Virtual and stereoscopic anatomy: when virtual reality meets medical education

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OBJECTIVE The authors sought to construct, implement, and evaluate an interactive and stereoscopic resource for teaching neuroanatomy, accessible from personal computers.

METHODS Forty fresh brains (80 hemispheres) were dissected. Images of areas of interest were captured using a manual turntable and processed and stored in a 5337-image database. Pedagogic evaluation was performed in 84 graduate medical students, divided into 3 groups: 1 (conventional method), 2 (interactive nonstereoscopic), and 3 (interactive and stereoscopic). The method was evaluated through a written theory test and a lab practicum.

RESULTS Groups 2 and 3 showed the highest mean scores in pedagogic evaluations and differed significantly from Group 1 (p < 0.05). Group 2 did not differ statistically from Group 3 (p > 0.05). Size effects, measured as differences in scores before and after lectures, indicate the effectiveness of the method. ANOVA results showed significant difference (p < 0.05) between groups, and the Tukey test showed statistical differences between Group 1 and the other 2 groups (p < 0.05). No statistical differences between Groups 2 and 3 were found in the practicum. However, there were significant differences when Groups 2 and 3 were compared with Group 1 (p < 0.05).

CONCLUSIONS The authors conclude that this method promoted further improvement in knowledge for students and fostered significantly higher learning when compared with traditional teaching resources.

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KEY WORDS anatomy; neuroanatomy; teaching materials; education; medical; multimedia; teaching methods

L EARNING and teaching medicine is a difficult task, partially due to the complexity of the subject and limitations of traditional pedagogic methods (lectures, textbooks, laboratory, and anatomical dissections).[11,22,24,39,43] These resources have been used for decades, with intrinsic drawbacks; traditional methods of teaching comprise noninteractive educational tools and do not provide any 3D experience (stereoscopy).[3,13,19,37,38,44,47]

Cadaver dissection is a valuable resource.[55,58] It provides an immersive and interactive experience allied with tactile feedback. However, it has several limitations, including availability of specimens, cost, and a substantial time commitment.[21,23,36,40–42] Substances used for fixation, preservation, and preparation, e.g., formaldehyde, can be toxic, in addition to posing inherent risk of contamination.[1,10,12,42] As a consequence, cadaver dissection repre-

sents a small part of the time dedicated to medical education.[4,9,20,21,33,39–42]

Computer-based virtual reality methods may overcome these drawbacks and provide interesting alternatives for medical training. However, virtual reality tools for general medical education are still expensive due to the technology necessary to create highly detailed, immersive 3D image environments with real-time, user-friendly interactivity.[2,5,6,15,17,18,24,29,48,54,59]

The QuickTime (QT) framework may function to impart the concepts of virtual reality methods that generate interactive environments. The platform can be used for interactive and photorealistic display of medical images (radiological, anatomical, and histological), and its nonlinear format provides interactivity. However, most medical educators are not familiar with these methods. Studies pub-

lished between 2000 and 2006 applied this technology, often coupled with robotic microscopes.[5,6,18,20,54] Nonetheless, their pedagogic efficacy remains controversial.

In this study, the authors used an interactive, photorealistic, and stereoscopic method for teaching neuroanatomy, a concept whose rationale was first described by Henn and coworkers.[20] Additionally, a pedagogic evaluation was performed to demonstrate the educational benefits, comparing it with conventional methods.

Methods

Forty fresh brains (80 hemispheres) were obtained at the Department of Pathology of the University of São Paulo and submitted to specific neuroanatomical techniques. The internal carotid and vertebral arteries were channeled with a PVC silicone probe (Embramed). Volumes of 5 ml and 10 ml of latex (Prevtex, Bagdalatex) previously mixed with a red dye (Chess R, Sherwin Williams Brazil) were injected into the vertebral and carotid arteries, respectively. The dissection was performed under magnification using a surgical microscope (Model L-860, Cemapo).

