A Knowledge-Based Database System for Visual Rating of fMRI Activation Patterns for Brain Language Networks

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ABSTRACT

This paper describes a novel multimedia tool to facilitate visual assessment of Functional Magnetic Resonance Imaging (fMRI) activation patterns by human experts. A great effort is placed by radiologists and neurologists to present a consistent methodology to provide assessment for brain activation map images. Since each radiologist has his own way to perform the visual analysis on the images and present the findings, rating a large and heterogeneous group of images is a hard task. Although this tool is focused on assessing fMRI activation patterns related to brain language network paradigms, the tool can be extended to other brain activation maps, such as motor, reading, and working memory. Moreover, the same tool can be used for assessing images acquired using different recording modalities as long as these images are saved in standard image formats such as JPEG, BMP, or PNG. The use of this tool is independent of the methodology used to generate the brain activation map, which can be done using specialized software tools such as Statistical Parametric Mapping (SPM) or fMRI Software Library (FSL). The main benefits of using this tool for brain activation image scoring are the systematic approach for rating the activation maps, the automatic descriptive statistics applied to the results and the reduction of assessment time from several minutes to seconds. For each study, the proposed system presents the activation pattern image, based on which the rater is asked to indicate the level and type of activation observed in general, and in specific on the following areas: frontal, temporal, and supplemental motor area.

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Categories and Subject Descriptors

D.2.11 *Software Architectures: Data abstraction, Domain-specific architectures.*

General Terms

Design and Standardization.

Keywords

Brain Activation Map, MRI, FSL, Medical Image Rating, Language Network, Multimedia Scoring Tool, SPM, Rater.

1. INTRODUCTION AND RELATED WORK

Functional Magnetic Resonance Imaging (fMRI) technology enables medical doctors to observe brain activity patterns that represent the execution of subject tasks, both physical and mental. In general, each subject exhibits his own activation pattern for a given task, whose intensity is affected by the physiology of the subject's brain, the usage of medications, and the parameters of the scanner used for image acquisition. Since it is possible to co-register the resulting activation map to a standard brain, all activation patterns from the different individuals can be analyzed in terms of consistency on the brain sections or brain coordinates where the activation is observed. The technology that enables us to observe visually the spatio-temporal behavior of the brain activation during a normal routine is based on the Blood-Oxygen-Level Dependent principle (BOLD) [1, 2]. One of the fundamental elements in the functional neuroimaging research is to track and study the spatio-temporal behavior of the activation pattern during the performance of a controlled task. This requires a team of expert radiologists and/or neurologists to review the activation map images and provide assessment related to the intensity and location of the activation observed. Traditionally, the human expert reviews the images on Radiology Information System (RIS) and Picture Archiving and Communication System (PACS), and after that, the raters write their comments regarding their findings. This procedure will be referred as “the traditional rating method”. The task becomes even more difficult when the rater has no access to the original RIS/PACS and only has access to a 2D image of the brain activation map to rate.

There are several tools that can be used to obtain the activation map out of the raw 4D-datasets (volume and time) obtained using the fMRI technology. The most commonly used tools are Statistic Parametric Map (SPM) [3, 4] and fMRI Software Library (FSL) [5, 6]. These tools allow post-processing the raw datasets to obtain the final brain activation map images which the radiologists can in turn assess.

Within this research mission, this study introduces a novel tool to help the human expert (radiologist/neurologist) to perform the rating task in a fast and systematic manner. The tool interface was written using Visual Basic for Application (VBA) and the assessment results were stored in a Microsoft (MS) Access database.

