Development and Evaluation of a Immersive Serious Game to Support Neuroanatomy Teaching and Learning

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***Abstract*—Using virtual environments (VEs) is a safer and cost-effective alternative to training people in different contexts. Immersive Virtual Reality (VR), combined with game aspects, have the potential to improve the user experience in the VE by increasing realism, engagement, and motivation. The digital game industry is one of main sectors of the global media market, and, according to Netscribes Gaming Market Research, is expected a significant growth (18.98%) by 2023. In the same way, Virtual Reality (VR) is gradually more accessible, which has enabled applying it in different areas besides research. In education, the development of VR has grown significantly, evidencing contributions to the teaching and learning processes. In Brazil, only a few research groups have developed projects that involve the development of VR for education, due to technical difficulties and high costs. This work presents the development and evaluation of an VR serious game to support the learning of neuroanatomy. The results of the evaluation suggest that the game created is easy to use, even by inexperienced subjects in VR, and is potentially useful for teaching and learning processes. In addition, the game was considered fun and did not cause discomfort, which is common in many RV applications. Considering the results of the questionnaire on the feeling of presence, a high average was obtained (6.13), and, for four of the six questions, averages above 6.3 were obtained on a scale of 1 to 7, with 7 representing the real sensation of being present in a certain place. In the knowledge test, we found a significant difference between the performance before (M=20.38) and after the experiment (M=46.3 in condition C1 and M=47.1 in C2), what indicates that the methods really contribute to the learning process. The not significant difference between the experimental conditions, evidenced that the virtual condition is equivalent to the synthetic, the present method of learning being used.**

***Keywords*-virtual reality, serious game, presence, neuroanatomy**

I. Introduction

Digital Games are one of the main sectors in the Global Media and Entertainment Industry, comprising games played on PCs, Mobiles, and Consoles. According to Netscribes Gaming Market Research, the digital games market is expected to have a significant growth of 18.98% (2018-2023), leading to a global digital gaming market size of $323.91 billion by 2023 [1]. At the same time, Virtual Reality (VR) software and hardware are becoming more sophisticated and inexpensive, which has enabled them to be applied in different areas besides research, such as training, therapy, education, marketing and entertainment [16]. According to a new report from International Data Corporation (IDC), worldwide spending on augmented and virtual reality is forecast to surpass $20 billion in 2019, an increase of 68.8% over the $12.1 billion in spent in 2018 [8].

Although extensive research has already been conducted in virtual and augmented reality, as well as in games, there are still few researches investigating the potentialities and limitations of VR games, especially regarding newly launched devices that provide unconventional interaction experiences [11]. The applications of VR in education are many and there is a consensus of its benefits in the teaching and learning processes. Among the possible benefits are the possibility of expanding the perceptions of the five senses, representing more than the real state of affairs, greater engagement with the student, appropriation according to each person's rhythm, exploration instead of deduction, active learning, interacting and facilitating a global analysis and their interrelationships. The cognitive process is not just about problem solving, but it also has inventiveness and creation. The data processing perspective no longer fits as the only answer to cognition. Objective and subjective are supporting the production of cognition. The available technology and cost limitations will define the type of application to be developed in each case.

In this context, this paper presents the development and evaluation of a VR serious game to support the neuroanatomy teaching and learning processes, in order to minimize the need for management of real anatomical parts. In addition, we aim to provide an innovative and engaging experience for the learning of neuroanatomy that allows the development of pedagogical activities with low cost, both in the classroom context, with the use of virtual reality glasses, and at home, with the use of the smartphone.

Section 2 presents the background and some projects related to this work. Section 3 presents the hypotheses, and the developed VR game is described in section 4. Section 5 describes the experimental design and shows the apparatus used in the in the user evaluation. Section 6 presents the results and discussion. Section 7 concludes the paper.

II. Background and Related work

Virtual reality is a computational application by which users can interact with virtual environments through their senses, such as sight, hearing and touch [3]. For Slater (2014), VR is a technological system that can precisely replace a persons sensory inputs to an alternative reality. VR is able to create the user sensation of being transported to a virtual three-dimensional world, providing a visceral and immersive experience, although this does not always occur [16].

