



ACADEMIC
PRESS

Available online at www.sciencedirect.com

SCIENCE @ DIRECT®

NeuroImage

NeuroImage 20 (2003) 50–57

www.elsevier.com/locate/ynimg

The Cerefy Neuroradiology Atlas: a Talairach–Tournoux atlas-based tool for analysis of neuroimages available over the Internet

Wieslaw L. Nowinski* and Dmitry Below

Biomedical Imaging Lab, Institute for Infocomm Research, 21 Heng Mui King Terrace, Singapore 119613.

Received 14 January 2003; revised 24 March 2003; accepted 24 April 2003

Abstract

The article introduces an atlas-assisted method and a tool called the *Cerefy Neuroradiology Atlas* (CNA), available over the Internet for neuroradiology and human brain mapping. The CNA contains an enhanced, extended, and fully segmented and labeled electronic version of the Talairach–Tournoux brain atlas, including parcellated gyri and Brodmann's areas. To our best knowledge, this is the first online, publicly available application with the Talairach–Tournoux atlas. The process of atlas-assisted neuroimage analysis is done in five steps: image data loading, Talairach landmark setting, atlas normalization, image data exploration and analysis, and result saving. Neuroimage analysis is supported by a near-real-time, atlas-to-data warping based on the Talairach transformation. The CNA runs on multiple platforms; is able to process simultaneously multiple anatomical and functional data sets; and provides functions for a rapid atlas-to-data registration, interactive structure labeling and annotating, and mensuration. It is also empowered with several unique features, including interactive atlas warping facilitating fine tuning of atlas-to-data fit, navigation on the triplanar formed by the image data and the atlas, multiple-images-in-one display with interactive atlas–anatomy–function blending, multiple label display, and saving of labeled and annotated image data. The CNA is useful for fast atlas-assisted analysis of neuroimage data sets. It increases accuracy and reduces time in localization analysis of activation regions; facilitates to communicate the information on the interpreted scans from the neuroradiologist to other clinicians and medical students; increases the neuroradiologist's confidence in terms of anatomy and spatial relationships; and serves as a user-friendly, public domain tool for neuroeducation. At present, more than 700 users from five continents have subscribed to the CNA.

© 2003 Elsevier Inc. All rights reserved.

Keywords: Electronic brain atlas; Talairach–Tournoux atlas; Internet; Brain warping; Human brain mapping; Neuroradiology

Introduction

The *Co-Planar Stereotactic Atlas of the Human Brain* by Talairach and Tournoux (1988) is based on the anteroposterior commissural system and contains gross anatomy on axial, coronal, and sagittal sections. The Talairach and Tournoux (TT) atlas has widespread familiarity and utilization, and the associated Talairach transformation is a practical way for normalizing brain images. Developed initially for stereotactic and functional neurosurgery, the TT atlas is widely used in human brain mapping for brain comparison across subjects (Lancaster and Fox, 2000) and the number of references to it has been growing exponentially (Fox et

al., 1998). In addition, the Talairach system is the most frequently used coordinate system in human brain mapping.

Despite its popularity, there is no application accessible publicly over the Internet containing the TT atlas. It is available only in the print version (Talairach and Tournoux, 1988), in electronic form on our three CD-ROMs (Nowinski et al., 1997, 2000, 2003) (distributed by the publisher of the original print atlas) and recently in Mayo's Analyze (however, without the parcellated cortical areas) (<http://www.analyzedirect.com/products/brainatlas.asp>). All these applications contain an electronic version of the TT from our Cerefy brain atlas database.¹ In addition, several image-

* Corresponding author. Fax: +65-6774-8056.

E-mail address: wieslaw@i2r.a-star.edu.sg (W.L. Nowinski).

¹ The electronic Talairach–Tournoux brain atlas along with the other atlases from the Cerefy brain atlas database is copyrighted by our institution and Thieme.

guided surgery companies also employ our electronic TT atlas (Nowinski and Benabid, 2002; Nowinski, 2001). To our best knowledge, the only Internet-based application related to the TT atlas is the Talairach Daemon (Lancaster et al., 2000). It enables the user to generate labels by means of the TT atlas but the atlas images themselves are not available explicitly (probably as the atlas is copyrighted) and the user is not able to display them overlaid on his/her own image data.

Another problem is a lack of electronic brain atlases for neuroradiology despite being prevalent in stereotactic and functional neurosurgery (Nowinski and Benabid, 2002; Nowinski, 2001) and neuroeducation (Hoehne, 1995; Nowinski et al. 2002; Sundsten et al., 1994). We believe that electronic atlases can also make difference in neuroradiology, particularly given the increasing demand for more advanced, economical, and faster processing of scans. The continuous increase in contrast and spatial resolutions of scans will require from the neuroradiologist more advanced knowledge of neuroanatomy. Introduction of new imaging modalities will also increase the difficulty to learn scan interpretation. Consequently, new approaches for speeding up and facilitating the interpretation of brain scans and reducing the learning curve of neuroradiologists are needed. In our opinion, the use of electronic brain atlases may be one of solutions. Neuro-radiologists can potentially benefit of brain atlases by faster scan interpretation, communicating information to other clinicians, increasing confidence, and speeding up learning as discussed in Nowinski (2002).

