

Original Article

BrainMap

The Social Evolution of a Human Brain Mapping Database

Angela R. Laird,* Jack L. Lancaster, and Peter T. Fox

Research Imaging Center, University of Texas Health Science Center, San Antonio, TX 78229

Abstract

Human brain mapping is an experimental discipline that establishes structure–function correspondences in the brain through the combined application of experimental psychology, human neuroscience, and noninvasive neuroimaging. A deep and diverse literature on the functional organization of the human brain is emerging, which has pushed neuroimaging squarely into the scientific mainstream. Because of this rapid growth, there is a great need to effectively collect and synthesize the body of literature in this field. The BrainMap database was created in response to this need as an electronic

environment for modeling the human brain through quantitative meta-analysis of the brain mapping literature. BrainMap was originally conceived in 1987 and has received continuous funding from 1988 to 2004. During this time, BrainMap has consistently evolved to meet the challenges of an ever-changing field and continues to strive toward higher levels of applicability. In this article, we discuss BrainMap's structure and utility, and relate its progress and development as a neuroinformatics tool.

Index Entries: Databases; BrainMap; human brain mapping; functional neuroimaging; neuroinformatics; data entry problem.

Introduction

Human brain mapping (HBM) is an experimental discipline that establishes structure–function correspondences in the human brain through the combined application of experimental psychology, human neuroscience, and noninvasive neuroimaging. The explosion of

research in this multidisciplinary field has led to a large and diverse collection of published studies aimed at mapping neural systems that govern cognition, perception, emotion, and action. In addition to mapping normal functions, noninvasive functional imaging is now used to study the pathophysiology of a wide range of diseases, normal and abnormal development, plasticity

*Author to whom all correspondence and reprint requests should be addressed.

E-mail: lairda@uthscsa.edu

and recovery of function, and pharmacological effects and treatments. Not unexpectedly, functional brain imaging studies are now reported in a host of journals, reflecting a broad range of fields. Despite the diversity of applications and approaches and the complexity of data analysis methods, HBM studies maintain two important commonalities. First, virtually all studies relate mental function to brain locations. Second, the great majority of studies have adopted a common, neuroanatomical terminology by way of reporting activation coordinates (x,y,z) expressed relative to a standardized brain volume, such as the Talairach atlas (Talairach and Tournoux, 1988). Thus, HBM data are uniquely well suited for quantitative meta-analysis and Internet-based data sharing. These standards, in effect, represent a community effort to create a functional-anatomical model of the human brain in terms that allow results from any laboratory and any method to contribute to the collective whole. This commonality of goals makes the creation of a database of human brain function and dysfunction an exciting possibility. In anticipation of this opportunity, scientists at the Research Imaging Center (RIC) at the University of Texas Health Science Center in San Antonio (UTH-SCSA) have spent the past 15 yr developing an electronic environment to support Internet-based sharing and quantitative meta-analysis of HBM data. This environment is the BrainMap database (Fox and Lancaster, 2002).

The Need for a Coordinate-Based Archive

HBM is a large, rapidly growing, highly interdisciplinary research domain, and searching its literature is a time-intensive, laborious task in which errors and omissions are not just possible, but highly probable. The most popular method of searching for studies of interest is to utilize an online indexing service, such as MEDLINE or PubMed, which offers users access to citation information and the published abstract for each entry. However, Because of the complexity and ubiquity of HBM studies,

there is an overwhelming demand for a database that indexes both the content and context of the published literature.

HBM papers began appearing in scientific journals in the middle 1980s. Since then, the rate of publication has steadily risen. To determine the volume of literature in HBM, MEDLINE searches were performed for each year from 1987 to 2002 using the criteria: "Brain Mapping" AND "Human" AND ("fMRI" or "PET") AND "Year" (Fig. 1). However, the retrieved listings include both functional and anatomical studies; BrainMap addresses only functional papers. Of the functional papers, not all publish their Talairach coordinates of activation that are required for inclusion in BrainMap. Thus, the MEDLINE-based estimates need to be corrected downwards. An estimate for this correction was obtained by selecting six categories of functional studies. For each study class, papers were retrieved for all years and all papers were reviewed to determine the fractions that were functional studies following our reporting standards. Fractions were as follows: (1) Stroop tasks (26/31); (2) n -back tasks (28/34); (3) picture naming tasks (20/21); (4) word generation tasks (36/65); (5) mental rotation tasks (14/27); and (6) pain tasks (38/115). In percentages, these ranged from 33% (pain) to 95% (picture naming) with an average value of 67%. This average fraction was used to correct the MEDLINE search numbers. From this, we estimate the total HBM literature following the reporting standards adopted by BrainMap to be approx 2489 papers, currently growing at a rate of approx 500 papers/yr.