In his 1999 article, that reviewed the state of virtual reality, Brooks noted that, at that time, the field had made great technical advances [2]. According to Slater, VR has become a commonplace tool in many areas of science, technology, psychological therapy, medical rehabilitation, marketing, entertainment, and industry, and is surely about to become commonplace in homes [16]. Today, we already have many devices and accessories compatible with VR. Among the most famous HMDs, we have the most powerful and expensive ones, such as HTC Vive (by Valve in 2015), PlayStation VR (by Sony in 2016) and Oculus Rift (by Oculus VR in 2016), and the cheaper ones based on smartphones, such as Gear VR (by Samsung in 2015) and Google Cardboard (by Google in 2014). All of them, however, are marketed for home use and offered at affordable prices.

Presence is an important feature of VR systems related to the users' sense of being present in the Virtual Environment (VE). Presence is defined as the subjective experience of being in one place when we are physically in another [22]. According to Sjölie (2013), the sense of presence is determinant and must be considered from the design to the use of VR systems [15]. In recent years, many researches related to presence have been developed, especially related to methods to measure it and to the VEs characteristics that contribute to increase the user's sense of presence. Many researchers and studies argue that the greater the sense of presence, the greater the chances that the users' behaviour in the VE will be similar to their behaviour if the situation was real. Consequently, the greater the effectiveness of the use of VR for the training, therapy or entertainment [19], [15], [14].

The methods to measure presence are divided into subjective and objective. The subjective ones are the most used, especially the post-questionnaires, such as SUS [21] and ITC-SOPI [7]. Besides the scale questionnaires, there are also some subjective observation techniques [6], [13]. More recently, there have been proposals to measure presence from non-invasively physiological data such as heart rate, skin conductance, eye movement and surface electromyography, obtained during the use of the VE [13]. Also, some techniques have been proposed that use neurological measures, obtained by Functional Magnetic Resonance (fMRI), Transcranial Doppler (DTC) and Electroencephalography (EEG) [4], have been proposed.

Slater (2003) argued over the difference between the term "immersion" and "presence", having reserved the term "immersion" to technology in an objective point of view. Presence is a human reaction to immersion. Given the same immersive system, different people can experience different levels of presence and, also, different immersive systems can give rise to the same level of presence in different people [17].

In the past decades, the VR community has based its development on interactive 3D graphics and visual simulation. Currently, the VR field is transitioning into work influenced by video games [12]. Because much of the research and development being conducted in the games community parallels the VR community's efforts, it has the potential to affect a greater audience. Given these trends, VR researchers who want their work to remain relevant must realign to focus on game research and development [24].

Console and Personal Computer (PC) games have become ordinary for home users since longtime, being released in the 70s the first home console, the Magnavox Odyssey. In 1984, the PC game market exceeded that of the consoles, and in 2000 began the modern era of gaming began, with the launch of the X-Box and PlayStation 2. The gaming world went from pixelated 2D to 3D in just a decade [5].

Just like video games, serious games (SGs) consist of gameplay, challenge, interaction, and objective, while gamified applications merely incorporate elements of games. Furthermore, SGs are constructed over pedagogical and educational frameworks, which define the relationship between learning and game mechanisms, ensuring a successful combination of such factors to reach its serious purpose [9].

The VR used in education in a playful way, can enhance learning through the exploitation of information. For example, proposals as clues in an immersive game, favoring the development of desired skills [6]. In the health field, VR has been used in the simulation of surgeries, mainly for operative training of video-laparoscopic surgery, in the preoperative planning and in the intraoperative support. The images of virtual digital models have the advantage of being able to evaluate the organs three-dimensionally, to observe the internal structure of the organ, to evaluate the relations between the organs with their topographies and to produce selective visions of the body. In addition, there is no time limitation for usage [23].

Currently, only a few research groups have developed projects with VR application for teaching and learning in the medical field due to technical difficulties and high cost. However, some proposals are emerging to minimize the difficulties of developing and maintaining the required systems and programs. In addition, skilled human resources, involving interaction between different areas, are being prepared for optimization and democratization in the use of this technology in teaching and learning processes [10].

III. Hypotheses

The general hypothesis defined in this paper is that the neuroanatomy learning process based on the use of a virtual encephalon has similar results to the present method, based on a synthetic encephalon. This general hypothesis was detailed in 5 specific hypotheses, presented below.