Research efforts were conducted in the past to assess the spatial relationship observed in medical images. In 1993, Wesley Chu presented the idea of a model for query formulation over clinical information systems including Hospital Information System (HIS), RIS and PACS data, to look for spatial relationship and temporal relationships between objects and events in medical multimedia databases. This work resulted in a knowledge-based multimedia distributed medical database system [7]. Also, a unified approach to handle medical images from different modalities was proposed by Chin Lin et al. in 1998 [8]. This approach introduced the idea of using a web-based interface to access the patient medical records and support telemedicine. In 2001, a web-based telemedicine system was proposed that allows the processing of patient information records using a java platform [9]. This system would do two things: serve as a remote tool to provide consultation between doctors to discuss case studies, and serve as a patient oriented telemedicine system for the health care system. This system included “case submission”, “medical image loading”, “case diagnosis”, “case presentation” and “case consultation” modules. In the same year, Yu Lim proposed a cost effective PACS system with web-based interfaced implemented in Java and Common Gateway Interface (CGI) scripts [10]. This project resulted in a web-based collaborative system for medical image analysis and diagnosis providing a Computer Supported Collaborative Work (CSCW) tool in the medical area. In 2003, Munch et al. proposed a web-based distribution of radiology images integrating medical images from the PACS with medical information from electronic patient record and making them available for consultation in the intranet and the internet [11]. This system was based on the Java Advanced Imaging Application program Interface (JAIAPI).

2. RESEARCH OBJECTIVE

The research objective of this study is to extend these research efforts and propose a multimedia solution that would allow brain activation map image raters to perform their task in a simple, fast and systematic way, while overcoming performance limitations experienced in the past.

Specific aims that were pursued on this paper were:

- Establish an effective multimedia tool to rate fMRI activation map images
- Generate the descriptive statistical results of the distinct activation patterns identified by raters in control and epileptic subjects who performed the auditory description decision task (ADDT) language paradigm.

Thanks to the collaboration of medical experts from 12 different medical institutions, it was possible to design and implement a high performance medical image rating platform, which accomplished these specific aims.

3. METHODOLOGY

The method used in this study consisted of the following steps:

a) Survey the radiologist/neurologist to obtain a consensus about the main features that can effectively be used to rate fMRI activation maps for language networks.

b) Design a database structure to hold the requested information.

c) Design and implement a graphical user interface (GUI) to provide users a reliable and easy to use system configuration with the freedom to define the location of images to be rated and facilitate data entry for faster and more precise image rating.

d) Generate a report that presents the descriptive statistics results.

e) Test the tool with a language network brain activation study with a large population of subjects.

The activation maps for rating were obtained from the web-based repository multi-site of fMRI medical images and clinical data for childhood epilepsy, mri-cate.fiu.edu [12, 13]. A total of 1 sites compose this consortium as shown in Table 1. All sites hold individual IRB approval for the clinical database, and all data stored in the database are de-identified at the acquisition site to preserve patient confidentiality. The activation maps, rated by this tool, were obtained from individuals performing the ADDT language task, where subjects hear a description of an object and the object name and have to decide if they match or not, for instance: “a round object...the moon”. It has been found that this paradigm task is a good probe for receptive language area [14].

Table 1. Medical institutions forming the pediatric multisite consortium

	Institution	Scanner
HSC	Hospital for Sick Children, Toronto , Ca	GE 1.5 T
MCH	Miami Childrens Hospital, Miami,FL, USA	Phillips Intera 1.5 T
CNMC	Children's National Medical Center, Washington,DC	Siemens Trio 3T
BCCH	BC Children Hospital,Vancouver, BC	Siemens Avanto 1.5 T
CHOP	Childrens Hospital of Philadelphia, PA, USA	Siemens Trio 3T
CHOA	Children's Healthcare of Atlanta, Atlanta, GA	Siemens 1.5 T
GOSH	Great Ormond Street Hospital for Children, London, UK	Siemens intera 3T
SLCH	St. Louis Children's Hospita, St Louis, MO	Siemens trio 3T
CMH	Children's Memorial Hospital, Chicago, IL	GE 1.5 T
RCH	Royal Children's Hospital, Melbourne, Australia	Siemens Trio 3T
SRCM	Scottish Rite Children's Medical Center, Atlanta, GA	
CCF	Cleveland Clinical Foundation, Cleveland, OH	

Several researchers have found that the language network can reorganize and move from its canonical locations to distinct ones either in the same or contralateral hemisphere, due to effect of structural or functional lesions of the brain related to seizure disorders (epilepsy) or tumors. This capability of change is known as brain plasticity [15]. Therefore, the proposed knowledge-based database system includes assessing the language network brain activation maps to track and document those observed brain changes related to language network activations. This tool is downloadable free of charge from http://mri-cate.fiu.edu/MAIN.

