Applied Medical Informatics for Neuroanatomy Training

Pablo Ruisoto Palomera
University of Salamanca
Salamanca, Spain of organization
ruisoto@usal.es

Juan A. Juanes Méndez
University of Salamanca
Salamanca, Spain
jajm@usal.es

Paula Mayoral Babiano
University of Salamanca
Salamanca, Spain
paulamb@usal.es

Alberto Prats-Galino
University of Barcelona
Barcelona, Spain
aprats@ub.edu

***Abstract*—In recent years, the efforts to apply developments in medical informatics within training contexts have increased. The objective of this paper is to illustrate the benefits associated to the use of three-dimensional visualization digital systems, in a neuroanatomical training context, and evaluate the satisfaction level and perceived usefulness of these tools by students. The three-dimensional models generated allowed the anatomical interactive study of brain structures and their spatial relationships in a complete, realistic and visually appealing manner for students, regardless of previous visuo-spatial skills.**

***Keywords*—medical informatics; training; evaluation; neuroanatomy.**

I. Introduction

Traditionally, neuroanatomical teaching has been based on the study of bisectional brain sections. For example, using sections from the Visible Human Project (VHP), a benchmark in this field [1][2][3]. However, these types of images only enable a limited brain structure representation of anatomical characteristics and spatial relationships, whose nature is three-dimensional (3D).

A good neuroanatomical knowledge will require the understanding of both morphological details of each brain structure and relationships between them in space. Therefore, this objective is inseparable from the ability to mentally visualize or reconstruct these structures.

In training settings, addressed contents are defined by an irregular structure relationship with a spatial arrangement that is difficult to grasp, and which may have contributed to the fact that learning neuroanatomy has become one of the most difficult tasks in neuroscience. On the one hand, we find individual differences in visuo-spatial skillslevel, or ability to establish and handle spatial relationships by students [4]; and on the other, we find the complexity associated with the cognitive mental reconstruction process [5].

At the same time, the development of diagnostic imaging techniques and of hardware and software for processing increasingly powerful images, have contributed to the widespread use of neuroimaging to study brain structure anatomy under normal and clinical conditions. Nevertheless, its interpretation in terms of anatomical structure location is still a challenge, especially in images of high clinical value, such as Single-Photon Emission Computed Tomography (SPECT) and Positron Emission Tomography (PET).

Medical informatics, along with information and communication technologies (ICTs), offer tools that allow the creative use of computers for medical training, capable of responding to educational needs in disciplines traditionally difficult to understand, like the present one.

The applications developed enable the content and method preparation for a visually appealing and interactive presentation [6-8].

The objectives of this paper are two:

First, show the 3D visualization system possibilities from the development of a visual and interactive digital environment for the study of neuroanatomical structures and the improvement of functional image interpretation.

Second, evaluate the satisfaction level and perceived usefulness of these resources in training settings, and see if there are differences according to the students' previous ability to work with spatial contents

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II. Material and Methods

The study had two parts. Initially, a brain structure 3D visualization system was developed. In a second stage, an empirical study was made aimed to be evaluated in training contexts.

A. Development of a brain structure 3D visualization system and a multimodal registration

First, images were acquired from the VHP database corresponding to brain serial cryo-sections in .jpg format; images acquired through Positron Emission Tomography (PET) in Digital Imaging and Communications in Medicine (DICOM) format; and images acquired through Single-Photon Emission Computed Tomography (SPECT) in DICOM format (Fig. 1).

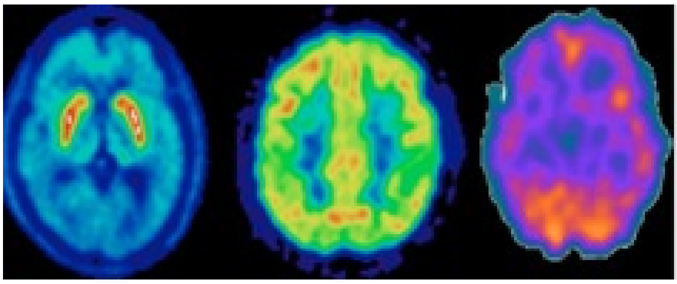

Figure 1. Functional axial images (PET DOPA, left image; PET-FDG, middle image; SPECT, right image). Note the difficulty in identifying brain structures in functional sections.