- H1: The use of virtual encephalon produces similar results to the use of synthetic encephalon in neuroanatomy learning.
- H2: The difficulty of virtual encephalon assembly is similar to the synthetic encephalon assembly.
- H3: The sense of presence in the virtual encephalon assembly is smaller than in the synthetic encephalon assembly does.
- H4: The virtual encephalon assembly causes more discomfort than the synthetic encephalon assembly.
- H5: The fun in the virtual encephalon assembly is bigger than in the synthetic encephalon assembly.

IV. The VR serious game

According to the literature, a serious game consists of gameplay, challenge, interaction, and objective and are constructed over pedagogical and educational criteria to reach its serious purpose. For a simple gameplay, the developed game was based on puzzle games. This game genre can test different player skills, such as logic, strategy, pattern recognition, sequencing, and part-whole relationships [8]. The challenge is to assemble a human virtual encephalon, based on its anatomic parts (frontal lobe, parietal lobe, occipital lobe, temporal lobe, cerebellum, corpus callosum and brainstem and diencephalon), which are randomly arranged on a virtual table (Figure 1), in the shortest time. Concerning to interaction, the user manipulates two virtual hands, to take, rotate and translate a pair of parts until its correct fit. Besides this, the user can rotate, in all directions, a reference encephalon to help them find the solution to the challenge (Figure 2). The objective of this serious game is to support the learning of the name and position of the different anatomy human encephalon parts, based on a playful, active and innovator method.

The randomness of position and colors of the pieces aims to maintain the challenge between matches, minimizing the possibility of solution by mere memorization. Among the initial configuration options, it is possible to activate or deactivate the labels that shows the encephalon parts' names , in order to offer different levels of difficulty. In addition, when starting a match, the user is invited to inform his name/nickname, considering that the game presents the short time top 10 ranking, as a motivational strategy for the challenge.

From the results of the preliminary assessment [20], a new version was developed and experiments with users were performed. In the new version of the system, environmental sound and sound effects were included in different moments of the interaction, as well as the possibility of configuring the environment to display the name of the parts of the brain and the possibility of moving the reference brain.

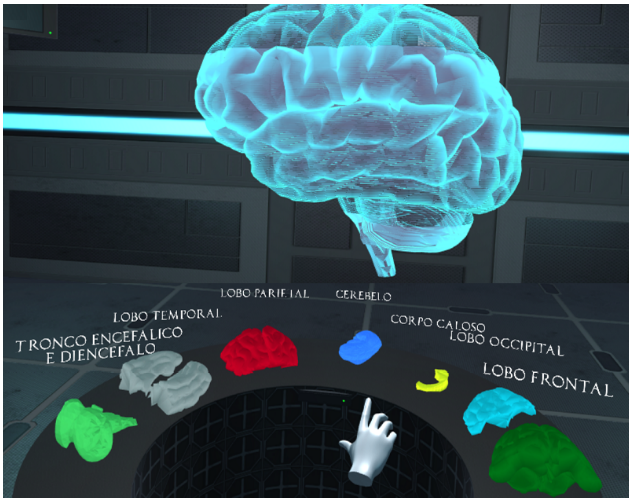


Figure 1. Game screenshot with the human encephalon parts to be assembly and the reference encephalon.

V. Evaluation

This section presents the within-subjects experiment performed to verify the hypotheses previously defined.

A. Dependent and independent variables

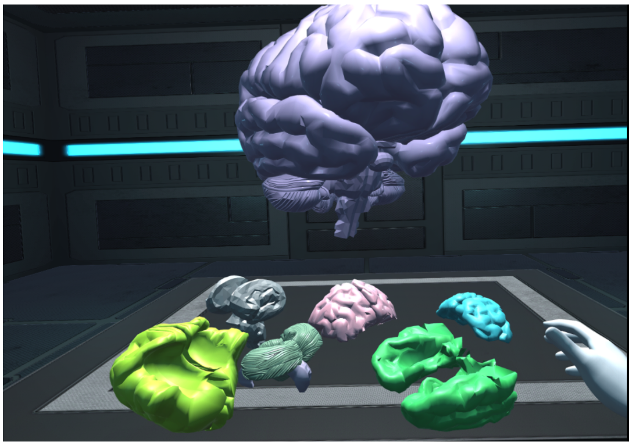
The aim of this study was to evaluate the presence and learning between the different test conditions, that is, the assembly, performed individually by the participants, of the human encephalon with synthetic and virtual parts (Figures 4 and 5). The independent variable was the type of encephalon to be assembled (synthetic and virtual) and the dependent variables were the presence and learning (grade in the knowledge test).