Image Acquisition

Specimens were placed on a manual-spin turntable platform developed specifically for this purpose (Fig. 1). The platform had a manual-swivel arm bracket on which to place a camera and provided the ability to control each 5°, 10°, 15°, or 20° angle of movement when mounted on the movable head (Model 300N, Manfrotto). The system enabled the camera to be move in a 180° arc. The turntable platform base was circular in shape, allowing a displacement of up to 360° clockwise and counterclockwise (Fig. 2).

For image acquisition, we used a Sony Cyber-Shot DSC-H55 digital camera (14.1 megapixels, 10× optical zoom, liquid-crystal display screen) with a 25-mm wide-angle lens. The camera was placed in the arm and the specimen was set onto the turntable platform. By moving the arm and the platform at predefined angles, images from different anatomical perspectives were acquired and recorded in a grid of consecutives images (Figs. 2 and 3). A pair of images (right and left) from each perspective was also used to obtain the stereoscopic pairs (Fig. 4).

The images were processed using commercially available VR Worx 2.6 software (VR Toolbox, Inc.), which arranges the pictures into a grid, allowing for composition in a nonlinear and interactive format. StereoPhoto Maker software (http://www.stereomaker.net) was used to combine the stereoscopic pairs. The right and left images were combined and integrated, stored in the form of anaglyph stereoscopic images in JPG format, and then reapplied in the VR Worx 2.6 software (Figs. 3 and 4). This methodology, first used by Henn et al., allows an immersive, interactive, and stereoscopic experience. A total of 7300 images were obtained and displayed in QT format.

Pedagogic Evaluation

We compiled a list of class topics from the curriculum at the University of São Paulo Applied Neuroanatomy Graduate Medical Program, and the limbic system was drawn
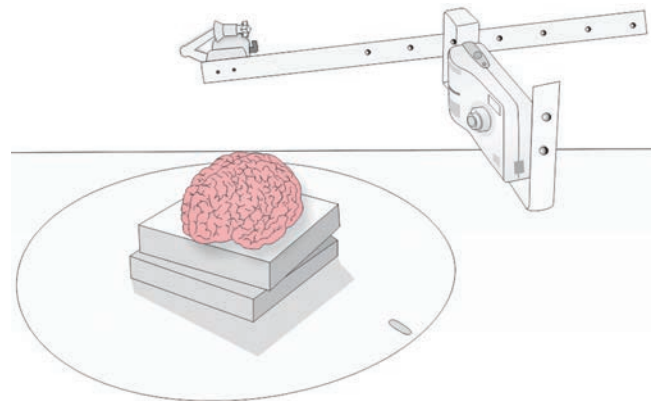

FIG. 1. Illustration showing the rotating platform built for image acquisition. Circular movements of the turntable at predefined angles provided horizontal panning. The arm (with the camera) provided movement in the vertical axis. By combining vertical and horizontal movements, it was possible to acquire images in different perspectives. Thus, the students could examine the anatomical structures from different points of view. Copyright Eberval Gadelha Figueiredo. Published with permission. Figure is available in color online only.

at random as the subject for the evaluation. To assess prior knowledge, the students were instructed to list limbic system structures. This "pretest" was used to verify whether there were previous differences in knowledge among the 3 groups. The groups scored very similarly in this regard (p > 0.05), demonstrating their homogeneity.

A total of 84 students were randomly assigned to 1 of 3 groups, each consisting of 28 individuals: Group 1 was instructed by conventional methods, Group 2 engaged in interactive nonstereoscopic learning methods, and Group 3 students were instructed by interactive stereoscopic lectures. Students in the first group attended a conventional lecture, with 2D images exhibited in a single-angle view. The second group attended a class where interactive teaching resources were applied without the use of stereoscopic images. In this environment, the instructor (J.W.V.F.) presented the lesson using features of the LanSchool software (Stoneware, Inc.); this program restricts students' classroom computer use to class-related resources only, which allows the class to proceed without student interference. The third group underwent the same interactive lecture as that of Group 2, but with the addition of stereoscopic methodologies (Videos 1 and 2).

