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Development of Low-Cost Tactile Neuroanatomy Learning Tools for Students With Visual-Impairment

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Visual impairment is the most common form of disability in the world and results in major challenges to the education and employment of affected individuals. It is important, therefore, to provide the best possible higher education for these individuals, not only providing the same access to theoretical contents but also training them for their future work environment. The reliance of neuroanatomy teaching on visual material creates a set of challenges for educators, a situation that is only worsened by the lack of specific neuroanatomy teaching tools for students with visual impairment. To overcome this problem, a set of tactile tools for neuroanatomy education was prepared using low-cost materials such as hot-melt adhesive, pins and easily found fabrics. These tools were then employed in an undergraduate class of physical therapy, speech therapy and occupational therapy students that included a student with visual impairment. The use of tactile tools allowed full integration of the student, who was able to participate in hands-on classes with her peers. We anticipate that the ease of fabrication and the low cost may allow this experience to be replicated in the instruction of neuroanatomy in undergraduate neuroscience programs at other institutions.

Key words: gross anatomy education; blindness; visual impairment; cooperative learning; inclusive education

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The anatomical sciences have long relied on visual representations of animal structures, from the groundbreaking vivisection works of Vesalius (1543) to the modern virtual humans that can be dissected on a touchscreen table (Fyfe et al., 2013). The study of the nervous system is no exception, with modern classes of neuroanatomy often relying on heavily-illustrated textbooks, anatomy atlases, medical imaging, hands-on classes with cadavers and the analysis of central nervous system sections on the microscope or in digital repositories (Ramos et al., 2008; Grisham, 2009). Although this multitude of visual tools is extremely beneficial for educators and students alike, it can easily exclude students who are visually impaired or blind, since most of the available didactic tools are designed for sighted individuals.

According to the World Health Organization, visual impairment is the most common type of disability in the world (Pascolini and Mariotti, 2012). Although refractive errors and cataract account for the majority of those cases, about 1.4 million people globally 14 years of age or younger are blind (Pascolini and Mariotti, 2012). There is, therefore, a significant number of individuals who will spend their lives unable to take part in sight-dependent activities. In Brazil alone, Salomão et al. (2009) report that 0.41% of children 11-14 years of age are visually impaired despite refractive correction. When this data is crossed with the national demographic census, it indicates that over 70,000 school children had severe uncorrectable sight problems in 2010 (IBGE, 2010).

We sought to develop assistive tactile graphical illustrations and three-dimensional models built from fixed brains that could be used in the classroom to improve learning and integration of students who are visually impaired or blind. It has been reported that individuals who are blind have heightened tactile discrimination (Van Boven et al., 2000; Goldreich and Kanics, 2003, 2006; Wong et al., 2011), and their hand cortical representation allow them better spatial perception through touch (Heller and Gentaz, 2013). Other authors have suggested that tactile material use is beneficial in science classes, with students reporting higher levels of interest when those tools are employed (Jones et al., 2006; Mulloy et al., 2014). Although there is specialized equipment that can create textures, this equipment is often expensive (Mulloy et al., 2014). It is possible, however, to create similar tools using craft materials (Mulloy et al., 2014). In this work, we report the process of development of low-cost tactile tools designed to teach core concepts of neuroanatomy using craft materials.

MATERIALS AND METHODS

We report the development of two sets of tactile materials for neuroanatomy. The first set consisted of pre-existing fixated brains (whole or dissected) that we covered in texture-rich materials. Authorization to perform this work was granted by the Brazilian National Committee for Ethics in Research. The second set consisted of printed electronic drawings showing specific structures and areas onto which we glued texture-rich fabrics.