B. Participants

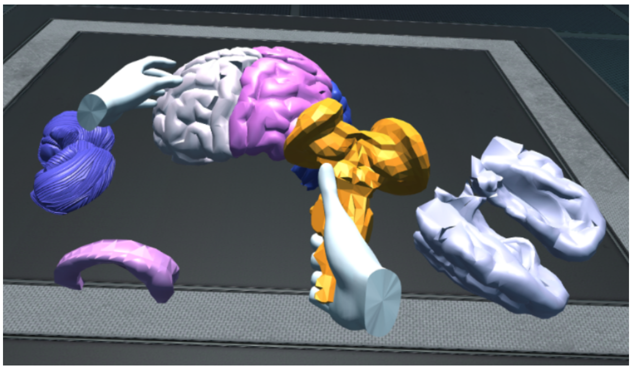
In order to carry out a user evaluation, the serious game was used by 16 students, 13 women and three men, from different undergraduate courses and stages, without *motor limitations*[1] (Table I). The participants' age range was 17 to 40 years, with a mean age of 26.8 years and a standard deviation of 6.3. Concerning the course, 7 were from Psychology, 4 from Physiotherapy, 2 from Law, 1 from Biology, 1 from History and 1 from Publicity. About the course stage, 3 are in the first year, 3 in the second year, 3 in the third year, 4 in the fourth and 3 in the last year.

When asked about their neuroanatomy knowledge, the participants answered a 4 point Likert scale (none, little,

[1] Limitations of functioning in the osseo-articular, muscular and / or nervous system.



(a) Parts of the brain to be assembled



(b) Partial assembly of the brain

(c) Completed human encephalon

Figure 2. Stages of the immersive serious game.

medium, high). Four subjects said they were unaware, six declared to have little knowledge and six average knowledge. Participants were also asked to indicate, on a scale from 0 to 100, their degree of knowledge concerning the anatomy of the human encephalon, being the mean 28.44 and the standard deviation 20.47. Related to the knowledge test, developed by a neuroanatomy professor, the mean performance was 20.38, with a standard deviation of 20.85.

Table I
PARTICIPANTS PROFILE

Sample	Students	16
Age	M=26.8	SD=6.3
Gender	Female=13	Male=3
Undergraduate Course	Psychology	7
	Physiotherapy	4
	Law	2
	Biology	1
	Publicity	1
	History	1
Course Stage	Fisrt year	3
	Second year	3
	Third year	3
	Fourth year	4
	Last year	3
Neuroanatomy Knowledge	None	4
	Little	6
	Medium	6
Neuroanatomy Knowledge Scale	M=28.44	SD=20.47
Neuroanatomy Test	M=25	SD=27.81
VR Experience	None	7
	Once	5
	Between 2 and 5 times	2
	Between 6 and 10 times	2
Videogame Experience	None	9
	Once a month	5
	Once a week	2

With respect to the VR experience, participants responded to a 5-point Likert scale (none, once, between 2 and 5 times, between 6 and 10 times and more than 10 times), so that 7 subjects never used, 5 used once, 2 used between 2 and 5 times and 2 used between 6 and 10 times. As for the 3D video gaming experience, participants also responded to a 5-point Likert scale (never, once a month, once a week, once a day, more than once a day): 9 subjects never play, 5 play once a month and 2 play once a week.

C. *Apparatus*

The game was developed in Unity3D and, for evaluation, a Dell XPS 8900 computer with 3.6 GHz Intel(R) Core i7-7700 processor, 16GB RAM and NVIDIA Gforce GTX 1060 6GB graphics card was used. The VR devices used were the Oculus Rift CV1 and the Oculus Touch control.

D. *Metrics*

Objective measures (performance and time), subjective (presence, ease of assembly, discomfort and fun in assembling and usefulness for neuroanatomy learning) were used in this study. The performance was obtained in the knowledge test, the time by the game log and the subjective measures were collected through the application of questionnaires.

