currently used procedure of physician-patient interaction during the awake craniotomy using Virtual Reality (VR) technology.

The state-of-the-art procedure currently involves testing of the visual and auditory senses during the stimulation of the corresponding brain area with a surgical instrument. The aim is to ensure that no sensory degradation will take place during the operation. The testing duration has to be as short as possible to reduce the risk of epileptic seizures.

The visual stimulation usually involves placing pictures in front of the patient, optionally on a laptop or tablet screen, accompanied by a request to describe the situation. The current procedure tends to be cumbersome, error-prone, and has the additional limitation that the physician is not able to see the test at the same time as the patient, thus not being able to verify the correctness of the answer. Figure 1 shows the surgical area during an awake craniotomy with the numbered areas for stimulation.

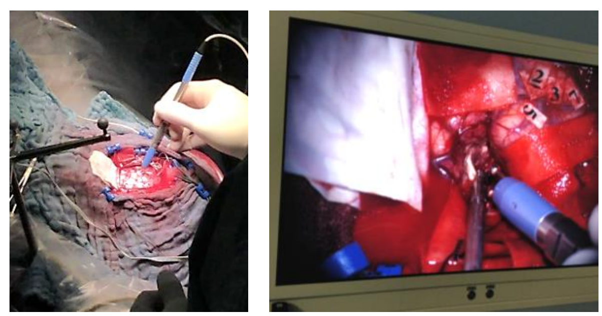

Figure 1. Surgical area during an awake craniotomy.

In the proposed setup, we use the VR technology as in [4], but generate much more expressive and complex stimuli in order to evaluate the possible degradation of brain functionality.

In Section 2, we show the features of the developed application. Section 3 deals with the hardware and software requirements. In Section 4, details of the implementation are briefly presented. Section 5 contains the conclusion, currently still occurring problems, and possible further developments.

II. APPLICATION FEATURES

The major goal of the setup is to support the physician during the brain surgery and to give him the possibility to test affected brain regions. For this task, a preferably full spectrum of sensory stimulations and corresponding responses is desirable. The sight is the most important sense for human beings, so the majority of the tests address the visual stimulation with the last two including hearing as well.

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In the first prototype, the following features have been selected for the implementation:

- Image recognition
- Interaction with a complex situation/environment
- Memory function
- Reflex and reaction
- Hand-eye coordination
- Auditory perception
- Combination of visual and auditory perception.

The usage of the novel technology will also force the personnel to change their routine, albeit not in a very significant way. The patient has to familiarize himself with the app and the displayed virtual world, and he has to perform the tests in advance in order to have a baseline or reference point of his performance. The patient should display no anxiety controlling the app. It should also be taken into account that the patient's awareness of being operated on his brain may induce high stress levels during the operation.

This preoperative procedure is also necessary to test patient's sensitivity to the so-called Virtual Reality sickness. In this case, the approach is not applicable.

A. *Image Recognition*

Figure 2. Image recognition of 2D and 3D images.

The basic configuration of the app already provides about 80 different two- and three-dimensional images, an amount that can easily be extended to include for example patient-specific images. 3D-objects even allow a complete 360-degree view, which is impossible with the currently used 2D-representations. Figure 2 shows a small selection of sample images from the application that the patient should recognize.

B. *Interaction with a Complex Situation/Environment*

Figure 3. Forest 3D-scenery.

In our application, we implemented a forest (as shown in Figure 3), a desert, and a town scenery, all three with their typical vegetation, earth conditions and animals. Additionally, we provide two uncommon and more challenging environments - a space station, and a room made of colored cubes. The different environments can be selected according to the patient's preferences and can help to reduce stress during the operation [4]. The patient is able to move freely and interact with the environment, which extends the range of possible questions significantly from the basic recognition to the deeper understanding of the given situation.