In the first set, we prepared five fixed human brain specimens by coating the main gross anatomical features including several neocortical hemispheres and one brainstem and cerebellum. All brains used belong to the Department of Anatomy of the Institute of Biomedical Sciences and were donated by the São Paulo Death Verification Service of the Medical School of the University of São Paulo. The brains were fixed using Giacomini's Method (Robson, 1882). The brain stem was cut just below the pyramidal decussation and just above the cerebral peduncles, and the cerebellum was connected to it by all cerebellar peduncles. In this specimen, we placed large

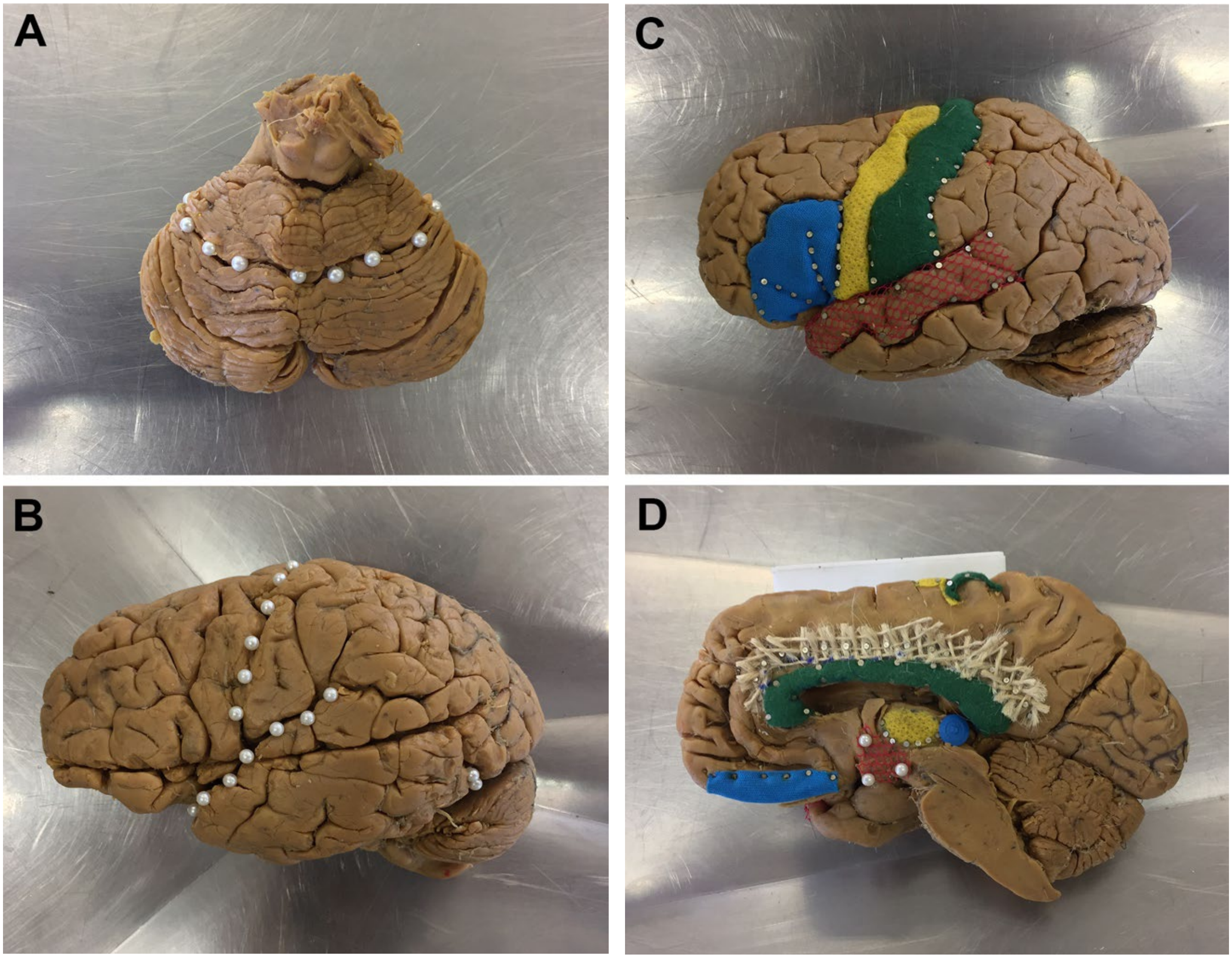

Figure 1. Three-dimensional tactile tools developed and used in class. Pictures of the three-dimensional tools after tactile material assembly were taken with a digital camera. *A)* cerebellum with the primary fissure outlined with pins; *B)* Lateral view of a human brain hemisphere where the main sulci studied are demarked by large head pins; *C)* Another lateral view of a human brain hemisphere with some of its gyri covered by fabric; *D)* Medial view of a human brain hemisphere where several structures are outlined, including the diencephalon, gyri, and the corpus callosum.