1) Performance: The knowledge test, developed by the professor responsible for the class of neuroanatomy in the university, was composed of an image of the human brain (Figure 3), in which were indicated the 6 parts that compose it. The participant was asked to indicate the name of each of the parts, according to the image indication, and the result was attributed in a score from zero to 100 points.

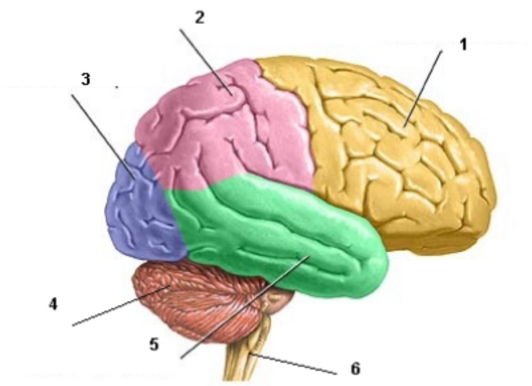


Figure 3. Human encephalon image used in the knowledge test.

2) Time: The virtual encephalon assembly time in the virtual has been recorded in a text file generated by Unity at the end of each section of the game. In the synthetic encephalon assembly, the time was counted and recorded by the researcher.

3) Presence: To measure presence, the Slater-Usoh-Steed questionnaire [18], also known as SUS, was used. The SUS questionnaire underwent some changes and currently consists of six items evaluated on a seven-point rating scale, 7 being the real sensation of being in a different place.

4) Assembly Ease: With respect to the ease of assembly, participants responded, in a 5-point Likert scale, to the affirmative sentence “It was easy to assemble the encephalon” with the following options: totally disagree, disagree, neutral, agree and totally agree.

5) Fun: With respect to the fun, participants also responded to a 5-point Likert scale related to the affirmative sentence “It was fun to assemble the encephalon”, with the following options: totally disagree, disagree, neutral, agree and totally agree.

6) Discomfort: Virtual reality sickness occurs when exposure to a virtual environment causes symptoms that are similar to motion sickness symptoms. The most common symptoms are general discomfort, headache, stomach awareness, nausea, vomiting, pallor, sweating, fatigue, drowsiness, disorientation, and apathy. To verify a possible cybersickness, a simple affirmative sentence was presented to the participants: “Assembling the encephalon caused me discomfort.” Subjects also responded to a 5-point Likert scale with the same following options: totally disagree, disagree, neutral, agree and totally agree.

7) Usefulness: To verify the usefulness to the neuroanatomy learning, in the subjective participants opinion, the affirmative sentence presented was “The assembly of the human encephalon was useful for my neuroanatomy learning”. Subjects also responded to a 5-point Likert scale with the same following options: totally disagree, disagree, neutral, agree and totally agree.

E. Procedure

The procedure followed a typical protocol, beginning with a general explanation of the experiment, signature of the consent term and use image term, characterization of the participant and application of a preliminary neuroanatomy’s test of knowledge, prepared by the responsible professor at the university. Subsequently, the participant performs the assembly of the synthetic (Figure 4) and virtual (Figure 5) encephalon, varying the order among the participants. After each test condition, the subject answered a questionnaire, with open and closed questions, to evaluate the experience. Through a 5-point Likert scale, participants opined about the ease of usage, fun, utility and possible discomfort caused by the VR. In a 7-point scale, they answered 6 questions from the SUS presence questionnaire [18]. Additionally, the subjects recorded their perceptions about the potentials and limitations of the game in open-ended questions and redid the knowledge test. Finally, comparative issues between the virtual and synthetic experiments were applied.

Figure 4. Individual assembly of synthetic human encephalon.

VI. Results and Discussion

In this section, the results of the study will be presented and discussed in the context of the five defined hypotheses. It is important to make it clear that the found results may be somewhat biased, since the sample size was small. To make it possible to generalize, further research is needed to determine the results in a greater sample.

For each of the aspects covered in the experiment, the Shapiro-Wilk test was applied to verify whether or not they had normal distribution, followed by an analysis of variance

Figure 5. Individual assembly of virtual human encephalon.

and paired tests, in cases in which a difference between the experimental conditions was identified, to verify among which conditions there was a significant difference. In the case of data with normal distribution, the One-way ANOVA variance test was applied and, when the difference was identified, the Student's t test was used to verify between which conditions there was a significant difference. On the other hand, for the non-normal distributed data, the non-parametric tests were applied: the Friedman test for analysis of variance and the Wilcoxon test to verify between which conditions there was a significant difference.

