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Development of a Digital Tool to Assist the Training of Health Professionals in the Determination of Brain Death

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Abstract

Due to technological advancement of medicine, patients have been maintained through mechanical ventilation and vasoactive drugs despite complete and irreversible brain injuries. Accurate diagnosis of brain death (BD) reduces costs, shortens family's suffering, and increases availability of intensive care beds and organs for transplantation. Guidelines were created to standardize BD diagnostic parameters, but knowledge of medical students and medical professionals has been demonstrated to be insufficient. To assist health professionals' in BD determination, a digital training tool that contained images, videos and interactive content was developed for desktops and mobile devices. Software to create and animate 3D models (MakeHuman™ and Blender™) and a game development platform (Unity) were used. Versions for all the major operating systems (iOS™, Android™, macOS™, Windows™ and Linux™) are being made available through online repositories and mobile application stores.

Keywords:
brain death; education, medical; mobile applications.

Introduction

Technological advances in the field of intensive care medicine, with artificial ventilatory support and use of vasoactive drugs, has contributed to the maintenance of hemodynamic and respiratory activity in patients with severe and irreversible central nervous system injury. Recognizing and diagnosing this situation is critical, since such therapeutic efforts can result in increased hospital costs, contributing to the shortage of intensive therapy beds, as well as prolonging the suffering of patients' families [1].

Additionally, patients with irreversible brain damage are recognized as potential organ and tissue donors. With the advent of transplantation in the 1960s, it is necessary to redefine the concept of death, avoiding controversies in obtaining organs [1].

Mollaret and Goulon, in their 1959 classic publication, were the first to define irreversible coma ("Le coma dépassé") [2]. In 1968, a committee created at Harvard Medical School established criteria for determining irreversible coma, with the definition of brain death (BD) [1]. The American Guidelines for Determination of Death, published in 1981, were based on Harvard Criteria [3]. The American Academy of Neurology published a review of the guidelines in 1995, and the more detailed descriptions of the steps of the examination specified parameters for the apnea test positivity, and six hour intervals between evaluations [4]. These latter guidelines are still valid.

Although there is some divergence, the American criteria are often referenced as guidelines in other countries. In 2002, Wijdicks reviewed the process for BD determination in 80 countries: 69% reported presence of legal standards on organ transplantation and 88% had practice guidelines for BD [5]. Some aspects varied among countries, such as the number of physicians needed to declare BD (more than 1 in 50%), apnea test (not performed in 24%), need for complementary diagnostic tests, observation time between examinations and the mandatory qualifications of the physicians. A 2015 publication found that among 91 countries, 70% had specific legislation, with institutional protocols established at 77%. Deviations in the guidelines from the American Academy of Neurology were observed in 53% of the countries [6].

In Brazil, Federal Council of Medicine published three resolutions with criteria to BD determination that were based on the American guidelines, most recently in December 2017. According to Brazilian law, the two clinical exams that are required, must be conducted with a minimum one hour interval hour, by different physicians, and consist of a confirmatory test proving absence of electrical or metabolic brain activity, or cerebral circulatory collapse. Physicians who perform the tests must have at least one year of experience in the care of patients in coma and follow or perform at least ten determinations of BD or participated in a training course [7].

Studies that evaluated the knowledge of physicians and medical students about BD diagnosis further demonstrate the need for training. Among the undergraduate students in Brazil, there is a lack of knowledge about BC, and few feel apt to perform the examination [8-11]. Other countries, such as South Africa [12] and the United States report similar challenges [13]. The knowledge of medical professionals also has been demonstrated to be insufficient, even those working within intensive or emergency units [14-17]. This low performance may be related to the limited number of opportunities to perform the exam during training, observed even among residents in neurology or neurosurgery [18].

This lack of practical experience can be reduced with the use of realistic simulation mannequins. The use of this didactic resource has been demonstrated to be effective in BD determination training, and has been positively rated by students [19]. The BD scenario is one of the most accessible in neurology for this modality of teaching, since BD requires testing of absent reflexes. The simulation of situations in which the findings would not be compatible requires the use of more advanced simulators that incorporate capacity for movement and pupillary reaction. The main barriers to the more frequent use of realistic simulation are cost, lack of structure (employees, physical space, supplies and technical support), longer time required for application, and lack of experience with the method. Cost remains the main barrier, as only the high-fidelity, and more expensive, mannequins can simulate respiratory movements during the apnea test [20].