head pins along the primary fissure in the anterior surface of the cerebellum and along the posterior fissure in the posterior surface of the cerebellum (Figure 1A). Care was taken to guarantee that the pin head protruded over the level of the surrounding tissue and that the pin was deep enough in the tissue, so it would not move upon light pressure. A similar procedure was performed in a brain hemisphere to outline the central and lateral sulci and the preoccipital notch (Figure 1B). Whereas the sulcus was too deep to allow vertical pin placement, we placed the pin in an angled position in the adjoining gyrus.

The third specimen was a brain hemisphere designed for the study of the main gyri. To coat the hemispheres, thin layers of fabric were cut to size slightly larger than the gyri and were fixed on the brain using small head pins along their whole extension. The pins were placed slightly inclined, anchoring the fabric to the wall of the adjoining gyri (Figure 1C). Fabrics of different colors and textures were used, including velvet, polyester microfiber, non-woven polypropylene fabric, felt, tulle, terry cloth and jute cloth. When possible, the pins protruded slightly over the level of the fabric to indicate the sulcus position relative to the gyrus. The fourth specimen was also a brain hemisphere, but the marked structures were in the medial face. The hypothalamus, thalamus, corpus callosum, cingulate gyrus and straight gyrus were among the structures coated with fabrics (Figure 1D). To hold the fabric over the hypothalamus, we placed three large head pins over the mammillary body, the infundibulum, and the anterior commissure. These pins had the double purpose of holding the fabric and marking these anatomical landmarks. A protruding line of small head pins was placed between the

