

## Original Article

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### BrainMap

#### *The Social Evolution of a Human Brain Mapping Database*

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#### **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

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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

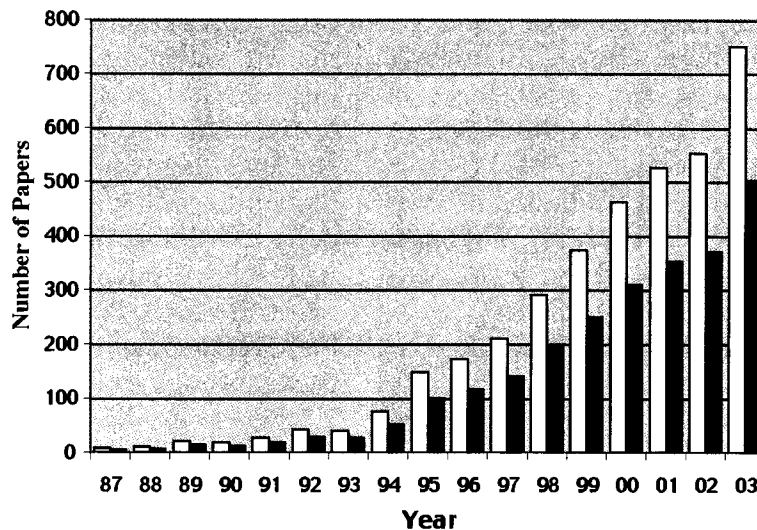


Fig. 1. The human brain mapping literature. Annual publications for all human brain mapping studies (light bars) and for the coordinate-based, functional mapping subset appropriate for BrainMap (dark bars) are shown. The total HBM literature following the reporting standards adopted by BrainMap is estimated 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](http://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

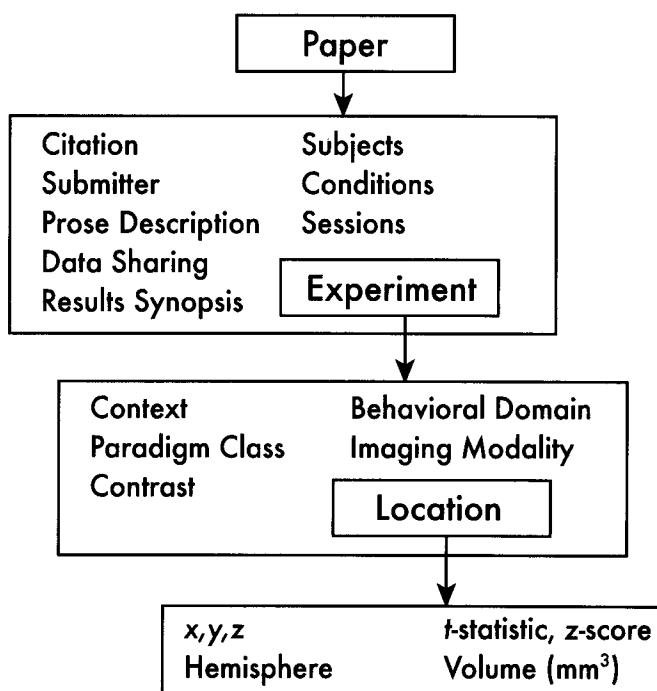


Fig. 2. The BrainMap coding scheme. Each paper is coded according to three levels of information: *Paper* (a set of one or more experiments reported in a single publication), *Experiment* (comparisons or contrasts that are generated when comparing different behavioral conditions), and *Location* ( $x,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

a standardized, consistent format allows the design of a study to be disseminated to the user at a greater speed. The prose description also allows support for publications in which the abstract does not sufficiently express information on conditions or experiments. However, a weakness of the prose description is that, it only takes the design of a study into account, and neglects the overall findings and conclusion. Thus, the second unique field in BrainMap is the results synopsis, which is a shortened version of the published abstract for each submission that only deals with the significance of the results and the conclusions for that paper.

Two high-impact classifications at the *Experiment* level are the paradigm class and behavioral domain. Paradigm class categorizes the challenge of the experiment using field-specific terminology and includes such options as action observation, delayed match to sample, finger tapping, saccades, Stroop task, and word-stem completion. Behavioral domain classifies the mental operations, both conscious and unconscious, isolated by the contrast and is coded by the intent of the experimental design. Behavioral domain is divided into six main categories: cognition, emotion, perception, interoception, action, and pharmacology. Each main category has various subcategories.