Second, the brain structure volumetric generation started by using the Amira Version 5.3® Visage Imaging GmbH software for advanced image visualization and manipulation. The procedure was the following:

- *Image segmentation.* Consisted in the bilateral delimitation of regions of interest (ROIs) for each structure, assigning a label to each neuroimage pixel. This segmentation process was very difficult and demanding in terms of time consumption, since it was done individually for each data set and under the supervision of an anatomist.
- *Edge delimitation and labeling*. Subsequently, edges were detected in deep brain structures selected based on shape, size and location. Overall, the faster the change in image intensity is produced, the easier the edge detection. Given that the intensity or edge shift between many deep brain structures is difficult to perceive due to the lack of border clarity, we employ manual segmentation strategies instead of automatic segmentation algorithms. The edge softening did take place automatically through the corresponding Amira® module, based on the average pixels in a region. The ROIs labeling was done by bilaterally identifying the different ROIs with terms like 'lateral ventricle' or 'putamen'. A label field was created for each one of the data sets with a complete list of structures in hierarchical order, each assigned a different color.
- *Surface extraction.* The volume visualization in conventional computers requires a preliminary step which consists in the surface extraction. This step significantly reduced the data load and as a result, the required visualization processing times as well. It included creating intermediate surface representations in polygonal mesh shapes, associated to the selected brain structures. They hold information from which the images will be rendered. In our case, the elements used for surface configuration were triangles (Fig. 2).
- *Rendering*. The volume rendering entailed visualizing the volumetric data from medical images corresponding to different brain structures, applying color and texture.
- *Multimodal registration*. An integration of the obtained volumes was done from VHP original sections in PET and SPECT sections. For this, the ROIs were aligned in three reference planes and transformed, to be able to compare individual data sets corresponding to each image modality. The following landmarks were employed: nasal, in the front and back junction, orbitomedial line and the center of the external auditory canal.

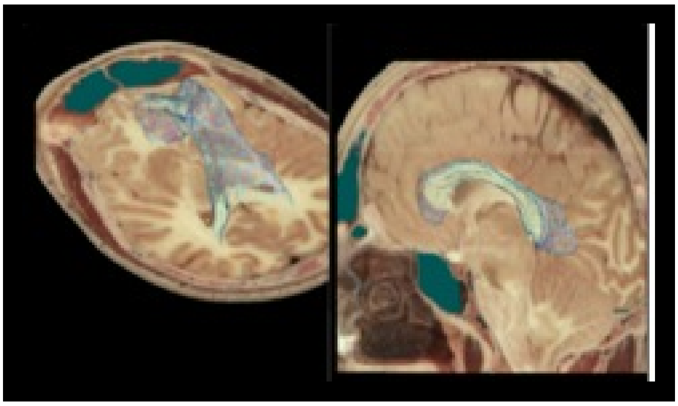

Figure 2. Mesh triangular structure of one of the three-dimensional modeled brain structures. The coronal VHP section is included as reference.

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B. *Empirical study*

Finally, the developed informatics application with training purposes was evaluated.

The participants were 60 final year medical students of both sexes, ages between 23 and 28 years old (M = 24,8; SD = 1.2) and who did not receive any compensation for their participation.

Following an ad libitum examination of the application, being the minimum time used 4 minutes and the maximum 15 minutes (M = 8.9; SD = 3.2), they anonymously answered two tests:

First, a survey comprised of two items that evaluated the satisfaction level with the brain structure 3D visualization system and the estimated perceived usefulness in training contexts. Item #1 stated: "I would recommend using three-dimensional models visualization for neuroanatomy teaching/learning". Item #2 stated: "The three-dimensional models visualization has facilitated the identification/location of brain structures". The participants answered a 5 point Likert type scale: strongly disagree (1), disagree (2), neither agree nor disagree (3), agree (4), and strongly agree (5).

Second, an adaptation of The Surface Development Test by Yela was used via computer (Yela adaptation, 1969)[8], aimed at assessing the visuospatial aptitude level.

The data was analyzed with SPSS (Statistical Package for the Social Sciences), Windows 18.0 version.

III. RESULTS

A. *Brain structure volumetric visualization*

A digital visualization system was developed with teaching purposes which included two main aspects: first, the three-dimensional volumetric generation of multiple brain structures that represent their anatomical characteristics and real spatial relationships; second, the integration of brain structure anatomy three-dimensional models generated in SPECT and PET functional imaging.

The result was a visual, interactive, realistic and complete representation of human neuroanatomy and the improvement of complex functional images obtained from diagnostic imaging techniques. The system developed allows the following features to maximize the interaction opportunities: selection and activation of different structures independently represented, the simultaneous visualization of multiple structures, rotation, translation and zooming, structure clarity and color for the study of anatomical details (Fig. 3-6).