A total of 14 national and abroad health care institutions have agreed to create a consortium that will allow a fMRI repository to operate. Note that there are different scanners used in these institutions.

4. SYSTEM DESIGN

4.1 Survey

A group of specialists from different hospitals (see Table 1) was surveyed about the main aspect to rate brain activation patterns related to language networks in the brain. As a result of this survey, the features shown in Table 2 were selected and the predefined choices for these feature scores were also established. Figure 1 depicts the 17 different activation patterns expected to be found on the brain activation maps for the language network.

Table 2. Rating features for fMRI activation pattern for language networks and their possible outcomes

Area of Interest	Predefined feature rating
Over all Language Localization	

	◻ Left
	◻ Right
	◻ Bilateral
	  ◻ True bilateral
	  ◻ Bilateral frontal/unilateral temporal
	  ◻ Bilateral temporal/unilateral frontal
	  ◻ Diaschesis (crossed dominance)
	  ◻ Task dependent
	  ◻ Bilateral Frontal Only
	  ◻ Bilateral Temporal only
	◻ Indeterminant
	  ◻ No activation
	  ◻ Movement
	  ◻ Non canonical area

Specific Lobule Localization	
Frontal Temporal	◻ Left ◻ Right ◻ Bilateral ◻ Indeterminant
Specific Areas	
IFG ;MFG;ITG;SFG;SMA TL(MTG /SFG/SMG) CINGULATE; PARIETAL AG	◻ 1 strong left (>80%) ◻ 2 weak left (60-80%) ◻ 3 bilateral (40-60%) ◻ 4 weak right (60-80%) ◻ 5 strong right (>80%)
Lessions Language Areas	
	◻ 100% eloquent area ◻ 50% eloquent area ◻ Minor portion eloquent area ◻ none
Confidance Rating strength	
	◻ 1 strong ◻ 2 ◻ 3 ◻ 4 ◻ 5 weak

Table 2 shows the structure of the interest areas and expected out coming to be identified by the clinical raters on reviewing brain activation map images. First, a general assessment of the spatial activation is given. Then, the frontal and temporal regions are rated in general. A more detailed analysis is done over the Inferior and Superior Frontal Gyrus (SFG), Medium Frontal Gyrus (MFG), Inferior Frontal Gyrus (IFG), and Temporal Lobes (TL). The assessment also includes the Cingulate and the Parietal Anterior Gyrus, each of this brain areas are assessed based on the intensity and laterality of their activation. A search for presence of lesions on the Language Area is also reported, as well as the confidence strength of the rating in their evaluation.

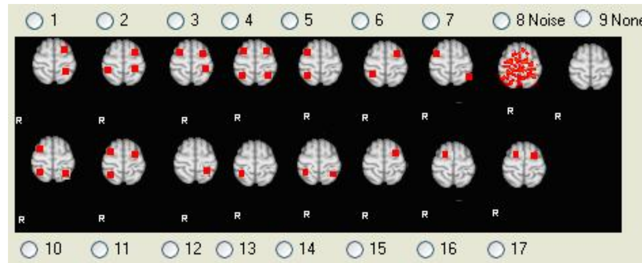


Figure 1. Clinic general patterns as suggested by expert raters.

4.2 Database Design and ODBM Selection

The database design was divided into two stages. First, a conceptual design was defined, which has the purpose of mapping the real world information provided by the human experts into conceptual blocks. The major objective of the conceptual design model was to integrate the different pieces of information coming from the medical experts into a consistent model, in which entities and relationships are explicitly declared resulting in a system data dictionary, as depicted in Figure 2.