### **Searching the BrainMap Database**

*Search&View* is a Java program that was developed to query the database and can be downloaded from the BrainMap website ([www.brainmap.org](http://www.brainmap.org)). BrainMap users are required to apply for a login and password on the website (<http://www.brainmap.org/application/>) so as to access the database. At the main Search&View window, the user is presented with five buttons on the left that open up secondary windows in which search criteria are selected. These buttons relate to different aspects of a study: citation, subjects, conditions, experiments, and locations. Search options can be combined using the logical operators of

“AND,” “OR,” or “NOT” within the secondary window categories, and are combined using “AND” across the primary and secondary window categories (e.g., subject criteria and experiment criteria in their primary windows or stimulus modality and instructions in the secondary window for conditions) (Fig. 3).

Once the search criteria have been correctly selected and the query made, the search results are listed by BrainMap ID, year of publication, first author, and journal name. Users may then download papers of interest into the BrainMap workspace, which contains the complete information about each paper. In the workspace, experiments may be selected for plotting on the BrainMap viewer. Papers are differentiated in the viewer by their color and graphical symbol, and experiments within a paper are numbered accordingly on the plot.

Other features of interest are the Location Report, which lists the Talairach coordinates for a particular coordinate point by experiment, and the Talairach Report, which lists the corresponding anatomical labels for the specified Talairach locations. As mentioned previously, Talairach coordinates are the community standard for specifying locations within the brain. Traditional anatomical terms are imprecise, nonexhaustive “fuzzy sets” that cannot be used uniformly throughout the brain. The widespread use of standardized coordinates in the imaging research community has done much to alleviate the problems associated with imprecise anatomical naming. Nevertheless, traditional terms are widely known and should be preserved and mapped onto coordinates as precisely as possible. To this end, a spatially comprehensive set of neuroanatomical names for the standardized space of Talairach was developed (Lancaster et al., 2000). This naming scheme has been implemented in a high-speed, Internet-accessible database, termed the Talairach Daemon, which has rapidly achieved a very high volume of use by the HBM community. The anatomical labels of the