As more studies present results establishing structure-function correspondences in the brain, a need has arisen to search the literature not only according to experimental design and methodology, but also by cerebral region of interest. With this goal in mind, BrainMap was designed as an HBM database of Talairach coordinates of activation locations and their

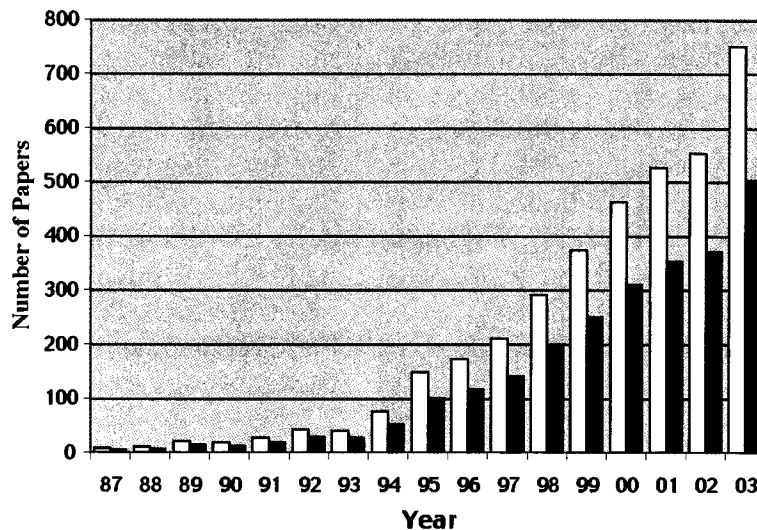


Fig. 1. The human brain mapping literature. Annual publications for all human brain mapping studies (light bars) and for the coordinate-based, functional mapping subset appropriate for BrainMap (dark bars) are shown. The total HBM literature following the reporting standards adopted by BrainMap is estimated to be approx 2489 papers, currently growing at a rate of approx 500 papers/yr.

associated meta-descriptions of data, or meta-data. By archiving coordinate locations, BrainMap differs from another functional neuroimaging database, the fMRI Data Center (fMRIDC), which archives raw fMRI image data. The primary emphasis of the fMRIDC is re-analysis and interpretation of collections of published data sets and using primary data sets for methods development (Van Horn et al., 2001). In contrast, BrainMap was created with the intent that the database be used as a tool to retrieve published studies of interest, and once retrieved, that these studies may be used in planning future experiments, reviewing them to develop new hypotheses, or performing meta-analyses.

The BrainMap Database

BrainMap was originally conceived in 1987 and received funding from the James S. McDonnell Foundation (1988–1990) for development of the first behavioral coding scheme and a HyperCard-based prototype. BrainMap development was funded by the Office of Naval

Research from 1991 to 1992 and by the Montreal-based EJLB Foundation from 1992 to 1996. During this time, the strategy of a centralized database of text and tabular data (not images) accessed via the Internet using a GUI and display graphics stored locally (on the users' computers) was developed. The original metadata coding scheme and entry tools were not sufficiently refined to warrant large-scale data entry. Despite the acknowledged limitations of this implementation of the BrainMap database concept, the original BrainMap attracted more than 1600 subscribers and supported a peak usage of 12,000 sessions per year (1997–1999).

The National Library of Medicine (RO1-LM6858) funded the BrainMap database from June 2000 to May 2003. This funding supported the reconstruction of the interfaces in Java (for cross platform operability), extensive refinements of the BrainMap Coding Scheme, and the development of meta-analysis strategies. BrainMap data have been used in meta-analyses on language (Xiong et al., 2000), speech (Fox et al.,

1997, 2001; Turkeltaub et al., 2002), and the Stroop task (Neumann et al., in press). BrainMap has also been used for development of several new meta-analysis methods such as functional volumes modeling (FVM) (Fox et al., 1997, 2001), activation likelihood estimation (ALE) (Turkeltaub et al., 2002), and replicator dynamics network analysis (RDNA) (Neumann et al., in press). In addition to meta-analysis methods development, BrainMap has been utilized to study intersubject variability (Xiong et al., 2000) and the detection of outliers (Nielsen and Hansen, 2002).

The current version of BrainMap takes advantage of Oracle Corporation's Object-Relational Database Management System served Oracle's Internet Application Server. The object-relational database allows for defining and storing objects into tables and defining specific methods that can run on the object. This feature enables objects to be viewed as a whole entity. Also, the relationship between each object is more clearly defined. The advantage of this feature is that retrieving data from the database is much simpler and quicker, than if we had implemented just a relational database. Interfacing with the database is accomplished via two Java applications, *Submit* and *Search&View*.