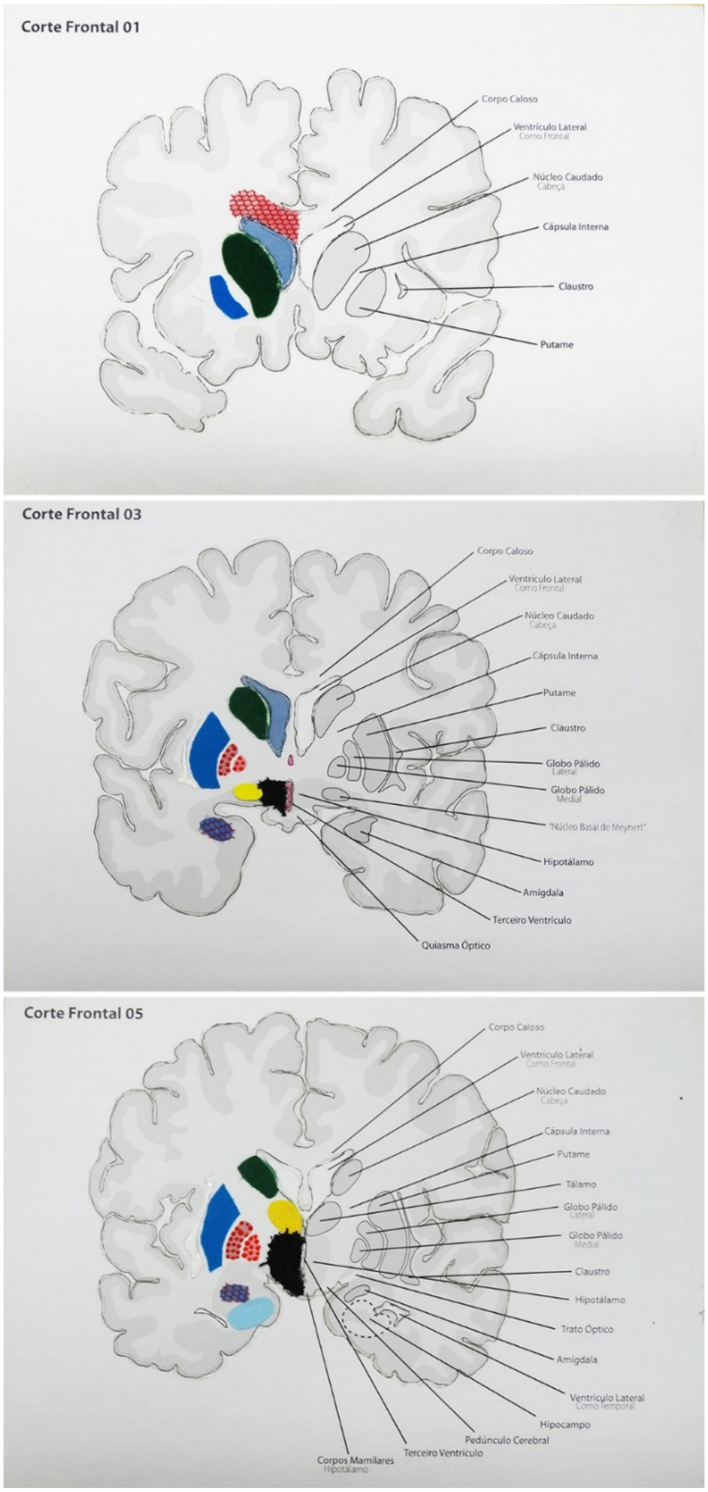

Figure 2. Pictures of the drawings of frontal sections after tactile material assembly. Pictures were taken with a digital camera. Structure labels are in Portuguese because these are the plates used in classroom. English versions of the same plates are available upon request from the authors.

thalamus and the hypothalamus to indicate the sulcus. A flat head pin has been put over the pineal gland to indicate the position of this structure.

The second set consisted of six plates illustrating coronal sections of the brain (Figure 2), three plates illustrating horizontal sections, and another plate illustrating horizontal sections of the spinal cord at different levels (Figure 3). These plates contained only the structures that were part of the class syllabus, to avoid overwhelming the impaired student during her process of creating mental images (Hatwell et al., 2003). To generate the brain illustrations, coronal and horizontal sections were prepared from formaldehyde fixated brains. We cut the whole brains in the frontal or horizontal planes with a sharp knife. We acquired digital photographs from six different rostrocaudal levels and three different dorsoventral levels. The pictures were then opened in Adobe Illustrator CC 2017 (Adobe Systems; San Jose, CA, USA) and we drew the outline of each section. Only structures included in the course syllabus were drawn for the sake of clarity. The illustrations were composed of two parts. On the left side, structures were colored to facilitate the identification and fixation of fabric to the structures. On the right side, the corresponding structures were outlined and labeled. The number of structures labeled varied from six to seventeen in the coronal illustrations and three to twelve in the horizontal illustrations. To prepare the spinal cord illustrations, we photographed myelin-stained human spinal sections under a microscope and repeated the procedure described above.

Once the illustrations were ready, they were printed on A4 paper and fixed on foamcore plates to increase their durability. Hot-melt glue was used on the outer margin of the drawing and around the ventricles to create a tactile margin. Pieces of several types of fabric were cut out with a pair of scissors or a box cutter and glued to the drawings with hot-melt glue. Figure 2 illustrates the tactile coronal drawings and Figure 3 shows the horizontal and spinal cord drawings.