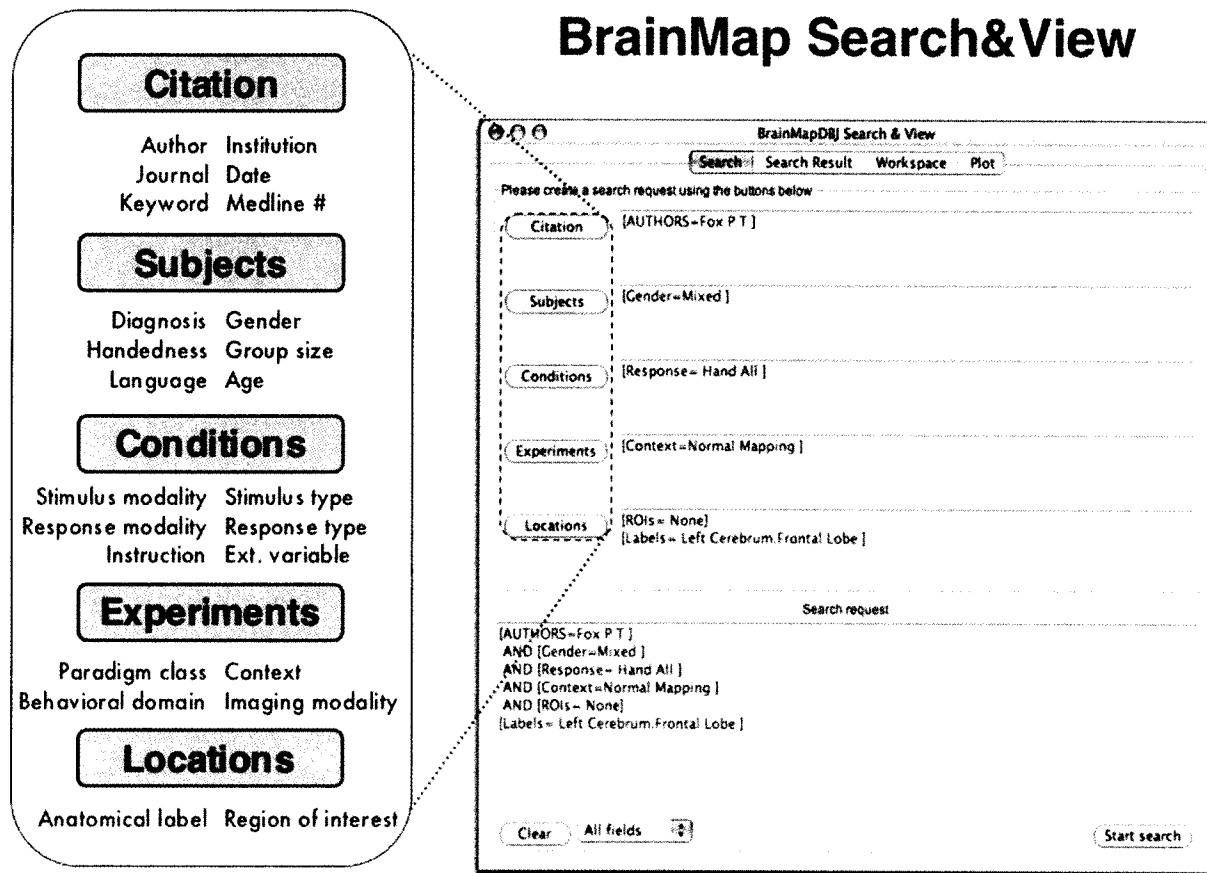


Fig. 3. BrainMap Search&View. Search&View is a software application used to search the BrainMap database ([www.brainmap.org](http://www.brainmap.org)). At the main Search&View window, there are six buttons on the left that open up secondary windows in which search criteria are selected. These buttons relate to different aspects of a study: citation, subjects, conditions, experiments, and locations. BrainMap can also be accessed with a web browser (<http://www.brainmap.org/bmapOnline.html>).

coordinates in the BrainMap database are obtained via the Talairach Daemon and listed in the Talairach Report.

### Status of BrainMap in June 2003

The BrainMap development team released their latest version of the database, "BrainMap DBJ," in June 2003 at the Ninth Annual Meeting of the Organization for Human Brain Mapping (OHBM) in New York city. The DBJ added to BrainMap's name indicated that BrainMap

had become a database (DB) that emulated a journal (J). A BrainMap Editorial Board was established, consisting of 30 scientists from the most prestigious and productive laboratories in the world, to review submissions and guide approved content into the database. Serving as Editors in Chief of BrainMap DBJ were Dr. Peter T. Fox and Dr. Jack L. Lancaster. BrainMap DBJ announced that any HBM study reporting coordinates of activation was eligible for electronic submission to the database by its authors once

the manuscript had been accepted for publication in a peer-reviewed publication.

### **Author-Based Submissions**

Previous to 2003, all BrainMap entries were coded in San Antonio at the RIC. However, because of the rapid growth of the field, it seemed unrealistic to expect that a single laboratory would have the time and manpower necessary to maintain a current, comprehensive database. As such, the database infrastructure was redesigned to facilitate and support author-created entries. The goal of this change in structure was to reduce interpretation errors and allow additional, unpublished data to be entered, such as additional experiments, individual subject data, and postpublication coordinates. The BrainMap development team believed that submission to the database would appeal to many authors who desired to increase the visibility of their results, allow more users to understand a particular paradigm or experimental design, and promote greater familiarity between collaborators. As an added feature designed to facilitate rapid entry to the database, two versions of coding were made available: sparse coding, in which only a portion of fields were required, and full coding. Sparse coding dramatically decreased the time needed to code a paper and it was thought that this method would appeal to authors who were unable to dedicate much time toward entering their papers. It was envisioned that author coding would have higher volume than in-house coding, as a greater work force could be mustered.