VIDEO 1. Video clip showing an interactive and nonstereoscopic movie depicting the ventricular surface of the hippocampus. The movie allows users to view anatomical specimens from all angles in 2 axes (vertical and horizontal) by dragging the mouse. It should be visualized using QTVR player and while wearing stereoscopic anaglyphic glasses. Copyright Eberval Gadelha Figueiredo. Published with permission. Click here to view.

VIDEO 2. Video clip showing an interactive and stereoscopic movie depicting the ventricular surface of the hippocampus. The movie allows users to view anatomical specimens from all angles in 2 different axes (vertical and horizontal) by dragging the mouse. It should be visualized using QTVR player and while using stereoscopic anaglyphic glasses. Copyright Eberval Gadelha Figueiredo. Published with permission. Click here to view.

At the beginning of the Group 3 class, the instructor confirmed with the students that they were able to visu-
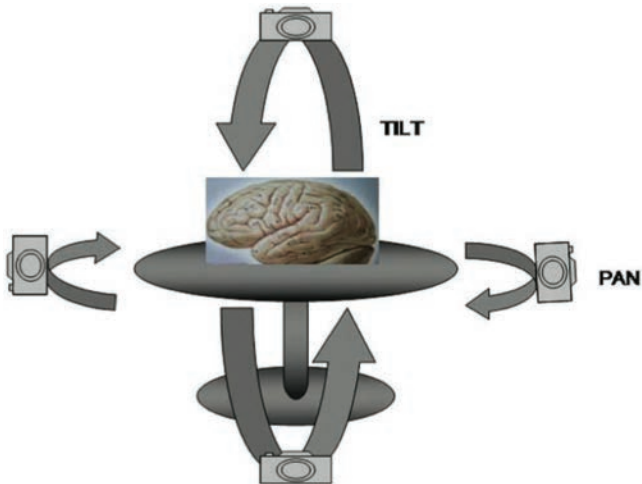
FIG. 2. Diagram showing how the camera was rotated around the anatomical specimen to obtain photographs from various perspectives. The camera was moved along 2 axes: horizontal (pan) and vertical (tilt) at predefined angles. Figure is available in color online only.

alize the stereoscopic images. The theoretical content of the 3 classes was identical, literally following a previously prepared text. The classes were 50–60 minutes in duration, and students were not allowed to intervene.

Pedagogic evaluation was carried out after each class. Students were asked to list the names of the structures of the limbic system. We considered those structures to be the cingulate gyrus, callosum, septal area, amygdala, parahippocampal gyrus, fornix, uncus, mammillary bodies, thalamus, and hypothalamus. Therefore, students could score 0–10, depending on how many structures they properly cited. Additionally, in the practicum, they were required to identify the same structures on real specimens. Practical assessment involved student recognition of anatomical structures in specimens distributed at 10 stations. At each station, students were asked to write the name of the indicated anatomical structure. The practicum instructor was blinded to the students' lecture group.

Students who attended the interactive classes with (Group 3) and without (Group 2) stereoscopy were asked to describe the advantages and disadvantages of these resources.