As described before, in the condition 1 (C1), the participant used the HMD and touch controls to assemble the virtual encephalon. In the condition 2 and (C2), the participants assembled the synthetic encephalon, that is, the present method used in the neuroanatomy course.

A. *Performance*

In the knowledge test, as showed in Figure 6, we found a significant difference (kruskal p=0.1664 - synthetic and p=0.4177 - virtual) between the performance before (M=20.38 SD=20.85) and after the experiment (C1 M=46.3 SD=32.4 and C2 M=47.1 SD=38.4), what indicates that the methods really contribute to the learning process. However, no difference was found between the experimental conditions, evidencing that the virtual condition is equivalent to the synthetic.

B. *Time*

Concerning the time to assemble the encephalon in the experimental conditions, in the synthetic condition the mean time was 6.14 with standard deviation of 0.13, and, in the virtual condition, the mean time was 9.52 with standard deviation of 0.32. It was possible to notice that the average time was higher in the virtual condition, which is acceptable since most participants are inexperienced in virtual reality.

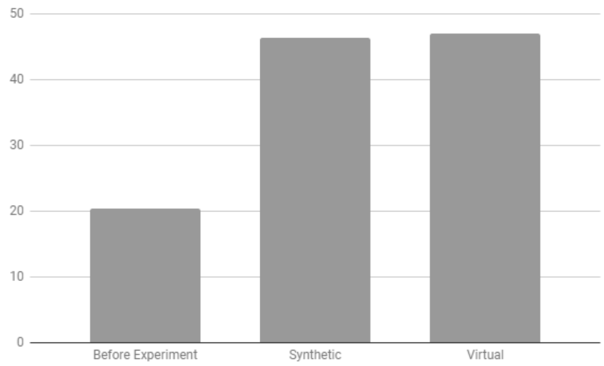


Figure 6. Knowledge test mean result, before and after each experimental condition.

However, it is also noted that the difference in mean assembly time between conditions was very small.

C. *Presence*

The SUS questionnaire, which is composed of six items evaluated in a seven-point evaluation scale, was applied to verify to what extent the developed virtual environment allows a good level of presence in the users, so that this is an important characteristic of an AV that proposes to contribute to the learning process. As can be seen in the Figures 7 and 8, no significant differences were found between the test conditions (wilcoxon p = 0.3049), and it was expected that in the synthetic condition the averages would all be very close to 7. This result may be associated with an inadequate interpretation of the real meaning of the sense of presence by participants, especially in the synthetic condition. However, even if we consider that in the synthetic condition the sense of presence is 7 in all the questions, it fair to notice that the sense of presence in the virtual condition was quite high, having a mean of 6.13 and standard deviation 0.83.

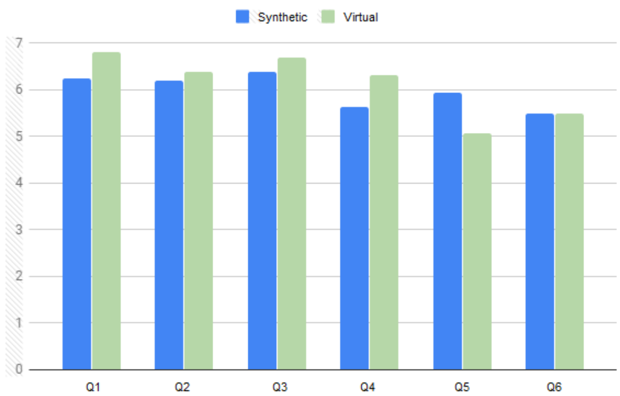


Figure 7. Mean of the SUS presence questions.

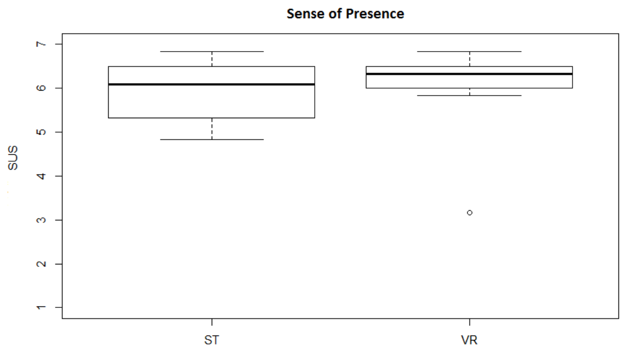


Figure 8. SUS Box Plot using the synthetic brain (ST) and using the virtual brain (VR). The bold lines are the medians and the boxes are interquartile bands with the result.