A Java-based tool introduced here containing a deformable TT atlas may fill both gaps being useful for human brain mapping and neuroradiology. It is called the *Cerefy Neuroradiology Atlas* (CNA) and enables the user to load anatomical and functional neuroimage data, correlate them, and label interactively with subcortical structures and cortical areas (gyri and Brodmann's areas); Brodmann (1909). Image warping for the given Talairach landmarks is near real time, so exploration of images can be done on the fly independently of their number. The anatomical and functional images and the atlas plates are displayed together as a single, blended data set. The user can explore the image data by studying morphology–function and spatial (triplanar) relationships, labeling the data interactively, putting regions of interest and annotations, and saving the atlas-enhanced data.

The CNA is applicable for a rapid atlas-assisted analysis of neuroimages. Its three major applications illustrated here include (1) interactive labeling of morphological images; (2) correlating structural and functional images enhanced by atlas-based labeling and triplanar display; and (3) rapid, atlas-assisted localization analysis of functional images. At present, more than 700 users from five continents have subscribed to the CNA.

Materials and methods

Materials

We have developed an electronic brain atlas database, called the “Cerefy brain atlas database” (Nowinski, 2001, 2002; Nowinski et al., 1997) with multiple, complementary 2D and 3D atlases. It has been derived from the classic brain atlases edited by Thieme. The Cerefy database has been integrated with several image-guided surgery systems (Nowinski, 2001, 2002) and Mayo's Analyze (<http://www.analyzedirect.com/products/brainatlas.asp>) and is also available on our five CD-ROM products.

The Cerefy database contains an extended and enhanced electronic version of the Talairach–Tournoux (TT) brain atlas. The print TT atlas was constructed from a single brain specimen sectioned and photographed sagittally. Coronal and axial sections were subsequently interpolated manually. To construct an electronic version, the original print plates (Fig. 1a) were digitized with high resolution and extensively processed, enhanced, and extended as follows: (i) the original grids, rulers, and annotations were removed; (ii) each atlas structure was assigned a unique color-coded representation, as opposed to a mixture of contour, color-coded, and texture representations in the print atlas; (iii) the left thalamic subnuclei, not available in the print atlas on the axial and coronal plates, were outlined and color coded; (iv) the right hemisphere cortex for axial orientation was added by mirroring the left hemisphere cortex; (v) Brodmann's areas and gyri, labeled but not segmented in the print atlas, were constructed and color coded for axial orientation (Fig. 1b).

Methods

Process of atlas-assisted neuroimage analysis

The process of atlas-assisted analysis of neuroimage data follows the concept (Nowinski and Thirunavuukarasuu, 2001) and is done in five steps as follows: (1) load a scan or multiple (anatomical and functional) scans in DICOM 3 format; (2) set the Talairach landmarks semiautomatically and/or interactively; (3) warp the atlas against the scan(s) automatically; (4) explore, label, and annotate the scan(s); and (5) save the atlas-enhanced scan(s) in DICOM 3 format.

Atlas warping

When the atlas is in register with the scan, the information available in the atlas is mapped onto the scan. Numerous brain warping approaches are proposed, including fully 3D nonlinear methods (Toga, 1998). Despite their theoretical advantages, the nonlinear methods (at present, at least) have several limitations making them impractical, particularly, in a clinical setting. Therefore the speed, simplicity, and feasibility to automate make the Talairach transformation (Talairach and Tournoux, 1988) ideally suited for clinical, low-cost, or Internet-based applications. This transfor-