Statistical Analysis

The performance of the groups was described using percentages, means, and standard deviations (SDs). Comparison between groups was made by ANOVA and the Tukey test for multiple comparisons. ANOVA was performed after data transformation by $\sqrt{(x+1)}$, which satisfied the assumptions of the analysis in which the residues of ANOVA showed normal distribution through the D'Agostino test. Size effect was calculated by using the standardized differences between the means (before and after lectures) of the groups. Size effects ≥ 0.2 and < 0.5 are low, ≥ 0.5 and < 0.8 are average, and ≥ 0.8 are considered high. The level of statistical significance was set at
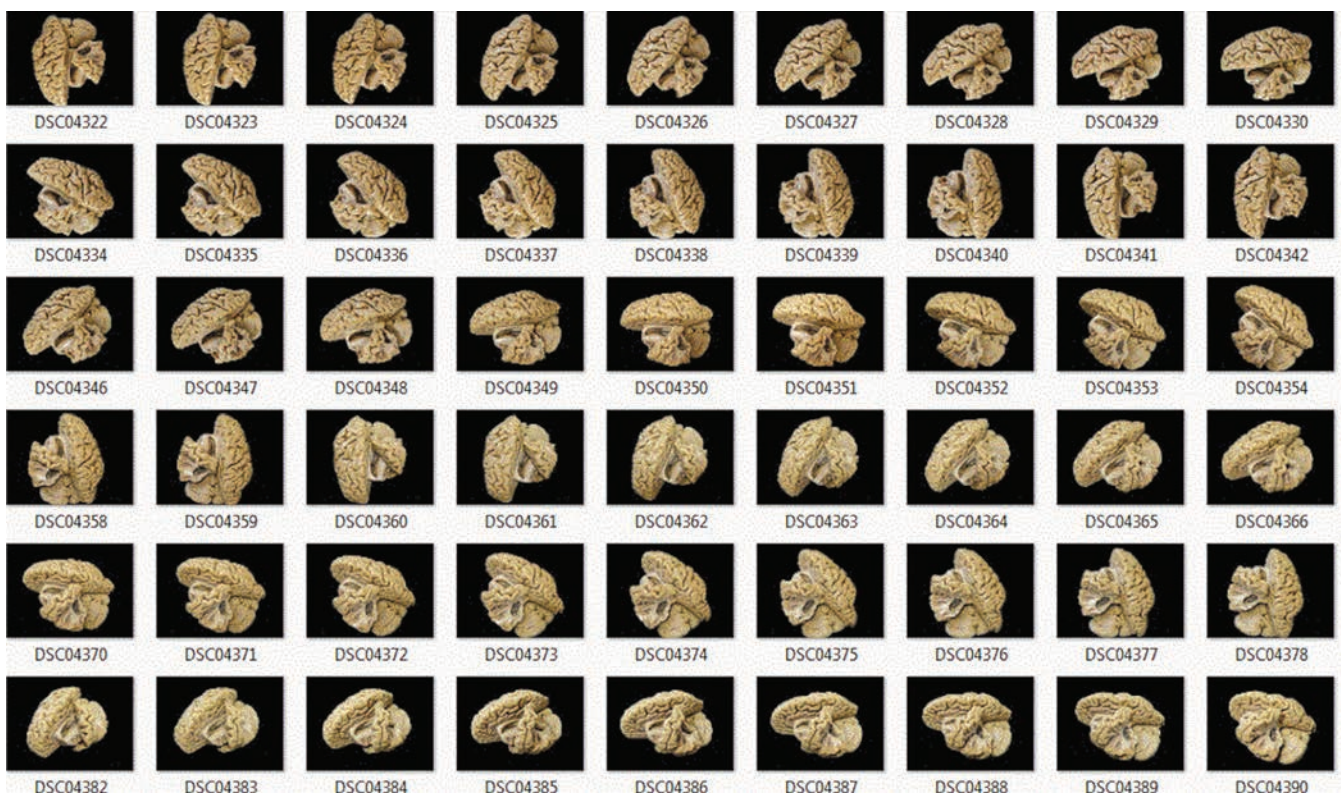