The use of computers to create virtual environments and virtual patients has emerged as a powerful educational alternative for health professionals. Training that is not dependent on face-to-face methodologies can reach a larger number of students, that may be in remote locations, without increasing costs [21].Additionally, there is increased opportunity for students to manage their own learning [22] with the growing availability of mobile devices, such as smartphones and tablets. Most students and physicians have a smartphone, and most of them use specific medical applications [23, 24]. Mobile devices can be used to quickly access scientific literature, self-assessment applications, calculators, and multimedia educational content, proving to be valuable tools in health education [25, 26].

Recognizing the educational gap in medical education about the diagnosis of BD, the use of a digital teaching tool that can be delivered through mobile devices, would be a valuable contribution to the training of health professionals. Thus, in this paper we review how we developed an application for computers and mobile devices that can assist the training of students and health professionals in BD determination.

Methods

Creating a Virtual Scenario

We used Blender ™ [27], a free and open source software, to create a virtual simulation experience consisting of three-dimensional (3D) models. Complex 3D figures can be created from basic geometric shapes (planes, cubes, spheres, cylinders, etc.), modified by the addition, subtraction or repositioning of vertices, edges and faces, and by combination with other shapes. Materials or textures can be assigned to the surfaces of the models providing color and brightness to the objects.

Using visual references as images searched on the Internet, 3D representations of object found in an intensive care unit were created. Examples included vital signs monitor, mechanical ventilator, hospital bed, infusion pumps, flow meters, cannula, as well as other equipment used in this hospital environment.

We found creating 3D human models to be a much more challenging task. We used MakeHuman™, also free and open source software, [28] to generate customized characters, Parameters that could be selected included gender, height, age, weight, skin and hair color. A male model was chosen as a patient and a female as a medical examiner. The created templates were exported to Blender™.

To demonstrate the clinical examination of BD a scene was created of an intensive care unit (see Figure 1). The male patient was placed on a hospital bed and wore a disposable diaper. The female medical examiner wore blue clothing and disposable gloves and was positioned on the left side of the bed. Medical equipment that was being used to monitor the patient included electrodes, oximeter, probe to measure esophageal temperature and was connected to a monitor, triple-lumen subclavian catheter, bladder catheter with urinary drainage bag and orotracheal tube connected to a mechanical ventilator. The final elements created for the scenario included walls and a floor, infusion pumps with intravenous administration sets and solutions bags, medical gas system (valves, flow meters, hoses and reservoirs), side table with material used in the examination (syringes, bowls, catheters, "cold" solution bottle, otoscope, flashlight and cotton swabs), negatoscope with tomography film, bed control, cover sheet and blanket, and clipboard inside a rack fixed to the bed. The final version of the file with both models and all of the objects totaled approximately 1.6 million vertices.

Figure 1 – Creation of Virtual Scenario of an Intensive Care Unit Using Blender ™

After adding light sources to the scene, Blender™ can be used to create a rendered image by calculating the color, shading and lighting of objects' surfaces, in a chosen angle of view of a virtual camera. Depending on the fidelity parameters, it can take several minutes on a typical home computer to create a single image. Thus, the time to process and obtain a single sample of the approximately 3,500 images used for the project would exceed 200 hours. The time render to images was reduced by 25 times due to the use of an useful Blender™ feature, that "bakes" an object's texture and color shading information, while maintaining quality of the images.

Creating Animations with 3D Models

Within Blender™, the process known of "rigging" allows for animations to be created through manipulations of 3D models., The changes to size, shape, or position of the 3D models in successive frames creates a perception of object movement.

To control the rigging process , the 3D models are given an "armature", which is a skeleton that can have its shape, size or location modified in relation to other objects. Human models are provided with more complex armatures, composed of several bones and joints, capable of reproducing a wide variety of poses.