RESULTS AND DISCUSSION

We deployed tactile material in the hands-on laboratory activity that followed all the expositive gross anatomy classes. The class was composed of physical therapy, speech therapy, and occupational therapy undergraduate students. Among the students there was a female individual, age-paired to her peers, who is blind. In each hands-on laboratory, there were prosected specimens of the brain and the rest of the body and stereo-microscopes with myelin-stained spinal cord sections, selected depending on the content of the previous class. Both cadaveric and tactile materials were distributed on steel dissection tables, and the students were divided into groups of up to eight students, including the student who is blind. All groups did turns on the different tables with the tactile materials described above. The student who is blind was allowed to stay as much time as necessary interacting with the tactile materials. All tactile material was also made available in the laboratory for all students to review after class. Following our anatomy laboratory policies, all laboratory users wore latex or nitrile gloves while handling the specimens but remained with bare hands while using books, models, or non-biologic materials. Figure 4 illustrates the student who is blind interacting with the tactile material during the class and highlights the differences in texture among the several brain areas illustrated.

The tactile material was effective in engaging the student who is blind during the hands-on classes. The use of latex gloves did not impair the tactile perception of the student who is blind which is consistant with previous research on the effect of wearing gloves on tactile perceptions (Gibson and Craig, 2005; Thompson and Lambert, 1995; Hatzfeld et al., 2018). The cerebellum specimen allowed her to successfully identify the anterior, posterior and flocculonodular lobes, as well as the primary and posterior fissures. The lateral hemispheres allowed her to determine the overall outer structure of the brain, including the lateral and central sulci, and the precentral, postcentral, inferior frontal and superior temporal gyri. The student identified the main divisions of the diencephalon, anatomical landmarks of the hypothalamus and inter-hemisphere connecting structures in the medial hemisphere. Using the tactile plates, the student could study the anatomical divisions of the central nervous system, the overall shape of the brain when sliced and the relative shape and position of the ventricles, several subcortical structures (e.g., caudate nucleus, putamen nucleus, *globus pallidus*, hippocampus) and the thalamus and hypothalamus.

To evaluate the teaching efficiency of the tactile material, the student who is blind performed theoretical and practical examinations. The decision to include this student in all testing activities was guided by the work of Golub (2006), which describes a higher acceptance by the peers when the same performance is expected from colleagues with visual impairment. For the theoretical component, the examination was applied on a text editor and a text-to-speech software. Care was taken to ensure that no complex formatting elements (such as tables and diagrams) were used in the examination, as assistive software often incorrectly conveys this kind of information. During the practical component, the student was free to explore the anatomical specimen and the tactile drawings. When ready, a member of the teaching