### **Supporting NIH's Data-Sharing Policy**

In the February 2003 statement released by the NIH supporting the sharing of final research data between scientific laboratories (NIH, 2003), all applications submitted to the NIH are now required to include a plan for data sharing. Data sharing in HBM will surely result in the advancement of science through the sharing

of ideas and the generation of new hypotheses; however, it presents many obstacles to researchers and is hindered by substantial limitations such as the lack of standards for metadata and data formats (Gardner et al., 2003). It was believed that this new NIH policy would greatly increase the number of author-created submissions to BrainMap DBJ, as participation in this database fulfills the NIH guideline to promote data sharing, without relinquishing authors' rights and control of their raw image data. Critics of the movement to encourage data sharing in HBM have argued that sharing raw individual subject data will compromise the rights and privacy of the subjects. Submitting Talairach coordinates of activation locations extracted from group analysis images to BrainMap eliminates the potential risk of subject identification, for example, by face reconstruction of anatomical magnetic resonance images. However, as an added vehicle to encourage data sharing among proponents of the new policy, BrainMap DBJ submissions were structured in such a way that they included information on whether scientists are willing to share their raw imaging data, to what level of detail, and with whom they would like to share (collaborative or public). In addition, BrainMap DBJ included an option to provide links to public access data-sharing sites.

### **BrainMap's Data Entry Problem**

Because of the interest in and use of BrainMap from 1992 to 2002, it seemed reasonable to database developers that many authors would choose to submit their work to BrainMap DBJ. The BrainMap team believed that while the coding scheme was comprehensive, coding papers was not an overly burdensome task and that after the meeting in June 2003 the author-based submissions would quickly increase. Tools for author coding have been available on the web since late 2002. Also in 2002, the BrainMap Editorial Board committed to having the entire published literature



of their laboratories coded and visits were made by the BrainMap team to 10 of these laboratories giving presentations and soliciting submissions. These talks were well attended and response was outwardly positive. However, despite years of careful planning and the knowledge gained through previous database versions, BrainMap DBJ possessed a single, overwhelming flaw. Reliance on author-initiated coding to populate the database was based on the assumption that authors would possess the motivation and interest necessary for them to sacrifice the time and effort needed to code their own papers.

Author-based coding proved incomplete, error prone, and low in volume. The number of papers submitted to the database that were author-coded between 2002 and 2004 fell far below expectations (21 papers total), and left the BrainMap team with the realization that author-based coding was not a viable logistic for populating the database. BrainMap DBJ fell prey to the universal *data entry problem* (Pittendrigh and Jacobs, 2003). The small amount of entries received was the culmination of repeated requests to the Editorial Board members for submissions. If Board members could not generate interest in BrainMap DBJ within their laboratories, then it seemed unreasonable that other scientists not associated with the BrainMap project would dedicate their time to creating database submissions.

In addition, when the submitted papers were forwarded to the BrainMap Editorial Board, the Editors in Chief found that many members were unable to find the time to review the submissions. It seemed a tedious job for these highly esteemed individuals to, in effect, re-review papers that had already undergone the peer-review process. All mainstream journals, both general audience (Science, Nature, and so on.) and domain specific (Human Brain Mapping, NeuroImage, and so on.), already enforce rigorous standards through the peer-review process. For the Board members willing to

participate, it was found that submission review was inefficient and error prone. Many members of the Board became uninterested in maintaining database procedures and it was soon determined that to survive, BrainMap was in serious need of restructuring.

### **Modifications to BrainMap**

The fMRIDC's partnership with the Journal of Cognitive Neuroscience, which requires database submission in conjunction with publication, is well known in the brain mapping community. However, this type of agreement was not pursued as a method to increase data content in BrainMap as it was anticipated that it could potentially generate negative response and ultimately be ineffective in populating the database. Once it was clear that author coding was not going to be the future of BrainMap, the Editorial Board was dissolved and BrainMap dropped the "DBJ" suffix. In addition, the financial model of requiring subscription fees proposed by Fox and Lancaster (2002) was abandoned, as BrainMap no longer functions as a journal.

### **Changes to the Coding Scheme**

Many authors reported that the coding scheme was *too* comprehensive, and thus too lengthy. Several extraneous categories of information were then dropped from the coding scheme, including software packages for analysis, method of spatial normalization, statistical design type (block, or event-related), and additional statistics on results (percent of signal change, *p*-value, and so on). This extremely detailed information was once deemed necessary to ensure quality control of submissions; however, all journals in HBM now share these requirements for quality control, and the essential filtering of papers is done during the peer-review process for publication. Because of this streamlining of the coding scheme, the option of sparse coding was no longer needed. But while the coding scheme was improved, the

question of data entry remained a major obstacle to BrainMap's success.