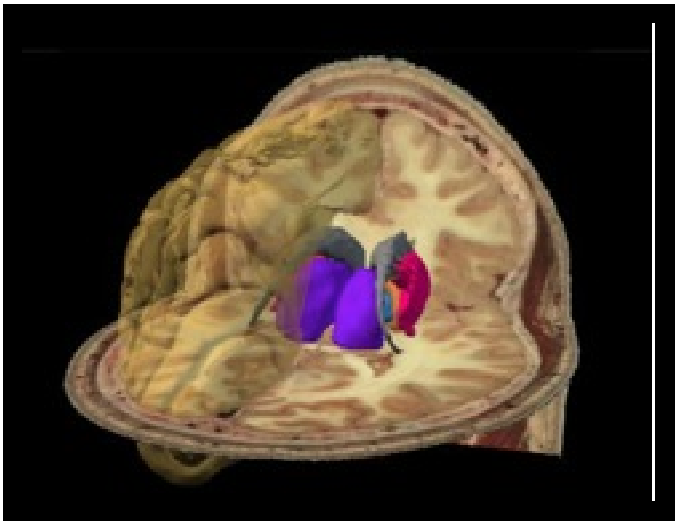

Figure 3. Volumetric generation of embedded brain structures in VHP images. Note the color of each structure independently and the possibility of using transparencies, in this case in the right hemisphere, that facilitate the deep structure visualization.

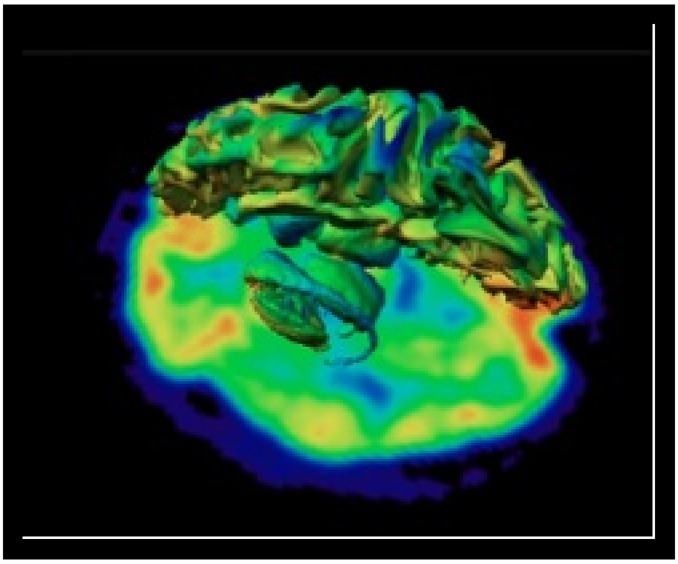

Figure 4. Volumetric embedded brain structure visualization in an axial PET fluorodeoxyglucose (FDG) section. Notice the contribution of three-dimensional models that aid in the interpretation of areas affected by different brain activation levels, improving the complex functional imaging interpretation.

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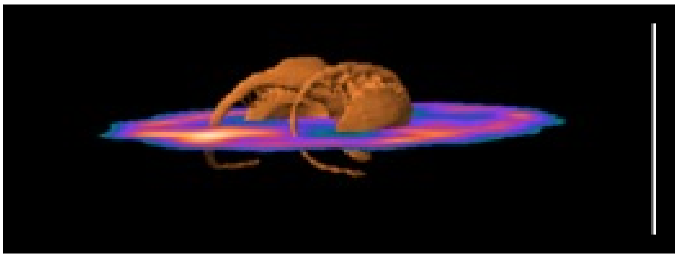

Figure 5. Volumetric embedded brain structure visualization in an axial SPECT section. It shows the difference in camera position in relation to previous images, according to user preferences, which enables exploration of anatomical details from different perspectives and angles.