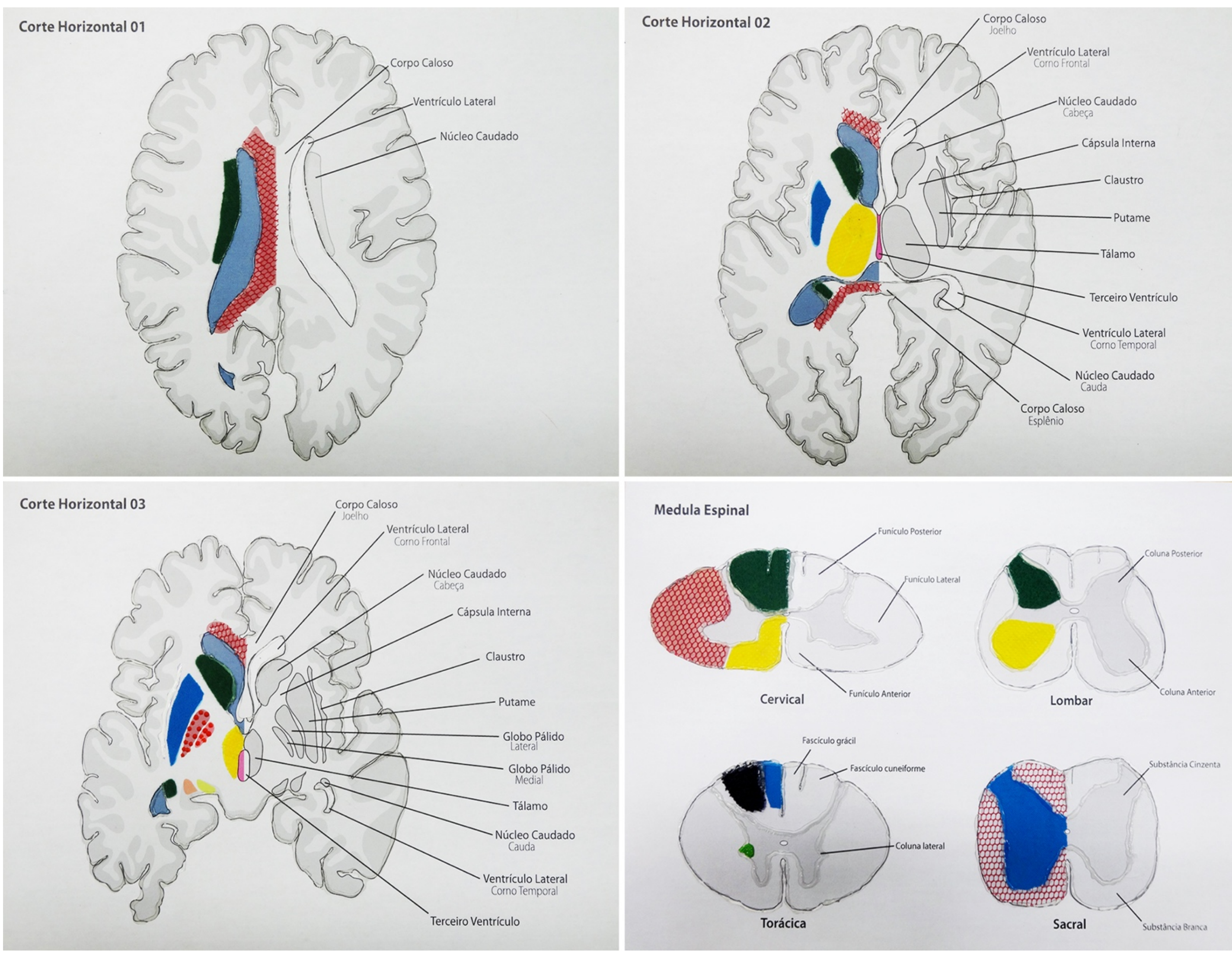

Figure 3. Pictures of the drawings of horizontal sections after tactile material assembly. Pictures were taken with a digital camera. Structure labels are in Portuguese because these are the plates used in classroom. English versions of the same plates are available upon request from the authors.