### **From Author Coding to Student Coding**

Before it was determined that author-driven submissions would never become a reality, other avenues were pursued as a method for indexing the HBM literature. Through an agreement with local universities in the spring of 2003, 3 h of research internship credit were offered to a premed student at the University of Texas San Antonio (UTSA) and an undergraduate student in the physics department of Trinity University. During the course of the semester, these students were taught the basic imaging techniques used in HBM and were instructed on proper procedure for entering papers into the database. The students were eager to acquire research experience in preparation for their graduate careers and adopted the standards of the database easily. Over the course of the semester, they were able to code 20 papers. Interest in this project spread to other students through word of mouth, and the internship was offered again during the summer of 2003. This time, five students were recruited from a wide range of backgrounds (one undergraduate biology student from Swarthmore College, one graduate student from UTSA's psychology program, two undergraduates in physics at Trinity, and one advanced high school student from a local magnet school). Working only 5 h a week at the RIC, these students coded 56 papers during the summer of 2003. We found that as we became more experienced in teaching novice students how to code, the student's production rate increased. Thus, in the fall of 2003 two psychology students (one undergraduate and one graduate) from UTSA were able to enter a total of 74 papers into the BrainMap database.

In response to the positive feedback from interns during 2003, the BrainMap internship was organized into a formal graduate-level class entitled, "Mind & Brain: Meta-Analysis

in Cognitive Neuroimaging." This interdisciplinary course was first offered at both UTH-SCSA and UTSA in the spring of 2004, with a total of nine students. Its purpose was to introduce students to HBM, have them select a topic of meta-analysis (i.e., working memory, saccades, visual motion, or emotion), and then to code papers on this topic into the database. Once their papers were successfully coded, they would use the coordinates that they had entered to perform a meta-analysis of their topic. The streamlining of the coding scheme in late 2003 seemed to greatly enhance the students' ability to read and code papers. They were no longer confused by the variations in statistical analysis and design from paper to paper, and coding became easier for them as a group. During the spring semester, the students from the meta-analysis course submitted approx 75 papers to the BrainMap database. Experience has shown us that students can learn to code well in about 3 wk; that they enjoy reading the literature with supervision; and that they do not object to coding papers for the database. Because these students are specifically engaged in meta-analysis projects, which use older papers as well as recent papers, this activity is well suited for addressing the backlog of studies not yet coded. Thus, it appears that student coding is an acceptable model for addressing BrainMap's data entry problem.

In addition, the RIC in San Antonio has employed a full-time research assistant to code papers for BrainMap, and she works at a rate of 20 papers a wk. These submissions, combined with papers contributed by the meta-analysis course students, represent the current mechanism for database population. Approximately 350 papers were coded during the spring 2004 semester (January–April). The BrainMap data entry problem has been solved for now by using two in-house coding models (full-time research assistant and university students). The high volume of database submissions now being produced is expected to easily