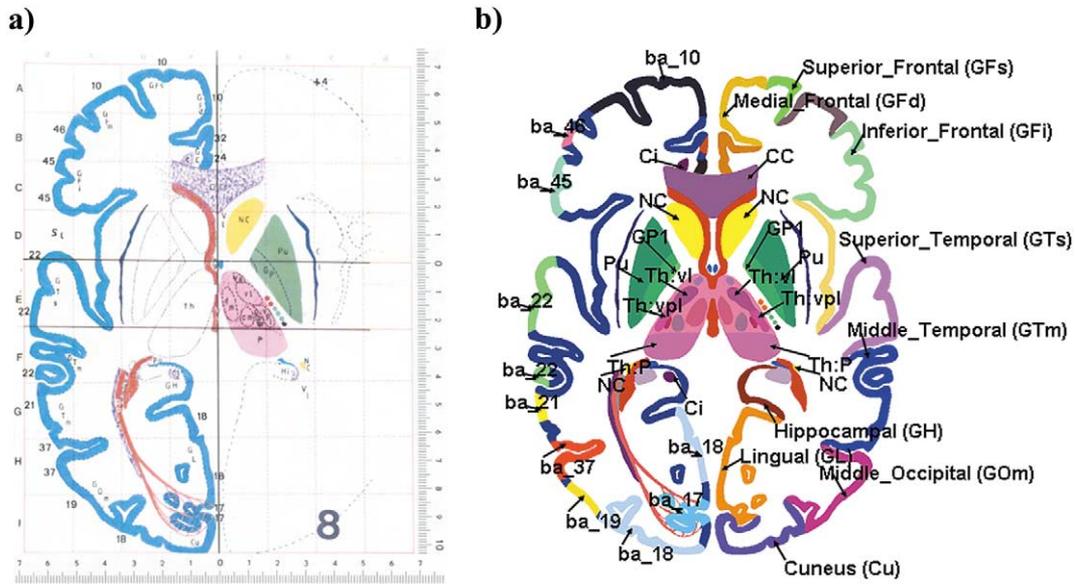


Fig. 1. Electronic Talairach–Tournoux brain atlas: (a) original digitized axial plate; (b) corresponding electronic fully color-coded atlas image labeled with subcortical structures, gyri, and Brodmann’s areas. Note that several subcortical structures not available in the print atlas (for instance, the left thalamic subnuclei or the right lateral ventricle) are included into the electronic atlas.

mation makes use of the following Talairach landmarks: AC, the anterior commissure; PC, the posterior commissure; L(R), the most lateral point of the parietotemporal cortex for the left (right) hemisphere; A, the most anterior point of the frontal cortex; P, the most posterior point of the occipital cortex; S, the most superior point of the parietal cortex; and I, the most inferior point of the temporal cortex. They divide the brain into 12 regions and the Talairach transformation warps the images within each region linearly.

The Talairach landmarks are set interactively on the

anatomical images and the atlas is subsequently normalized. The functional images have to be available in the same orientation and with the same field of view and matrix as the corresponding anatomical images.

Cerefy Neuroradiology Atlas

The *Cerefy Neuroradiology Atlas* (CNA) supporting the process of atlas-assisted neuroimage analysis has been developed as a Java-based application. It can be downloaded from www.cerefy.com along with the encrypted atlas once

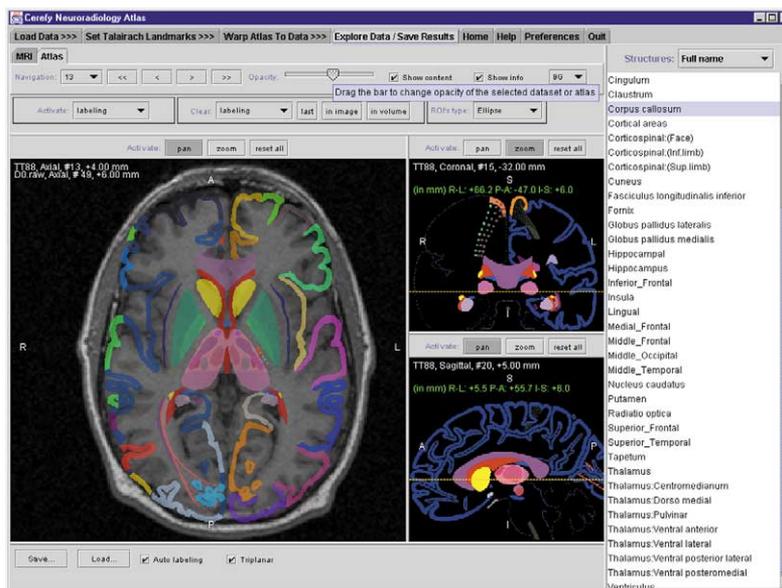


Fig. 2. User interface of the *Cerefy Neuroradiology Atlas* with the triplanar display, anatomical index (right), and control panel (top). For every data set loaded, its own control module is created. For each component of the user interface, a tip is provided explaining its function/use.

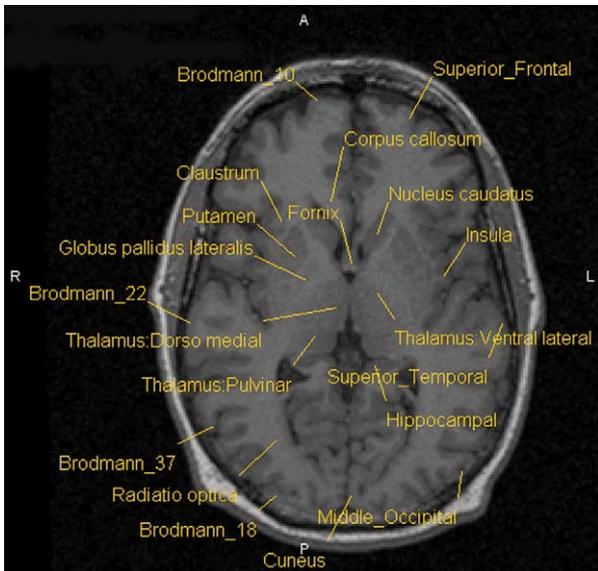


Fig. 3. Interactive labeling of an MRI scan. The neuroradiologist can place a label (composed of a line and name of structure) at any location interactively. The scan is labeled with subcortical structures, gyri, and Brodmann's areas. The labels are generated by the atlas whose display is disabled in order to not obscure the MRI images.