FIG. 3. An example of a grid of images obtained in the cerebrum from various perspectives. The photographs will be processed in the VR Worx 2.6 software, whereby the images will be viewed as a continuum, giving the impression that the brain is moving and, thus, revealing its anatomical nuances. Figure is available in color online only.
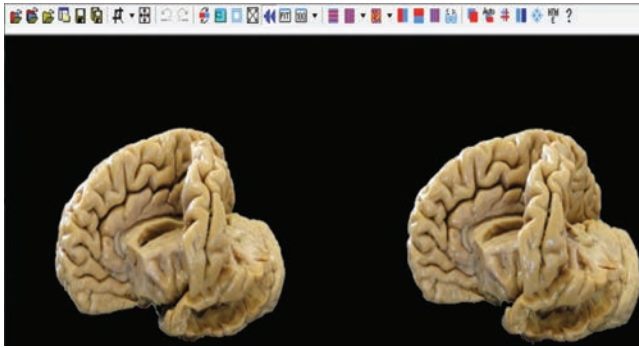
FIG. 4. An example of stereo-paired images (right and left) combined using StereoPhoto Maker. Figure is available in color online only.

0.05. The SPSS software version 17.0 (IBM) was used for analysis.

Results

The means of the scores obtained before classes were analyzed for each group and did not statistically differ (p > 0.05), showing similar previous knowledge (Table 1). Groups 2 and 3 presented the highest means and differed from Group 1 (p < 0.05) in the theoretical exam (Table 1). Group 2 did not differ statistically from Group 3 (p > 0.05). The size effect measurement demonstrated a relevant and meaningful improvement (42%) in the means of Groups 2 (6.77) and 3 (6.78) compared with Group 1 (4.77) (Table 1). Size effect was greater than 0.8 in Groups 2 and 3 and ≥ 0.2 and < 0.5 for Group 1.

ANOVA results and the Tukey test demonstrated a statistical difference between the mean scores (± SD) of Group 1 (4.36 ± 1.33) and Groups 2 (6.36 ± 1.58) and 3 (6.45 ± 1.3l) in the practicum (p < 0.05). Similarly to the theoretical test, there were no statistical differences between Groups 2 and 3 (p > 0.05).

Students in Group 3 pointed out several negative aspects of this method: 4 students complained of eyestrain, 12 cited the absence of names and texts, and 4 noted the impossibility of physical contact.

Discussion

Neuroanatomy is difficult to teach, mainly due to the structural complexity of the brain and limitations of conventional methods.[43,49–53] In this scenario, methods based upon virtual reality technology may represent alternative resources.[58] Nonetheless, these methods increase educational costs and sometimes cannot be applied to large audiences. Despite, their potential advantages over conventional resources, their pedagogic effectiveness has not been assessed thus far.

Interactivity and QT Virtual Reality

QT is a standard set of operating system–level graphics, audio, and digital video extensions developed by Apple Computer, Inc. First released in 1992 for the Macintosh operating system, QT 1.0 primarily emphasized the handling of usual, time-based "linear" digital video and audio.[5,6,16,20,54]

TABLE 1. Comparison of the mean scores before and after class and size effect of intervention in each group*

Group	Before Class	After Class	Size Effect
1	1.62[a] ± 0.65	4.72[b] ± 1.20†	4.77
2	1.57[a] ± 0.65	5.97[a] ± 1.28†	6.77
3	1.62[a] ± 0.65	6.03[a] ± 1.20†	6.78

* Scores are based on a scale of 0–10.
† Values represent the statistical difference between mean scores (p < 0.05). Means followed by the same letter (a or b) do not differ statistically in Tukey test (p > 0.05).

Linear video is conceptually similar to a regular movie, as classically conceived: a sequential, time-based sequence of single image frames. Linear videos play back frames at a constant pace starting with the first image and finishing with the last. When a video is played back, central visual mechanisms, described physiologically as persistence of vision, permit the viewer to realize movement within the sequentially displayed frames, generating a sensation of continuity.[5,6,16,20,54] However, one of the disadvantages of linear movies is that they do not deliver interactivity.