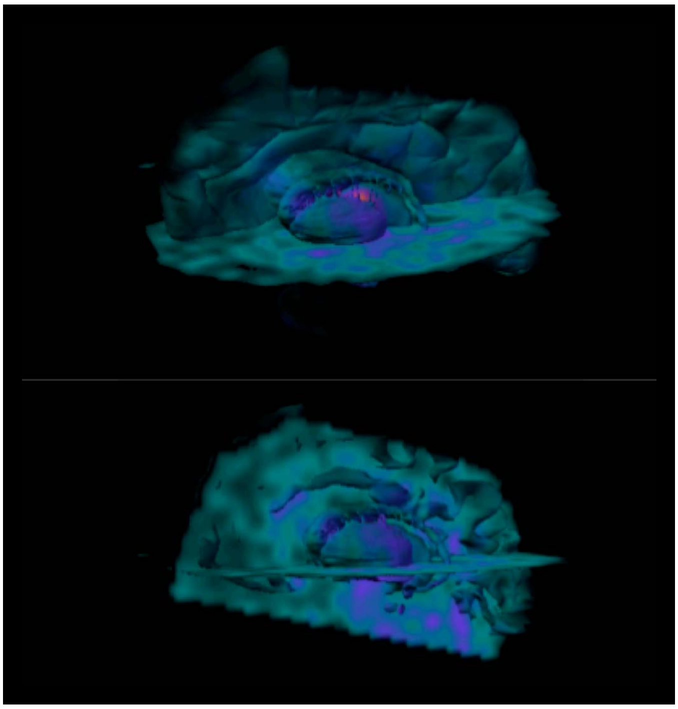

Figure 6. Volumetric embedded deep brain structure visualization in SPECT functional imaging. Note the difference in camera position, one of the basic features that allow interaction with the brain structures.

B. Satisfaction, perceived usefulness and differences according to visuospatial aptitude level.

The survey results in final year medical students reflect a high satisfaction level with the visualization system developed for use in neuroanatomy training.

In the item assessing the satisfaction level or perceived attractiveness regarding the application: 'I would recommend using three-dimensional visualization for teaching/learning in neuroanatomy', the mean score was 4.6; being 5, 'strongly agree'. In the item evaluating perceived usefulness of the developed visualization system in training contexts: 'The three-dimensional model visualization has facilitated the understanding of brain structures', the mean score was 4.3; being 4, 'agree'.

Regarding the possible influence of visuospatial aptitude level in these assessments, there weren't significant differences in satisfaction level, nor in perceived usefulness between the group made up of students with higher visuospatial aptitude level scores (M = 23.11, SD = 3.29) (percentile > 50) and the group made up of students with lower visuospatial aptitude level scores (M = 18.02, SD = 2.86) (percentile < 50).

There weren't any significant differences ($p > 0.05$) in satisfaction level or perceived usefulness of three-dimensional visualization systems according to visuospatial aptitude level. of students who scored above the 50th percentile and low visuospatial aptitude level. In the first item 'I would recommend using three-dimensional visualization for teaching/learning in neuroanatomy' the mean score was 4.6 for high visuospatial aptitude and 4.7 for low visuospatial aptitude. In the second item, 'The three-dimensional model visualization has facilitated the understanding of brain structures', the mean score was 4.4 for high visuospatial aptitude and 4.2 for low visuospatial aptitude.

IV. Discussion

This paper applies the resources offered by medical informatics and ICTs to the development of a visualization system with a training purpose in neuroanatomy. It provides evidence for its appeal and perceived usefulness amongst medical students, not only in those with better visuospatial aptitudes but also in those with greater difficulty in handling spatial relationships, necessary for three-dimensional model visualization and manipulation.

These types of tools allow the cognitive demand reduction associated with brain structure mental reconstruction [12][13] using volumetric representations of the structures [14][15][16].

This paper complements previous studies that have highlighted the importance of 3D visualization systems, which provide more complete, realistic, interactive and visually appealing information than traditional systems. These elements are associated with a higher learning level and long-term retention of contents presented this way [10][11].

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This medical informatics application in neuroanatomy training, directed towards the volumetric visualization system development as the present one, not only offers visually sophisticated images, but also a more complete and efficient vision of brain structure anatomical features [17-19].

For example, medical students that had visual training resources in digital format through computers, scored significantly higher than those who did not have access to the online content in anatomy exams [14], and medical students that accompanied their lectures with a 3D neuroanatomy tutorial also scored significantly higher in the final exam, especially in the most difficult tasks [15].

Incorporating these benefits to neuroanatomy training is a priority for three reasons. First, because it is a basic discipline in the curriculum of any neuroscience professional, and considered their common language; second, because the neuroanatomy knowledge level has fallen drastically in recent years, partly by the lack of opportunities to interact directly with anatomy's real object of study [20-23], and third, given the increasing number of research that uses functional imaging diagnostic techniques that are specially difficult to interpret.

To sum up, the versatility of this type of teaching resources offer the possibility of integrating classical declarative knowledge with real navigation systems that enable summarizing and visualizing information anatomically and functionally, included in serial two-dimensional images [24-27].

In the future, new medical informatics developments and ICTs will enable new and more powerful three-dimensional visualization systems like the one presented in this paper, that is currently defining the basis of modern education.

V. CONCLUSIONS

Brain structure three-dimensional visualization and functional imaging integration within an interactive informatics environment offer a complete and realistic representation of anatomical and spatial characteristics present in multiple brain structures. In a training setting, students showed a high satisfaction level with the application and perceived usefulness for teaching and learning neuroanatomy.

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