only. Although running the CNA, the Internet connection is necessary initially to login and get the access key to decrypt the atlas, after which the connection can be terminated. In this way, a time-consuming operation of atlas downloading is avoided every time the user starts a session; more important is that the confidentiality of his/her data is assured.

When connected, the user receives automatically the updates from the Cerefy server. We also provide broadcasting capabilities to all or selected users. In addition, on-line feedback and a helpdesk are available on www.cerefy.net

Results

The CNA has been designed, developed, and put on the Internet for public use. It is empowered with multiple windows and numerous tools. Three image windows display the triplanar, i.e., the axial, coronal, and sagittal planes. The control panel provides buttons and sliders for controlling the process of neuroimage analysis and data-atlas navigation, (Fig. 2). In each of three windows, the user is able to label atlas and data images; get coordinates; and pan, zoom, and reset the window. In addition, textual annotations, drawing of rectangular or elliptical regions of interest, and mensuration in millimeters are provided in the main (largest) window. In many operations, atlas-generated labels rather than the atlas itself are needed as the atlas superimposed on the data obscure it. There are two ways to disable the atlas display—by switching it off (turning the “Show content” button for the atlas off) or by setting the atlas to be fully transparent (by dragging its blending slider). The usefulness

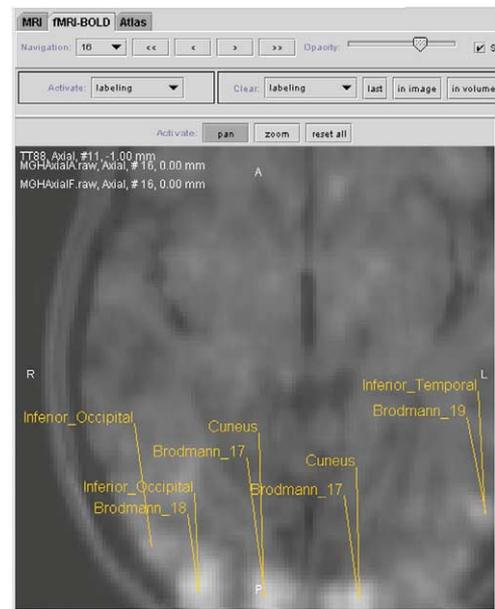


Fig. 4. Localization analysis. The anatomical data (MRI), functional data (generated from fMRI-BOLD time series), and atlas plates (whose display is disabled) are coregistered and displayed as a three-in-one volume. The activated regions are labeled with gyri and Brodmann's areas involved.

of the CNA is illustrated below for (i) interactive labeling of morphological images, (ii) localization analysis in human brain mapping, and (iii) correlating structural and functional images.

One of the most practical clinical applications of the brain atlas, being in register with the scan, is labeling of this

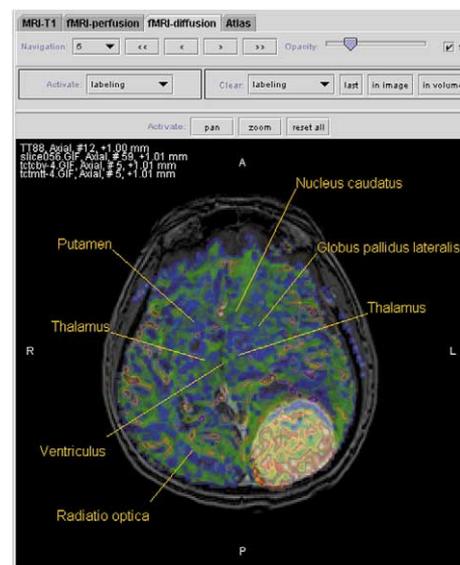


Fig. 5. Fusion of one anatomical data set, two functional data sets, and the atlas (whose display is disabled). An MRI pathological data set is fused with color-coded diffusion and perfusion data sets, and all three data sets and the atlas can be blended interactively. The images are labeled with subcortical structures.

scan as illustrated in Fig. 3. The atlas is warped automatically in near real time (preceded by an interactive placement of the Talairach landmarks) and a T1-weighted MRI with 112 slices can be labeled interactively.