In the second stage, an implementation design was accomplished to create the tables holding the information revealed on the conceptual design, which lists the actual tables needed to hold the information defined in the conceptual design. Figures 3 and 4 depict respectively the table structures and the relationships defined in the database design. Microsoft (MS) Access was the database management system chosen to implement the data structures. The main reason for this selection was to use a widely distributed platform that provides easy to setup multimedia support.

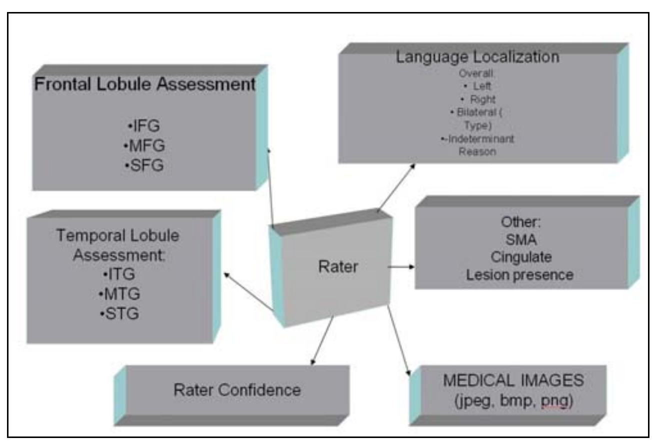
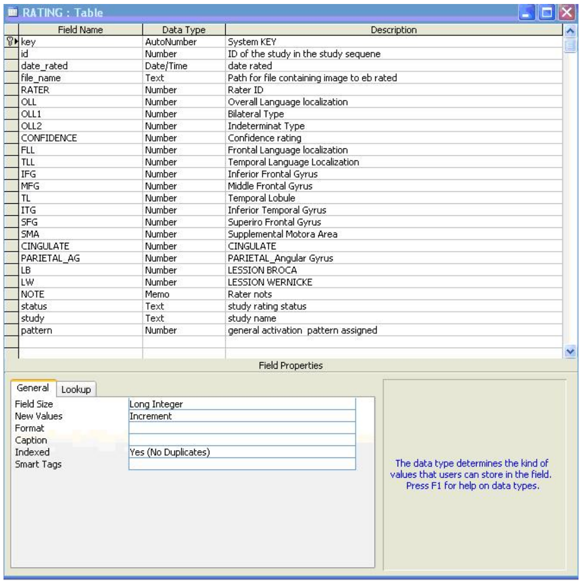
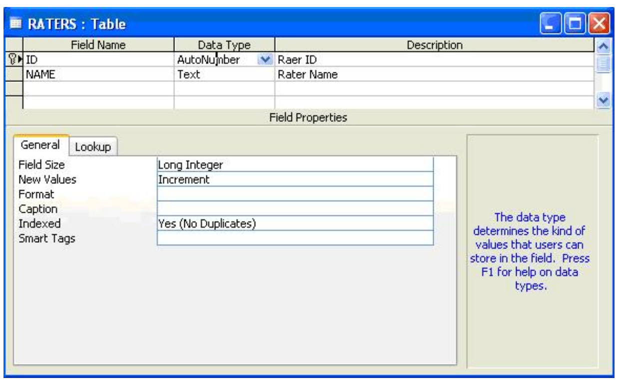


Figure 2. Conceptual design for multimedia rating tool for language networks.



Field Name	Data Type	Description
key	AutoNumber	System KEY
id	Number	ID of the study in the study sequene
date_rated	Date/Time	date rated
file_name	Text	Path for file containing image to eb rated
RATER	Number	Rater ID
OLL	Number	Overall Language localization
OLL1	Number	Bilateral Type
OLL2	Number	Indeterminat Type
CONFIDENCE	Number	Confidence rating
FLL	Number	Frontal Language localization
TLL	Number	Temporal Language Localization
IFG	Number	Inferior Frontal Gyrus
MFG	Number	Middle Frontal Gyrus
TL	Number	Temporal Lobule
ITG	Number	Inferior Temporal Gyrus
SFG	Number	Superiro Frontal Gyrus
SMA	Number	Supplemental Motora Area
CINGULATE	Number	CINGULATE
PARIETAL_AG	Number	PARIETAL_Angular Gyrus
LB	Number	LESSION BROCA
LW	Number	LESSION WERNICKE
NOTE	Memo	Rater nots
status	Text	study rating status
study	Text	study name
pattern	Number	general activation pattern assigned

(a)



Field Name	Data Type	Description
ID	AutoNumber	Raer ID
NAME	Text	Rater Name

(b)

Figure 3. Structure of the rating tables: (a) Image rating, (b) Rater identification.