Conversely, nonlinear video is a subset of a movie that allows the viewer to play back videos in a randomized and interactive way. The images may be displayed depending on the user commands and not obligatorily in a linear manner, i.e., from the first to the last frame.[5,6,16,20,54] This capability permits interactivity as the user may entirely manipulate the movie content, regardless of the sequence of the frames.[5,6,16,20,54]

In the nonlinear mode, instead of playing back at a defined frame rate, users may actively control which frame of a QT virtual reality (QTVR) video will be displayed at a specific time. Using the personal computer mouse as an input device, students can look at a panoramic view or rotate a highly detailed anatomical object. Since the format is nonlinear, QTVR content provides indiscriminate access for control over the fourth dimension, time, in visualizing medical images.[5,6,16,20,54]

The "object movie" allows users to appreciate objects from all angles, in 2 different axes: vertical and horizontal (Fig. 2). The camera orbits the object and is rotated in predefined angles. The object is at the center and is, thus, visualized from several perspectives (Fig. 2). Congruent with the format of QTVR videos, object movies are composed of a set of individual image frames (Fig. 3) that are played in a nonlinear fashion.[5,6,16,20,54]

This format is appropriate for presenting structural details of anatomical specimens from almost every perspective. The student may virtually manipulate the specimen and visualize the anatomical relationships. The QTVR object movie format provides a practical means of simulating the handling of anatomical specimens. Object movies offer a compelling experience in settings where real specimens are unavailable or unpractical.[5–8,16,20,54]

We added stereoscopy by taking stereo pairs (left and right images) and delivered "immersivity," which depends upon interactive and stereoscopic visualization of photorealistic images.[45,46,57]

Image Acquisition and Stereoscopy

Stereoscopic images were captured using a single non-stereoscopic camera, moved directly into convergent axes. Verging axis configurations, the intersection of canonical optical configurations created by parallel camera angles, lead to "keystone" distortion resulting from vertical misalignment, and may cause discomfort for the observer.[14] Images obtained at lower angles (5°) had fewer distortions than those in larger displacement (15°).

Similarly, acquisition from the displacement of images in parallel axes causes a deformation called "frustum." This deformation requires that part of the image be omitted to present a common visual field, and then the small portion of the picture that is not common to both photographs is removed.[14] In our study, no specific complaint about the quality of image display was made; however, 4 students in Group 3 (class with stereoscopy) complained of eyestrain.

The images were displayed on an anaglyph system.[45,46,57] The advantages of this system is that it can be displayed with just 1 projector, a metalized screen is not needed, and glasses are passive, requiring no additional technology. The image can be printed or viewed on a common personal computer monitor.[45,46] The drawback is that the color filters may impair the quality of the images;[14,37,45,46] nonetheless, the polarized method using a silver screen produces quality images and better display of all colors. However, polarized or active glasses may also be used, if additional costs are not an issue.

Previous Studies

Trelease and colleagues published a review suggesting the possibility of using QT for viewing anatomical structures.[54] Henn and colleagues were the first to couple QTVR methods with stereoscopy to display cadaver dissections. They used a robotic microscope with operator motion control to acquire anatomical images,[20] and the images were viewed using shutter glasses. However, in addition to being expensive, this methodology is difficult to reproduce worldwide and the acquisition of content in this manner is restrictive.

In 2004, Balogh and coworkers recorded surgical steps through microscopic images obtained using a robotic microscope.[6] The authors discussed the possible superiority of the QTVR stereoscopic format over commonly obtained videos of surgeries and questioned the real benefit of using virtual reality in medical pedagogy.[6] This method involves the application of an expensive technology, and no pedagogic evaluation was carried out.

In 2006, Balogh and colleagues created a volumetric model using a multilayered construction process that allows the user to explore the surgical field in the surgical procedure sequence, without the tactile experience. The authors assume that future refinements of this technology will enable the replacement of anatomical dissections.[5,6]

Our study differs from previous works in many aspects. First, it uses an affordable methodology to generate interactive, immersive, and stereoscopic content that can be easily acquired, customized, and adapted to specific educational purposes. It does not require expensive tools, and it can be applied in lectures or accessed remotely on personal computers by fellows, residents, and students. It can be easily adapted to display contents of other fields, such as neurology, radiology, pathology, etc.