To illustrate the process of localization analysis, we use data from an experiment studying visual spatial attention. An anatomical MRI scan containing 40 T1-weighted axial images, functional data generated from fMRI-BOLD time series with 40 axial images, and the atlas plates are blended as a three-in-one volume. The activation loci are labeled with gyri and Brodmann's areas (Fig. 4).

An example in Fig. 5 illustrates multimodal fusion and display of underlying anatomy for functional images. Four image volumes are fused together in this case, as the application supports (theoretically) an unlimited number of volumes loaded. An MRI scan of 113 T1-weighted images acquired for the whole brain with 1.5-mm slice thickness is fused with two color-coded fMRI diffusion and perfusion data sets acquired in the region of tumor with 7.5-mm slice thickness. The functional images were generated by using GE's Func Tool (General Electric, 1997). The neuroradiologist controls independently blending for each data set, exploring in this way the morphological–functional relationships. In addition, he or she can explore three-dimensional relationships on the triplanar. This approach provides correct morphological–functional relationships. Labeling, especially in the region of tumor, is qualitative only and should be interpreted with caution (see discussion in the next section).

Discussion

When in register with the data, the atlas provides the underlying anatomy as well as enables the user to label interactively any pointed structure. In addition, any location can be annotated with text. The activation regions are displayed along with the atlas, which facilitates the user to ensure that any activation locus is labelable. Otherwise, when the localization of a locus and its labeling are separated, as in "BrainMap" (Fox et al., 1994), the information about the activation region is lost. Consequently, there is no unique solution to the labeling problem when the locus happens to be placed outside the segmented atlas. In this case, some regularization is necessary to label the loci located outside the atlas structures. For instance, "BrainMap" uses the Talairach Daemon (Lancaster et al., 2000), which searches for the cortical area closest to the activation locus, and the label of this cortical area is assigned to the considered locus. Our approach makes no assumptions that may not be valid in a particular case and the user has full control over the placement of the activation locus with respect to the atlas.

The comparison of multimodality scans acquired in different planes is difficult. Any standardization in terms of orientation and reference anatomy would facilitate scan

interpretation. The Talairach system along with the atlas offers a solution. By using the intercommissural (AC-PC) plane as the standard acquisition plane, the comparison of multimodal studies would be greatly facilitated.

The CNA can assist the neuroradiologist in speeding up scan interpretation by rapid labeling of morphological and/or functional scans, displaying underlying anatomy for functional studies, facilitating multimodal fusion, and providing triplanar display with one plane from the scan and the other two from the atlas.

The CNA is also an efficient mean for communicating clinical information. The understanding of underlying anatomy in the scan is easy for a neuroradiologist; however, communicating this knowledge to others may be tedious and time consuming. The CNA is well suited for an efficient transferring of this knowledge to other clinicians, such as neurosurgeons, neurologists, referring physicians, and medical students. For instance, the CNA enables the neuroradiologist to annotate the scan with text, regions of interest, and measured distances and then to interactively label the structures. The annotated and labeled scan can be saved in the DICOM 3 format, giving the neuroradiologist the possibility of storing the atlas-enhanced scan in a PACS. In this way, the scan interpretation done by the neuroradiologist can easily be communicated to other clinicians and medical students. The CNA also increases the confidence of these neuroradiologists who do not interpret brain scans often or radiology residents interpreting brain scans in urgent cases when experienced neuroradiologists are not present. The atlas increases an anatomical confidence by providing anatomy labeling and a spatial confidence by giving triplanar relationships.

The CNA has the following numerous advantages, which make it useful in research and clinical environments.

1. It contains an enhanced, extended, and fully segmented and labeled version of the Talairach–Tournoix atlas, including gyri and Brodmann's areas.
2. It displays atlas simultaneously with (multiple) anatomical and functional data sets with user controlled atlas–structure–function blending. The number of simultaneously loaded and displayed data sets is unlimited theoretically (i.e., limited by the available hardware) and any new data set loaded is provided with its own control panel (i.e., each data set has its own blending slider).
3. It is fast on a standard personal computer. The computational time is less than 5 ss (on a Pentium III, 800 MHz) regardless of the number of images. Atlas warping is near real time, so exploring and labeling numerous images can be done on the fly. In addition, interactive atlas warping enables the user to fine tune the accuracy of atlas-to-data fit in real time.
4. It is multiplatform, i.e., the same Java application runs on Windows, Solaris, Linux, and Mac OS X platforms, which makes this tool affordable.