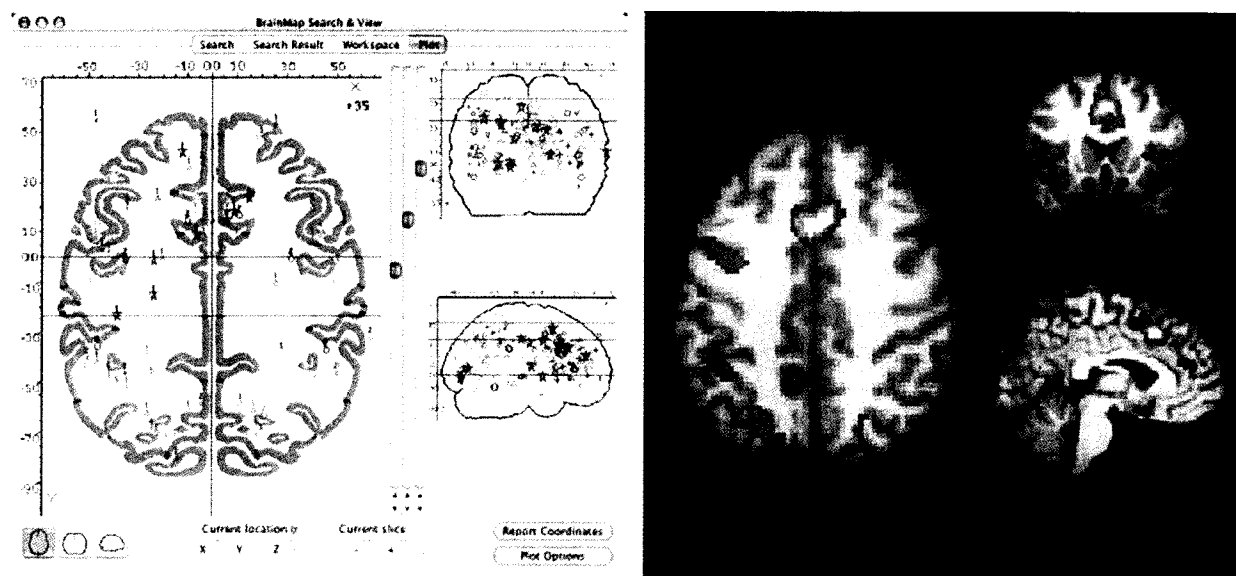


Fig. 4. Progress in meta-analysis research. Raw data for a meta-analysis of the Stroop task in the plot panel of BrainMap Search&View is shown on the left. Results of an ALE meta-analysis (Turkeltaub et al., 2002) of the same data are shown on the right (Laird et al., in press). Currently, Search&View exports raw data in a file format suitable for ALE analysis. Future work on the BrainMap project will incorporate quantitative spatial probability estimation methods such as ALE so that meta-analyses may be performed from beginning to end completely in the BrainMap environment.

maintain the current rate of new publications and also to address the backlog of older publications.

The experience gained during the transition from author coding (BrainMap DBJ) to student coding has been extremely useful in generating interest in meta-analysis, one of the primary objectives of the BrainMap initiative. The recent influx of data for the purpose of meta-analysis has encouraged local growth in utilizing the quantitative meta-analysis method ALE (Turkeltaub et al., 2002) (Fig. 4). The BrainMap faculty and staff are currently interacting with investigators carrying out ALE meta-analyses. Collaborators are: James Bower (UTSA), Edward Bullmore (University of Cambridge), Michael Farrell (University of Melbourne), David Glahn (University of Texas Health Science Center San Antonio), Roger Ingham (University of California Santa Barbara), Jose Pardo (Minneapolis VA Medical Center), Tomas

Paus (Montreal Neurological Institute), Cathy Price (Wellcome Department of Cognitive Neurology), and Li-Hai Tan (University of Hong Kong). These coordinate-based meta-analyses were designed and are being interpreted by the investigator, with the BrainMap staff providing advice and technical assistance (e.g., coding data and computing the meta-analysis results). These meta-analyses will be published in a special issue of Human Brain Mapping devoted to coordinate-based meta-analysis (May 2005).

### Future Evolution of the BrainMap Database

Although in-house coding by the BrainMap research assistant and students in the meta-analysis course has solved the data entry problem, BrainMap will continue to accept author-based submissions. It is envisioned that the author coding will be encouraged by the

future publication of meta-analyses and meta-analysis methods, giving a model that authors can adopt. The expectation would be for authors to submit data that would allow them to carry out a meta-analysis using the BrainMap environment. While this will take time to evolve, it could also provide a large amount of coded studies. There are currently 326 subscribers to BrainMap who query the database in over 6000 sessions/yr. While these numbers do not exceed those of the previous version of BrainMap, it is anticipated that interest in BrainMap will increase as interest in meta-analysis research increases.

In addition to a growth in data, BrainMap is also progressing toward a growth in applicability. Plans are underway to resolve the spatial normalization issues created by using different software packages, such as Analysis of Functional Neuroimages (AFNI) (Cox, 1996) and Statistical Parametric Mapping (SPM) (Penny et al., 2001), which utilize different brain templates. Future *Search&View* versions will incorporate quantitative spatial probability estimation methods such as ALE (Turkeltaub et al., 2002), and RDNA (Neumann et al., in press) so that quantitative meta-analyses may be performed from beginning to end completely in the BrainMap environment.

It is widely agreed that a more complete understanding of the way the brain functions will be gained by examining multiple studies, as opposed to any single investigation. The creators of BrainMap are striving toward this goal and are committed to improving the neuroinformatics tools that will be crucial for dynamic progression in the field of functional neuroimaging.

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