C. *Memory Function*

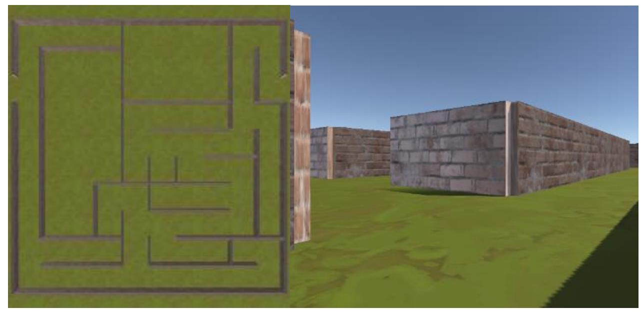

Figure 4. Memory game with bird's eye view (left) and first person's field of view (right) [5].

The memory and especially the short-term memory, is of utmost importance to human beings, thus it should be tested during the awake craniotomy.

We implemented the well-known memory game "pairs" and a labyrinth escape situation. In the latter, the patient is asked to memorize the path from entrance to the exit for a few minutes from the bird's eye perspective as shown in the left part of Figure 4. After that the app switches to the person's field of view as shown in the right part, requesting him to navigate to the exit of the maze. This test also aims to estimate the spatial ability and the sense of orientation, i.e. if the patient uses the same dead-end repeatedly.

D. *Reflex and reaction*

Figure 5. Arachnophobia scenery.

In the previous test procedure, there is neither a standardized test nor a measurement of patient's reaction time, which can be an important indicator of his condition. In

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our app, we addressed the problem by implementing two tests to estimate the patient's reflexes and reactions:

- The supervising physician lets a spider appear in the field of view of the patient whilst he walks in a forest. This is shown in Figure 5. If there is any reaction, the patient did not lose his reflex.
- In a second test, the patient is on a grass pitch and a ball appears from a random direction with varying speed. The patient is asked to stop the ball in the middle of his field of view by pressing a button.

E. Hand-Eye Coordination

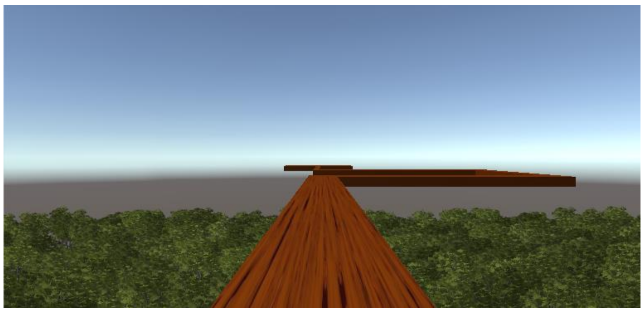

Figure 6. Test for hand-eye coordination and acrophobia [5].

This specific part of the app tests the accuracy of the coordination ability and of the user interaction and its possible degradation during the operation. The patient has to walk virtually on a narrowing wooden beam placed in midair as shown in Figure 6.

F. Auditory Perception

The app provides a typical hearing test. A sound is coming from the left, right or both sides and the patient has to choose the corresponding button with the controller. Correctness of the answer is visualized by the change in the button coloring or communicated by the physician.

G. Combination of Visual and Auditory Perception

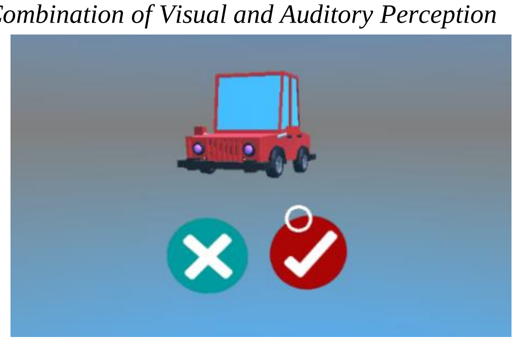

Figure 7. Combined tests [5].

One final test combines seeing and hearing. The patient has to decide if the presented 3D-object matches the sound by selecting a corresponding screen area and the correctness of the choice will be indicated by the change in the button's color. An example can be seen in Figure 7. A short sound file is played at the same time. For example, if the patient hears a car horn, he has to select the red tick on the right; if it is a bird's song, he must select the turquoise cross on the left. If the patient makes mistakes during the stimulation or gives no answer at all, this is an important sign for the operating team as they continue to perform the awake craniotomy.

III. Realization

In this section, we will show the technical realization including the necessary hardware and the software requirements.