5. It is user friendly with an intuitive user interface; navigation along with cross-referencing is available on the triplanar. In addition, hints are provided for all components of the user interface and FAQ at www.cerefy.net/FAQ.html.
6. It is powerful, as the CNA provides numerous functions for fast atlas normalization, mensuration of images in millimeters, drawing regions of interest and putting annotations, and simultaneous processing of multiple data sets. It has also several unique features, including interactive warping facilitating fine tuning of atlas-to-data fit, interactive labeling, navigation on the triplanar formed by the scan and the atlas, multiple-images-in-one display with atlas-anatomy-function blending, and saving of the labeled and annotated data set.
7. It is available publicly; additionally, it provides on-line services (at www.cerefy.net), including subscription to the CNA and other applications, free dataset samples, automatic updates, news (broadcasting capabilities), helpdesk, and user feedback facilities.

The CNA has several shortcomings resulting mainly from TT atlas inaccuracy and limitations of the Talairach transformation. The shortcomings of the print TT atlas are well known in terms of images, landmarks, and grid (Nowinski and Thirunavuukarasuu, 2001; Nowinski, 2001), and the Cerefy TT atlas has inherited some of them. The first author had a few discussions with Professors J. Talairach and P. Tournoux about the process of atlas construction. It was a monumental, manual, and tedious process as many technologies and tools we have today were not available then. Consequently, it resulted in some discrepancy between the specimen and the print atlas. The original TT atlas is not consistent in 3D, so labeling of the same structure on different orientations may result in different labels. By putting all atlas plates together in the Talairach space, the differences between the structures at the points of plate intersections are becoming apparent (Nowinski and Thirunavuukarasuu, 2001). Some of them are in the range of 3–5 mm, rising up to 10 mm in a region of the corpus callosum. Our electronic TT atlas is generally different from the print TT atlas due to enhancements and extensions listed in p. 2.1 (the Cerefy atlas database also contains 3D version of the TT atlas which is not included in the CNA (Nowinski, 2002)). For instance, the print atlas does not contain some structures which are added in the Cerefy atlas to improve its 3D consistency (e.g., the pulvinar on the axial slice +1) or extend its content (e.g., the left thalamic subnuclei or the right lateral ventricle; Fig. 1). The atlas images have been continuously corrected and/or enhanced in a long-term editing process.

Brodman's maps, despite their limitations (Zilles et al., 2002), play a dominant role in studying localization of brain function. Brodman's areas in the print TT atlas are merely labeled. Consequently, labeling of Brodman's areas by

means of the print TT atlas is not unique, which hampers the comparison of results produced by various groups. As opposed to the print TT atlas, our electronic Brodman's areas are fully segmented (i.e., they have uniquely defined borders) and labeled.

Brodman's areas available in the print TT atlas did not result from any cytoarchitectonic study, but rather were approximated and extended from the Brodman's print maps. This approximation and the fact that the brains used by Brodman and Talairach varied in size, shape, and sulcal patterns resulted in some discrepancy between them. Brodman's areas in the CNA were adopted from our previously developed products, including *The Electronic Clinical Brain Atlas* (Nowinski et al., 1997) and *Brain Atlas for Functional Imaging* (Nowinski et al., 2000). Electronic Brodman's areas were derived from the Brodman's print maps by a direct transfer of the regions from the TT atlas into the Brodman's maps, supported by some empirical interpolation to fully cover the cortex. This practical solution resulted in a substantial enhancement of the print TT atlas. Recent advances in cerebral architectonics open new avenues in defining cortical architectonics more precisely and robustly based, for instance, on receptor distribution patterns (Zilles et al., 2002) and by applying more sophisticated parcellation techniques such as multivariate statistical analysis (Amunts and Zilles, 2001).

Reformatting of the TT atlas is limited by a relative sparseness of the atlas plates and to perform the atlas-to-data superimposition the data set has to be acquired in parallel or perpendicular to the intercommissural plane. Alternatively, the acquired data set has to be reformatted along the AC–PC plane. The CNA provides no means for data reformatting, as there are many commercial and public domain packages to do that. Several of them have been listed in the user guide (available publicly from www.cerefy.com) of our *Brain Atlas for Functional Imaging* (Nowinski et al., 2000).

To facilitate reformatting, we have been working on an automatic solution. Two patent-pending algorithms have been developed for rapid and automatic detection of the midsagittal plane (Hu and Nowinski, 2002) and identification of the AC and PC landmarks on it (Nowinski and Thirunavuukarasuu, 2000). By combining them, it will be possible to reformat data automatically in the bicommissural orientation within few seconds.

Limitations of the Talairach transformation are well known. As a low degree of freedom method, it is not able to cope with a substantial variability of sulcal patterns (Steinmetz et al., 1989). On the other hand, its accuracy within the subcortical region is comparable with that obtained by nonlinear methods (Grachev et al., 1999). Speed wise, for the identified Talairach landmarks, image normalization takes a fraction of a second, so processing of hundreds of (anatomical and functional) images can be done on the fly as opposed to days required by using nonlinear methods (Nowinski and Thirunavuukarasuu, 2001).