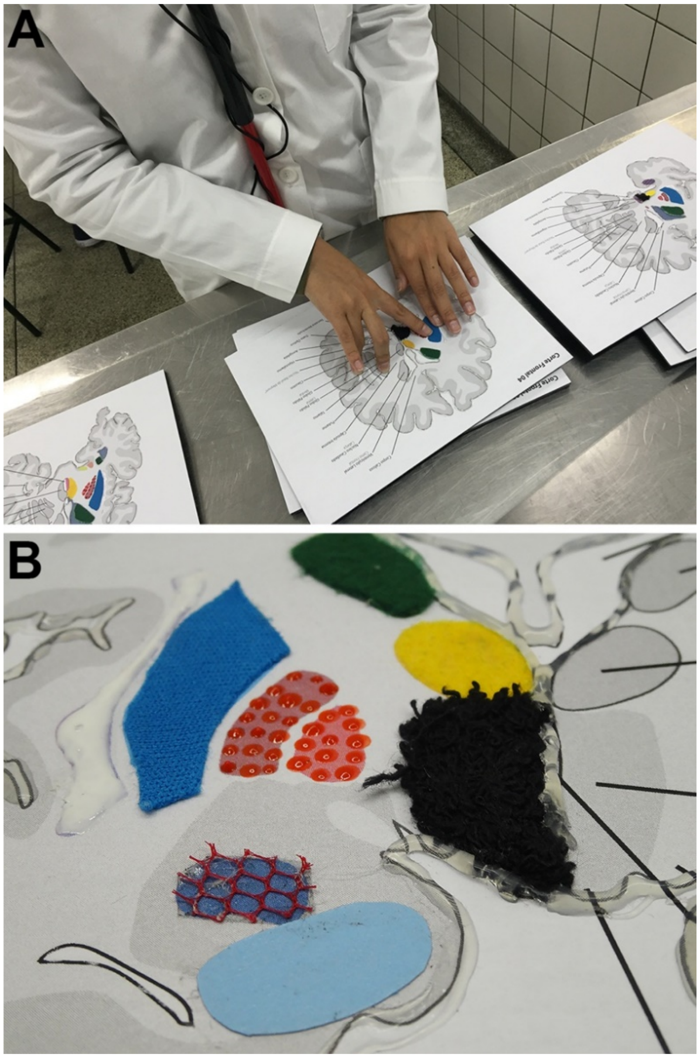

Figure 4. The use of tactile materials in the classroom. Pictures of the tactile materials in the classroom were taken with a digital camera. A) The tactile materials allow for visually impaired and blind students to identify several key subcortical structures; B) Higher zoom of a tactile plate to highlight the differences in composition, roughness, and height.

staff directed the student's finger to the structure being asked, and the student named that structure. The teacher noted the answers and graded the examination along with those of her peers. Her performance was similar to her sighted colleagues. The class mean ± SD score was 6.3 ± 1.7, and the student who is blind attained 6.2, indicating that she was able to acquire a similar amount of content during the class period. This is suggestive that the student was able to create mental images using haptic perception, and later evoke this mental image to correctly answer the exam questions (Hatwell et al., 2003).

An important consideration to be made was the design choice not to make the structure captions available in Braille. During the designing period of the tactile material, we considered two main questions: how effective each specimen would be in communicating the morphological aspects of the structure under study, and how much interaction the student who is blind could have with her classmates during class. As pointed out by Fichten et al (2012) and Golub (2006), colleagues are important facilitators for individuals with disabilities in order to overcome academic and workplace barriers. Furthermore, allied health professionals often must work with people with several types of disability, including partial or complete loss of sight. By directly interacting with the student who is blind during the hands-on class, the other students were able to follow closely how a person who is blind interacts with the world, and in this case, with the tactile neuroanatomy material. Braille captions may be necessary, however, depending on the available time for hands-on class activites and the interpersonal dynamics of the students in the class.

Bryan (1950) has long described that lack of engagement or active learning is a significant problem for students with visual impairment or blindness in biology and related science laboratories. Though some teachers solve this issue with private classes (Womble and Walker, 2001), the current best practice is adaptating the study material in a way that promotes more effective learning (Mastropieri & Scruggs, 1992). With that in mind, schools have implemented the use of 2D and 3D models in biology classes to support the learning of students with visual impairment or blindness (Reynaga-Peña, 2015). Many 2D models for the Blind were developed by American Printing House (n.d.) and are available online for printing. These images do not, however, cover the knowledge taught in neuranatomy classes in higher education.

Another design concern we had during the material development was the overall cost, avoiding the use of embossing printers and 3D printers, which is still inaccessible to many educational institutions in developing or low-income countries (Ishengoma and Mtaho, 2014). In this work, the overall cost of specimen and plates preparation was approximately USD$25, and the only required hardware was a common printer and a hot-melt glue gun. The development of tactile neuroanatomy teaching material as described here, therefore, is virtually universal and can be used regardless of pre-existing infrastructure.

To conclude, highlighted here is the necessity for better tools to teach neuroanatomy to students who are visually impaired or blind. In the experience described in this work, the use of tactile neuroanatomy materials was a successful way to engage a blind student in hands-on class activities and to integrate the student with her peers. We have described an approach to create low-cost, easily-assembled tactile materials that are universally accessible to all students including those with visual disability. We hope these tools can be reproduced and expanded upon in other environments such as in an undergraduate neuroanatomy course. As the number of neuroscience majors continues to grow, educators will need resources and skills to educate diverse student populations, including those with visual impairment.

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