More discrete movements such as breathing, blinking, and heartbeat are difficult to control through armatures. For these, we used the shape keys feature to generate various versions of the same object that can re-position in the different vertices.

In Blender's™ timeline windows, we could select different frames, numbered sequentially. By default, every 24 frames in the timeline equaled one second of animation. When modifying the armatures poses or the shape keys in different frames, Blender™ was set-up to automatically calculate the expected shape of the objects in the intermediate frames. The rendered images of each frame was combined in sequence to create a video.

Seven virtual cameras were used, with different viewing angles, to better visualize the steps of the examination (See Figure 2).

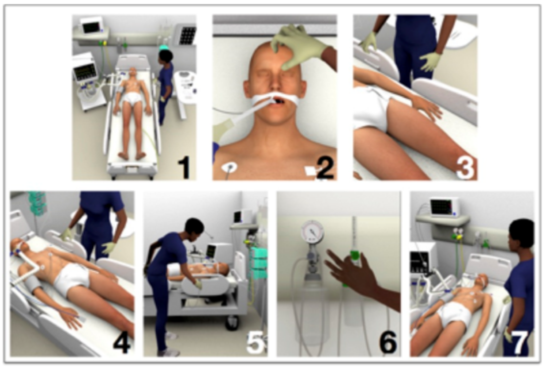

Figure 2 – Different Viewing Angles of Cameras Used in Animation Sequences

Creating and Editing Videos

Blender™ also provided a useful tool for creating and editing videos. The rendered images of all frames were combined and exported as video files (using H.264 MPEG-4 format), one video was created for each step of the clinical examination. The video editor allowed the addition of layers and transitions effects. The application of this feature was demonstrated in the development of the video for the apnea test, where an accelerated clock sequence was superimposed on the patient's image to represent the 10-minute observation time.

Editing Images

We used the GIMP™ (GNU Image Manipulation Program), a free and open source software [29], to edit and retouch the images used as textures in Blender™ and create the application (opening screen, icons, backgrounds, etc.).

Sample images of complementary exams were downloaded from Radiopaedia.org [30], a free collaborative radiology educational web resource. The images did not contain patients' data, and credit for reproductions followed Radiopaedia's user-contribution agreement.

Using a Game Engine

Developed by Unity Technologies, we used Unity™ (also known as Unity3D™ or Unity Engine™), as our cross-platform game engine [31]. Unity has a user-friendly interface and within a single project can generate application versions for all the major operating systems (Windows™, MacOS™, Linux™, iOS™ and Android™). Although it has paid subscriptions, it offers a free license for beginners whose project does not result in annual revenue over US $ 100,000 [32], fitting in with the proposal of our work.

For our project, Unity™ was used to create a game or application containing images, sounds, videos and 3D models (collectively called Assets), combined with user interface elements such as windows, text and buttons. These elements were divided into several scenes, which could be alternated according to the player's interaction with the elements on the screen.

A total of 20 scenes were created, with interactive elements that could be clicked (or touched) to display videos, text windows with relevant information or change to other scenes. Screens representing the Term of Declaration of Brain Death, similar to what was available within the Brazilian guidelines, played the role of "command center" in the application structure, from which all stages of the examination could be accessed through numbered icons. Users were allowed to revisit them as often as necessary to ensure understanding.

Some steps were chosen to be demonstrated in a more interactive way, requiring the user to perform gestures of clicking (or touching the screen of mobile devices) and dragging to interact with the content. Examples include:

- In the pupillary light reflex test, the user moved the examiner's hand with a flashlight to illuminate the patient's eyes, with fixed pupils. An icon with a question mark showed the expected response in normal situations, with reduction of pupil size to light exposure.
- In examining the corneal-eyelid reflex, the user moved the examiner's hand with a cotton swab to touch the patient's cornea, without reactivity to the stimulus. It was also possible to observe the normal find, with blinking as the response.
- In the oculocephalic reflex test, the user was instructed to horizontally drag the mouse pointer (or finger on the screen) to move the patient's head to the left or right. The patient's eyes followed the movement of the head. In the demonstration of the normal reflex, the eyes moved in the opposite direction of the head.