D. Ease

Concerning encephalon assembly ease, as illustrated in Figure 9, there was a split of opinion among the participants, especially in the case of the synthetic encephalon, in which exactly half of the people agreed that it was easy to assemble, while the another half disagreed. Regarding the virtual encephalon, a significant group, 6 of the 16 participants, agreed that it was easy to assemble, being that the most of the subjects disagreed. This result is probably associated with little experience in virtual reality, reported by most of the people who participated in the experiment, 7 of whom had never used it before and 5 used it only once.

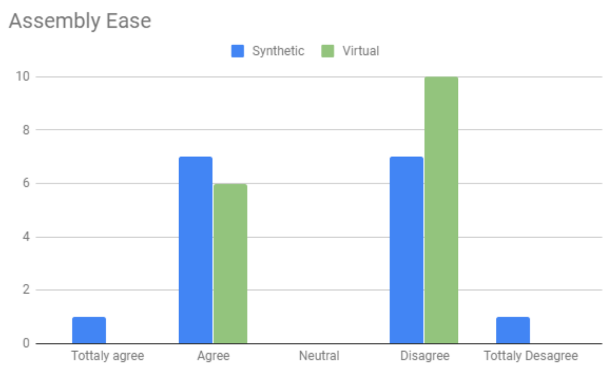


Figure 9. Virtual and synthetic assembly ease.

E. Fun

Regarding the fun, participants also responded to a 5-point Likert scale, related to the affirmative sentence "It was fun to assemble the encephalon". According to the Figure 10, it is clear that the method, whether virtual or synthetic, was considered fun by the subjects. In spite of this, the results indicate that the use of virtual reality was even more fun than the assembly of the synthetic parts, being that, in this condition, 10 subjects fully agreed and 6 agreed, whereas in the synthetic condition, 5 fully agreed and 11 agreed.

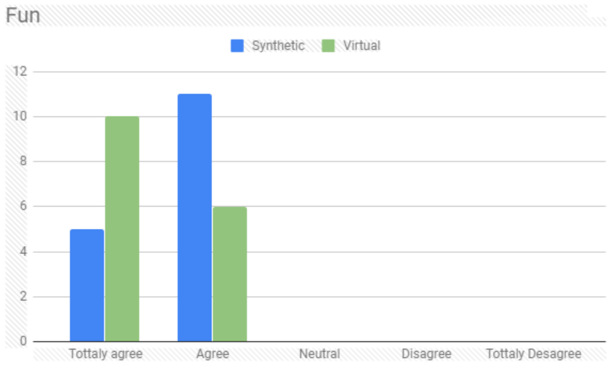


Figure 10. Participants' opinion on the fun in the virtual and synthetic encephalon assembly.

F. Discomfort

In order to evaluate if the virtual condition could cause cybersickness, the affirmative sentence "The assembly of the encephalon caused discomfort" was presented to the participants. The subjects also responded to a 5-point Likert scale with the options "totally disagree", "disagree", "neutral", "agree" and "totally agree". The Figure 11 shows the results of the participants' answers, with the majority disagreeing both in the synthetic and virtual conditions, with slightly more disagreement in the virtual condition, which suggests that the game is applicable without depletion for the players.

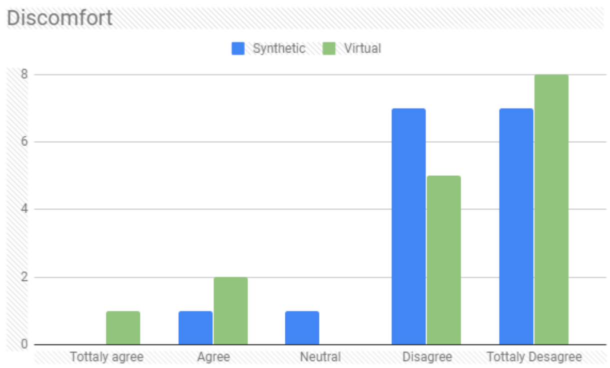


Figure 11. Participants' opinion on the discomfort in the encephalon assembly.