A. Technical Setup

Figure 8. Used VR glasses (left) and controller (right) [5].

The project setup contains an Android-based smartphone as a central processing and visualizing gear, the VR app, a pair of Destek V4 VR glasses, and a gaming controller, used as a steering device for the app. This equipment, excluding the smartphone, can be seen in Figure 8. An additional control screen for the surgical team is also needed for the verification of test results. A pair of headphones or small speakers is necessary for the auditory tests.

We chose a smartphone VR holder instead of full-fledged VR glasses due to the cost factor and higher flexibility. The Android Operating System, being the most common mobile OS, was selected for the development of the VR app.

An additional focus needs to be put on the controller. Since the head tracking, as the regular way of navigation in the VR environment, is not possible due to the head fixation, the steering has to be done with an external device. A game controller emerged as the best-suited device so far. To meet the requirements on the wireless signal interference in the medical setting (s. below) it can be connected by wire instead of Bluetooth.

B. Implementation Requirements

In order to develop a user-friendly VR app, the scope of all possible users has to be determined - it includes different physicians - surgeons, anesthesiologists, neuropsychologists, nurses, and, on the other hand, the patients. An intuitive and easy to use user interface has to be developed for both of these user groups with a special focus on the latter, to avoid contributing to the heavy stress during the operation. In addition, of course, the approach has to improve the current patient-physician interaction to justify its development.

The following functional requirements were considered:

- The use of the app should not require any special knowledge or experience.
- The patient should not endure any additional risks compared to an awake craniotomy without the app.
- The app should never cause any hassle or stress for the patient.

- The app should be reliable and robust with respect to system crash.
- Software has to be extensible and modifiable to fit different use cases.
- The app should be able to deal with wrong interactions.
- All the information presented to the patient should be synchronized to the control screen.
- Additional constraints arose due to the medical environment (and were met):
- The number of signal transmissions should be reduced to a minimum.
- The app must not interfere with any other device in the operating theater.
- The app should be implemented with special regards to IT security due to the highly health-critical environment.
- The data protection act has to be respected.
- The code quality should meet industrial standards typical for medical software.
- The entire setup and its components have to be accordingly certified ("work in progress").

One final note should address the general usability - the VR glasses and, optionally, headphones are head-mounted, so that they may interfere with surgeons' access to some regions or the sterility requirements. It should be obvious that in these cases, the setup is unusable and other methods should be employed.

IV. Implementation Details

The app and the 3D-scenery were implemented using Microsoft Visual Studio with Unity. Unity is a set of tools primarily used for the game development, allowing creating feature-rich environments with natural physical conditions, which are necessary to make the user feel comfortable using the app. The main user interface was also designed with Unity. To create the stereoscopic images, we used the Google VR SDK for Android.

V. Conclusion and Future Work

During a demonstration and following discussion with three participating surgeons they agreed that our approach shows promising potential, however further development of the technical setup is necessary to meet the specific requirements of awake craniotomy and other types of awake surgeries.

One conclusion was that the highest benefit could be seen in the availability of more specific and flexible tests than with state-or-the-art procedures. Especially, further brain functions, for example short-term memory, situational perception and combination of senses, can be tested. Additionally, the ability to adapt the VR environment to patient's personal or professional interests and preferences is a great improvement. In addition, it could potentially reduce the stress and anxiety during the surgery at the same time as in [4], so patients might prefer our approach, but this needs further evidence in future work.

Another insight resulting from the discussion was that our approach is one step ahead of the current state of the brain mapping, since it adds the possibility to test currently unmapped functionalities, for example, it is still not fully understood which brain regions affect spatial ability. Additional research is necessary in this area to tap the full potential of this approach.

The consensus was that this is not only a new opportunity but also the future.

In our future work, we will:

- Address the setup's shortcoming, that in contrast to the regular interpersonal communication, the usage of VR prevents the eye contact between the neuropsychologist and the patient.
- Extending the supervisor interface with additional information and better test control.
- Test the setup under clinical conditions.

Compliance with Ethical Standards

Conflict of Interest: The authors declare that they have no conflict of interest.

This article does not contain any studies with human participants or animals performed by any of the authors.

This article does not contain patient data.

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