For more complex responses such as those shown in the steps described above, Unity requires the creation of scripts, text files containing commands written in programming language and instructions detailed to accomplish the task.

At the end of the work, executable files were created for the main operating systems. Only small differences could be seen between versions of application, such as screen resolution or some icons images (e.g. mouse pointer for computers and a drawing hand for mobile devices).

Results

The "Brain Death Determination: A Digital Guide" application beta version was created for Windows™, MacOS™, Linux™, iOS™ and Android™ operating systems.

The user is guided through the Brazilian Term of Declaration of Encephalic Death, from identification of the patient, definition of cause of coma, exclusion of confounding factors, measures for clinical stabilization of the patient, and all steps of the neurological examination with tutorials videos and interactive content. During the process, the user is alerted to important aspects and possible pitfalls during examination. In some stages it is possible to display the expected findings in normal patients. A brief explanation and sample image are given on the complementary tests used in the BD determination. At the end, the user is congratulated and invited to review the steps as many times as necessary. See Figure 3 for screenshots of examples of the application.

No images and videos of actual patients were used. This study was approved by the university ethics board (3.079.856).

The application is currently in the test period to evaluate bugs and area of improvements. Once testing is complete the application will be available for download in Internet repositories and mobile app stores (App Store™ and Google Play™).

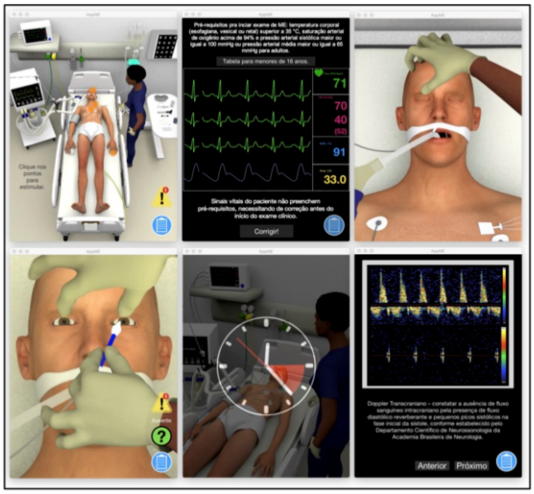

Figure 3 - Screenshots of the Application "Brain Death Determination: A Digital Guide"

Discussion

Knowledge concerning BD has proved insufficient among medical students and health professionals, highlighting the need for more effective teaching practices. A digital tool with multimedia tutorials, available in several platforms, could be a valuable tool to assist the training in the determination of BD.

With the lack of opportunities for students and residents to follow the BD examinations in practice, we choose a game-like approach to integrate content. We selected this approach for students based on its appeal, strength in experiencing of realistic simulation with mannequins, and frequent use as a methodology for training courses. The use of computers and mobile devices has the additional benefits of reaching a greater number of students with reduced cost.

The program could be easily adapted for use in other countries, with language modification and adjustments to the local guidelines. There is also the opportunity to provide updated versions to meet specific needs (e.g. providing a module for self-evaluation).

In recent years, similar applications have been used to assist in the training of different medical skills, proving to be valuable educational tools. A mobile application simulator has been demonstrated to be an effective education tool for of medical students, improving the performance in several operations and practical procedures, such as male urinary catheterization and chest tube insertion [33, 34]. For laparoscopic cholecystectomy, the same application was useful for learning cognitive aspects of procedure when used in combination with virtual reality in a multimodal training approach for general surgeons and medical students [35]. In a blinded randomized controlled study, the use of a web-based otoscopy simulator increased the diagnoses of otologic diseases by medical students, with a 24% higher score than the control group using standard otology lectures [36].

Limitations

The true potential of the application in practice still needs to be evaluated through a randomized blinded study that measures the impact of the acquisition of knowledge that involves a comparison of the application with other traditional teaching methodologies.

Conclusions

Using open-source software to create and animate 3D models (MakeHuman™ and Blender™), and a game development platform that offers free license for beginners (Unity), we were able to create a low-cost application to assist health professionals' training in BD determination. Available for all major operating systems (iOS™, Android™, macOS™, Windows™ and Linux™), this teaching tool can be used for students through their desktops or mobile devices.

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