The Talairach transformation in the CNA is not fully automated yet. The identification of the Talairach landmarks is semiautomatic. The user has to specify the AC–PC plane and the Talairach landmarks are attempted to be identified automatically. The above-mentioned algorithms for the identification of the midsagittal plane and the AC and PC landmarks along with the modified Talairach landmarks (Nowinski, 2001) will form the basis for a rapid and automatic Talairach transformation.

The CNA contains a simple help, displays hints for all components of the user interface, and provides a helpdesk and FAQ. Nevertheless, a lack of the user guide may be a hindrance, particularly to the users not familiar with the Talairach landmarks and transformation. These users are referred to our *Brain Atlas for Functional Imaging* (Nowinski et al., 2000), which provides a very detailed user guide along with a preview illustrating setting of the Talairach landmarks and atlas-assisted analysis (this user guide and preview are available publicly from www.cerefy.com). Some difficulty may be encountered by users with a correct placement of the AC and PC landmarks. In (Nowinski, 2001), we have analyzed four definitions of the AC and PC landmarks and proposed their optimal, application-dependent use.

The functionality of the CNA is inferior to our *Brain Atlas for Functional Imaging* (Nowinski et al., 2000). In particular, the CNA does not permit the user to edit the locations of the activation loci in 3D, which is important when coping with atlas inconsistencies across orthogonal orientations. In addition, warping of the data against the atlas is not feasible and the anatomical index is not clickable. The current solution does not deal well with pathology, which is critical for neuroradiology. Our novel approach (Nowinski et al., 2001), segments the tumor and warps the atlas against it rapidly (within 15 s on a standard PC) and, when validated and optimized, it will be included in the next version of the CNA. The CNA provides no tools for metanalysis and building probabilistic atlases over the Internet by communities. We have already developed a solution to this problem for stereotactic and functional neurosurgery (available from the same website) enabling the community to build an electrophysiology-based probabilistic brain atlas over the Internet (Nowinski et al., 2002).

The discrepancy between the material used and its print representation with the resulting shortcomings has not precluded the print TT atlas to become the gold standard, at least in human brain mapping. This reasoning can be extended into an electronic TT atlas. The Cerefy version of the TT atlas is different from the original print materials it was derived from. Contentwise it is much richer and enhanced than the original print material and its contour and image representations facilitate the development of useful tools for atlas warping as well as structure labeling, highlighting, and searching. Therefore, we conclude that this is more beneficial to use an electronic TT atlas, for instance such as ours, as the new, enhanced standard as opposed to the print TT

atlas, at least until a much better brain atlas is introduced and accepted by the community. This is particularly important in metanalysis to adapt and use consistently a common TT reference source that is fully segmented and labeled and is accessible explicitly within a useful tool available publicly to the community.

Acknowledgments

The first author is deeply grateful to Professors Jean Talairach and Pierre Tournoux for several insightful discussions on their atlases.

References

- Amunts, K., Zilles, K., 2001. Advances in cytoarchitectonic mapping of the human cerebral cortex. *Neuroimaging Clin. N. Am.* 11 (2), 151–169.
- Brodman, K., 1960. Vergleichende Lokalisationslehre der Grosshirnrinde in ihren Prinzipien dargestellt auf Grund des Zellenbaues. Barth, Leipzig 1909, in: Some Papers on the Cerebral Cortex, translated as On the Comparative Localization of the Cortex, Thomas, Springfield, IL, pp. 201–230.
- Fox, P.T., Mikiten, S., Davis, G., Lancaster, J.L., 1994. BrainMap: a database of human functional brain mapping, in: Thatcher, R.W., Hallett, M., Zeffiro, T., John, E.R., Huerta, M. (Eds.), *Functional Neuroimaging: Technical Foundations*. Academic Press, San Diego, pp. 95–106.
- Fox, P.T., Parson, L.M., Lancaster, J.L., 1998. Beyond the single study: functional/location metanalysis in cognitive neuroimaging. *Curr. Opin. Neurobiol.* 8, 178–187.
- General Electric, 1997. *FunctTool Operator Manual*. General Electric Company.
- Grachev, D., Berdichevsky, D., Rauch, S.L., Heckers, S., Kennedy, D.N., Caviness, V.S., Alpert, N.M., 1999. A method for assessing the accuracy of intersubject registration of the human brain using anatomic landmarks. *Neuroimage* 9 (2), 250–268.
- Hoehne, K.H., 1995. *VOXEL-MAN, Part 1: Brain and Skull*. Springer-Verlag, Heidelberg.
- Hu, Q.M., Nowinski, W.L., 2002. Method and apparatus for determining symmetry in 2D and 3D images. PCT patent application PCT/SG02/00006, January 2002.
- Lancaster, J.L., Woldorff, M.G., Parsons, L.M., Liotti, M., Freitas, C.S., Rainey, L., Kochunov, P.V., Nickerson, D., Mikiten, S.A., Fox, P.T., 2000. Automated Talairach atlas labels for functional brain mapping. *Hum. Brain Mapp.* 10 (3), 120–131.
- Lancaster, J.L., Fox, P.T., 2000. Talairach space as a tool for intersubject standardization in the brain, in: Bankman, I.N. (Ed.), *Handbook of Medical Imaging, Processing, and Analysis*, Academic Press, San Diego, pp. 555–567.
- Nowinski, W.L., Thirunavuukarasuu, A., Benabid, A.L., 2003. *The Cerefy Clinical Brain Atlas*. Thieme, New York.
- Nowinski, W.L., Benabid, A.L., 2002. New directions in atlas-assisted stereotactic functional neurosurgery, in: Germano, I.M. (Ed.), *Advanced Techniques in Image-Guided Brain and Spine Surgery*, Thieme, New York, pp. 162–174.
- Nowinski, W.L., Thirunavuukarasuu, A., Bryan, R.N., 2002. *The Cerefy Atlas of Brain Anatomy: An Introduction to Reading Radiological Scans for Students, Teachers, and Researchers*. Thieme, New York/Stuttgart.
- Nowinski, W.L., 2002. Electronic brain atlases: features and applications, in: Caramella, D., Bartolozzi, C. (Eds.), *3D Image Processing: Tech-*