A Behavioral Coding Scheme

The field of functional neuroimaging is tremendously complex, from the way the data is acquired to the statistical methods used in analysis, and as such, the metadata about these studies is also complex. Indexing the HBM literature requires a classification scheme that is able to accurately characterize the intent of a study. BrainMap was therefore designed to facilitate searches of published papers according to metadata not found in traditional citation indexing databases. This indexing is guided by the BrainMap coding scheme, which is a concise description system composed chiefly of structured keywords that explain and

categorize experimental methods, including the experimental question addressed, the imaging methods used, the behavioral conditions during which imaging was acquired, and the statistical contrasts performed. The original metadata coding scheme for BrainMap was designed almost 10 yr ago and had been gradually refined and augmented to accommodate research trends. By design, the BrainMap coding scheme allows for the rapid retrieval of each paper through a number of different searches.

To electronically submit to the database, users must first visit the BrainMap website (www.brainmap.org) and download the Java application *Submit*. *Submit* guides the user to input information concerning citation, subjects, experimental design, and most importantly, tables of activation coordinates in spreadsheet format. To create a standardized scheme for coding the volume of literature in HBM, a system of nomenclature for describing studies was implemented. In a typical study, functional images are acquired during different *conditions*, which are the behavioral states during which subjects are presented with a stimulus and are given instructions regarding the appropriate response. Data on two or more conditions are acquired in each study. The contrasts that are generated when comparing conditions are referred to as *experiments*, from which localized maxima of activation are extracted and reported via Talairach coordinates. The most common experimental contrast is between two images acquired in the same subject but under different behavioral conditions. Typically, one condition serves as the activation state and the other as the control. Experiments also include the comparisons of images across different subject groups, sessions (such as before-and-after treatment), and external, nonimaging variables (such as heart rate, response time, or eye movements).

Under the BrainMap coding scheme, each paper is coded according to three levels of information: *Paper*, *Experiment*, and *Location* (Fig. 2). A *Paper* is a set of one or more experiments

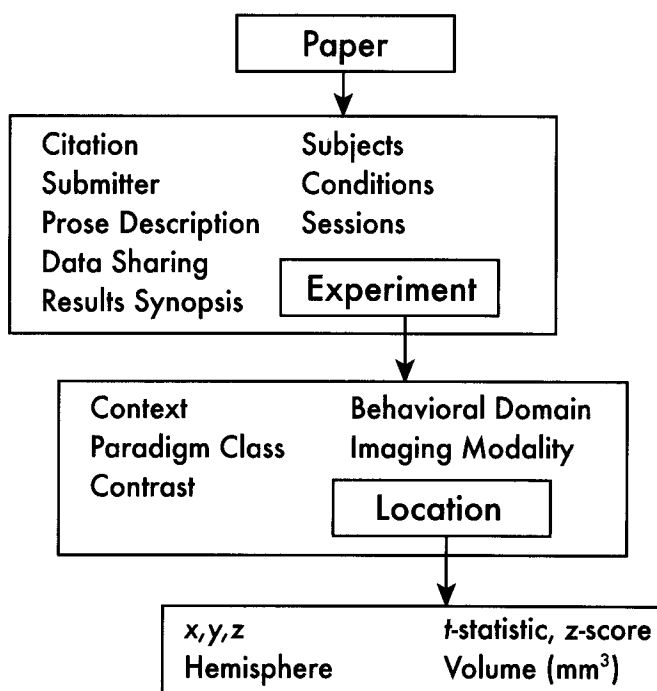


Fig. 2. The BrainMap coding scheme. Each paper is coded according to three levels of information: *Paper* (a set of one or more experiments reported in a single publication), *Experiment* (comparisons or contrasts that are generated when comparing different behavioral conditions), and *Location* (x, y, z -coordinates of activation).

reported in a single publication. At the *Paper* level, the database contains metadata concerning citation, submitter, prose description, data sharing, subject groups, conditions, sessions, and brain template. The next level in the coding scheme, the *Experiment* level, details the experimental context, paradigm class, source of contrast, behavioral domain, and functional imaging modality. The final level of *Location* encompasses the anatomical locations of functional activation as x, y, z coordinates, left or right hemisphere of activation, statistical parameter (t -statistic, z -score), and volume of activation (cubic millimetres).

There are two fields at the *Paper* level that briefly summarize the design and results of each submission and are unique to the BrainMap system of categorizing papers. The first field, the prose description, is a brief synopsis of the conditions and experiments in each

paper and conforms to a highly stylized format. The prose description does not include any information on background, results, or conclusions and must be composed by the submitter. An example of the prose description might be:

Subjects underwent 3 conditions. Condition 1: Naming: subjects viewed pictures and named the objects. Condition 2: Verb Generation: subjects viewed pictures and generated semantically related verbs of the objects. Condition 3: Rest. Experiment 1: Naming vs. Rest. Experiment 2: Verb Generation vs. Rest. Experiment 3: Naming vs. Verb Generation.

This description is extremely useful when searching the database as it immediately conveys the information needed to understand the intent of each paper. While the abstract of a paper often contains this information, reporting it in