G. Usefulness

To verify the usefulness for neuroanatomy learning, in the participants' subjective opinion, the affirmative sentence "The assembly of the human brain was useful for my neuroanatomy learning" was presented. As shown in Figure 12, the vast majority of subjects fully agreed or agreed to the claim, while none of them disagreed and only two considered themselves neutral. This opinion was confirmed by the significant difference found between the performance of the participants in the knowledge test applied before (M=20.38) and after the experiment (C1 M=46.3 and C2 M=47.1), with no significant difference (t-test p=0.9572) between the experimental conditions (Figure 13).

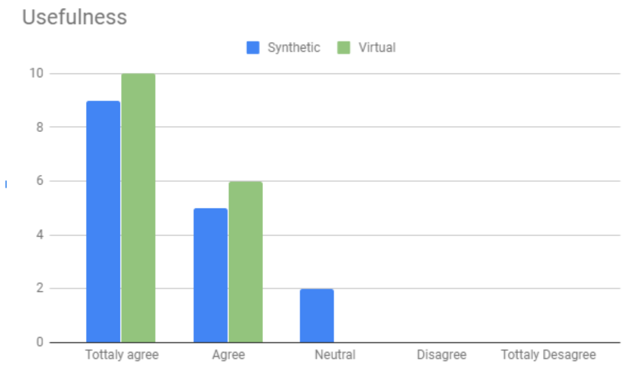


Figure 12. Participants' opinion on the assembly of the encephalon for the neuroanatomy learning.

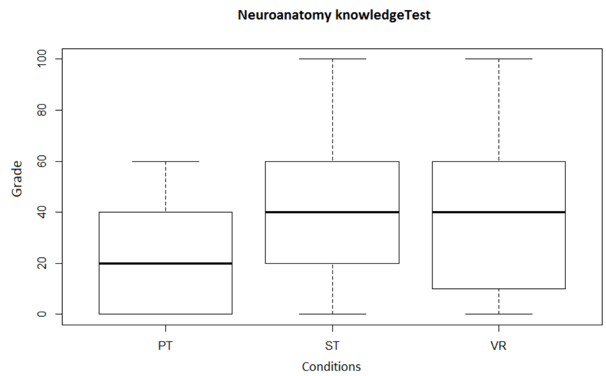


Figure 13. Neuroanatomy knowledge test Box Plot: Pretest (PT), using synthetic brain (ST) and using virtual brain (VR). The bold lines are the medians and the boxes are interquartile bands with the result.

We found no significant difference in ease, utility and discomfort between the assembly of the synthetic and virtual encephalon. Regarding the degree of fun, the participants considered the virtual condition more fun than the synthetic one.

VII. Conclusions and Future Work

In the recent past, the VR researchers and the industry have based its development on interactive graphics and visual simulation. Nowadays, the VR field is heavily influenced by video games, with the potential to affect a greater audience. Based on this context, this article presents the development and evaluation of the immersive serious game to support the neuroanatomy teaching and learning processes.

The evaluation compare the present teaching and learning method, based on the use of a synthetic human encephalon, with a proposed virtual version, that intend to motivate the students trough the immersive serious game characteristics. The results of the experiment with 16 participants suggest that the game created is easy to use, even by subjects that are inexperienced in VR, and is potentially useful for teaching and learning processes. In addition, the game was considered fun and did not cause discomfort, which is common in many RV applications. Considering the results of the questionnaire on the feeling of presence, a high average was obtained (6.13), and for four of the six questions, averages above 6.3 were obtained (on a scale of 1 to 7, with 7 representing the real sensation of being present in a certain place). In the knowledge test, we found a significant difference between the performance before (M=20.38) and after the experiment (M=46.3 in condition C1 and M=47.1 in C2), what indicates that the methods really contributes to the learning process. The not significant difference between the experimental conditions, evidenced that the virtual condition is equivalent to the synthetic, the present method of learning used.

Overall, the results demonstrated a great potential for of the immersive serious game in the learning process. However, we are wary of generalizing our results, as further study is needed to determine whether such results will appear in a more typical population and with other immersive serious game. In future works, we intend to evaluate the game with the different classes of neuroanatomy students, considering a bigger sample and with different visualization and interaction devices.

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