- niques and Clinical Applications, Medical Radiology series. Springer-Verlag, New York, pp. 79–93.
- Nowinski, W.L., Belov, D., Benabid, A.L., 2002. A community-centric Internet portal for stereotactic and functional neurosurgery with a probabilistic functional atlas. *Stereotac. Funct. Neurosurg.* 79, 1–12.
- Nowinski, W.L., 2001. Modified Talairach landmarks. *Acta Neurochir.* 143 (10), 1045–1057.
- Nowinski, W.L., Thirunavuukarasuu, A., 2001. Atlas-assisted localization analysis of functional images. *Med. Image Anal.* 5 (3), 207–220.
- Nowinski, W.L., 2001. Computerized brain atlases for surgery of movement disorders. *Semin. Neurosurg.* 12 (2), 183–194.
- Nowinski, W.L., Thirunavuukarasuu, A., Kennedy, D.N., 2000. *Brain Atlas for Functional Imaging: Clinical and Research Applications*. Thieme, New York/Stuttgart.
- Nowinski, W.L., Bryan, R.N., Raghavan, R., 1997. *The Electronic Clinical Brain Atlas: Multiplanar Navigation of the Human Brain*. Thieme, New York/Stuttgart.
- Nowinski, W.L., Fang, A., Nguyen, B.T., Raphel, J.K., Jagannathan, L., Raghavan, R., Bryan, R.N., Miller, G., 1997. Multiple brain atlas database and atlas-based neuroimaging system. *Comput. Aided Surg.* 2 (1), 42–66.
- Nowinski, W.L., Belov, D., Thirunavuukarasuu, A., Yang, Y., 2001. Atlas-assisted interpretation of brain scans in the presence of tumor. Scientific Program, 87th Radiological Society of North America Annual Meeting, Nov 2001, Chicago, IL, USA, Supplement to *Radiology*;221(P):647.
- Nowinski, W.L., Thirunavuukarasuu, A., 2000. Methods and apparatus for processing medical images. PCT patent application PCT/SG00/00185. International Publication Number WO 02/43003A1, 30 May 2002.
- Steinmetz, H., Furst, G., Freund, H.J., 1989. Cerebral cortical localization: application and validation of the proportional grid system in MR imaging. *J. Comput. Assist. Tomogr.* 13 (1), 10–19.
- Sundsten, J.W., Brinkley, J.F., Eno, K., Prothero, J., 1994. *The Digital Anatomist: Interactive Brain Atlas*. CD ROM for the Macintosh, University of Washington, Seattle.
- Talairach, J., Tournoux, P., 1988. *Co-Planar Stereotactic Atlas of the Human Brain*. Thieme, Stuttgart/New York.
- Toga, A.W. (Ed.), 1998. *Brain Warping*. Academic Press, San Diego.
- Zilles, K., Schleicher, A., Palomero-Gallagher, N., Amunts, K., 2002. Quantitative analysis of cyto- and receptor architecture of the human brain, in: Toga, A.W., Mazziotta, J.C. (Eds.), *Brain Mapping: The Methods*, 2nd ed., Academic Press, San Diego, pp. 573–602.
- Zilles, K., Palomero-Gallagher, N., Grefkes, C., Scheperjans, F., Boy, C., Amunts, K., Schleicher, A., 2002. Architectonics of the human cerebral cortex and transmitter receptor fingerprints: reconciling functional neuroanatomy and neurochemistry. *Eur. Neuropsychopharmacol.* 12 (6), 587–599.