Additionally, this study was specifically designed to evaluate pedagogic effectiveness of interactive stereoscopic virtual reality methods. This method was found to be pedagogically superior when compared with traditional teaching methods ($p < 0.05$). We have found no studies that evaluate the use of stereoscopic virtual tools in teaching microscopic or macroscopic neuroanatomy.

Pedagogic Evaluation

Lamperti et al. created a multimedia teaching resource from 2D photographs of encephalon cuts and dissected structures, which were scanned using Asymetrix multimedia software, composing a computerized atlas and a laboratory manual with a clinical cases section.[27,28] Student performance was not affected by the use of this computer program when compared with conventional teaching methods; however, it allowed the students to follow directions and learn proactively, without the instructor's assistance. Nonetheless, content was not interactive or stereoscopic.

Elizondo-Omaña and coworkers compared a group of students who received traditional instruction using textbooks, laboratory for the study of anatomical specimens, and conventional lectures to a group of students who received the traditional teaching associated with virtual reality laboratory classes.[14] The authors found that the traditional method supplemented by the virtual laboratory is a superior option to the traditional method alone.[14]

Levinson and colleagues evaluated the effects of learning controlled by the student versus controlled by a programmer.[30] When using multiple images or key pictures, better performance was noted when the programmer used key images, leading to the conclusion that multiple images may impair learning.

Our study consisted of multiple images; nonetheless, the sequence of images is interpreted by the brain as a continuum, since it is presented as a nonlinear movie. The multiple images are fused, giving the impression of a single object that can be moved continuously, without interruption, though from different perspectives. Besides allowing the user to visualize the image as a single solid object, the sum of various individual images paired nonlinearly enables the visualization of the structures and their anatomical correlations and allows the user to literally navigate the image during class.

This work also demonstrates that stereoscopy (Group 3) does not add any benefit when compared with the interactive nonstereoscopic group (Group 2). It seems that the capability to virtually "manipulate" the brain, examining with continuity its multiple perspectives and structural relationships, is more important pedagogically than offering the stereoscopic perspective. However, stereoscopy is an important resource to better understand the anatomical relationships rather than improving the memorization of the structure names. Nonetheless, this particular aspect of learning has not been addressed in this study. Another explanation for the lack of advantage of stereoscopy may be related to the anatomical structures being studied (limbic system) rather than to intrinsic limitations of the method.

A new study is under way to examine this issue in a different anatomical data sets.

A gap regarding the application of virtual reality interactive stereoscopic methodology in medical pedagogy remains.[25,26,31–35] We think this methodology may help to fill this gap in combining easy application, immersivity, interactivity, and stereoscopy at affordable costs.

Conclusions

This study presents the process of implementing and evaluating an interactive, photorealistic, and stereoscopic tool for the study and teaching of neuroanatomy. The method presented a significant gain of knowledge and pedagogic yield when compared with the traditional techniques.

Acknowledgments

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Disclosures

Author Contributions

Conception and design: Figueiredo, de Faria. Acquisition of data: Figueiredo, de Faria. Analysis and interpretation of data: Figueiredo, de Faria. Drafting the article: Figueiredo, de Faria, Teixeira, Sousa Júnior. Critically revising the article: all authors. Reviewed submitted version of manuscript: Figueiredo, de Faria, Teixeira, Otoch. Approved the final version of the manuscript on behalf of all authors: Figueiredo. Statistical analysis: de Faria. Administrative/technical/material support: Figueiredo, Teixeira, Sousa Júnior, Otoch. Study supervision: Figueiredo, Otoch.

Supplemental Information

Videos

Video 1. https://vimeo.com/142885661.
Video 2. https://vimeo.com/142885660.

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