5. SYSTEM IMPLEMENTATION

5.1 Graphical User Interface of the Multimedia Rating Tool

The GUI was designed in such a way that allows a user to quickly define the set of images to rate, to scroll among image records, and to find a recording in a methodological way making use of predefined scales. It also allows for a general assessment of the image as well as a specific assessment of particular areas, indicating the level of certainty of the rater on his rating. Furthermore, the GUI provides flexibility to record rater notes. The tool is also capable of recording scores for multiple raters and reporting the corresponding descriptive statistics of the findings observed. Moreover, the raters can perform their scoring operations on a shared version of the database or they can perform their rating on individual subsets to be consolidated later via database synchronization. Two interrelated components of the GUI were designed: the first component allows the system configuration to provide the following functions: image path import (both at file level or folder level); individual name definition for each study, deletion of study, and descriptive statistics report generation. The second component takes charge of the actual rating, allowing the user to input and store the observed feature description of the images. For a fast implementation, Visual Basic for Application (VBA) was selected as the programming language to be used.

Generally, it is necessary to transform the medical image generated by the post-processing software into a standard image format. The typical output formats for the activation maps are DICOM, NIFTI and ANALYZE. The images of the activation maps obtained for rating must be saved in a standard image format such as JPG, PNG, or BMP in a user-defined folder. The tool does not require keeping all the images in the same folder, although it is easier to import all the images from the same location at once than browsing for each image from distinct locations. However, the system was designed to perform both operations.

5.2 Descriptive Statistic report

The ultimate output of the system is a descriptive statistics report of the findings on the scoring on the image population. This report was designed to take into consideration each feature shown in Table 2, and also to calculate the counting of subjects exhibiting specific findings and corresponding percentages. The report generates a pie diagram for the distribution of findings for each feature during the assessment of the brain activation map.

6. RESULTS

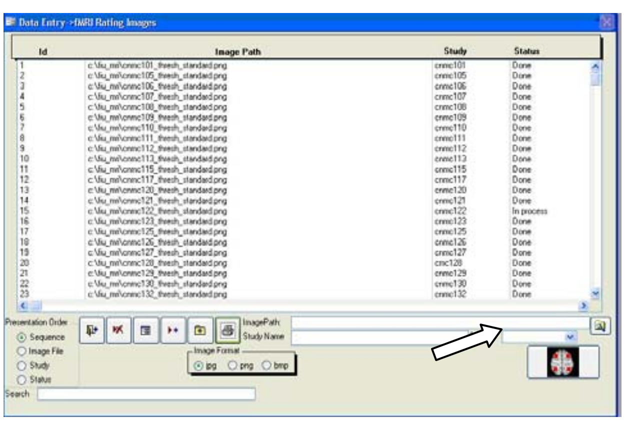
Essentially, the rating tool consists of a database application with a multimedia GUI that allows the user to define the images to be rated and then mark the features observed on each of the displayed images. As the user navigates through the records, the corresponding image is presented. Using a field to serve as a pointer to the image path and a multimedia object, the associated activation patterns are displayed and the rater can select his assessment in the features. Figure 4 shows a snapshot of the two components of the GUI that were implemented.

From the configuration component of the GUI, the user can delete studies, add subjects at the individual level or study level, and import all subjects' brain activation map images from a folder at once. During the subject uploading process, the system can search for specific image formats that are pre-selected by the user such as JPG, PNG, and BMP. From this GUI component, the final report with descriptive statistics of the results can be generated. There is also a button to access the rating, as illustrated in Figure 4 (a).

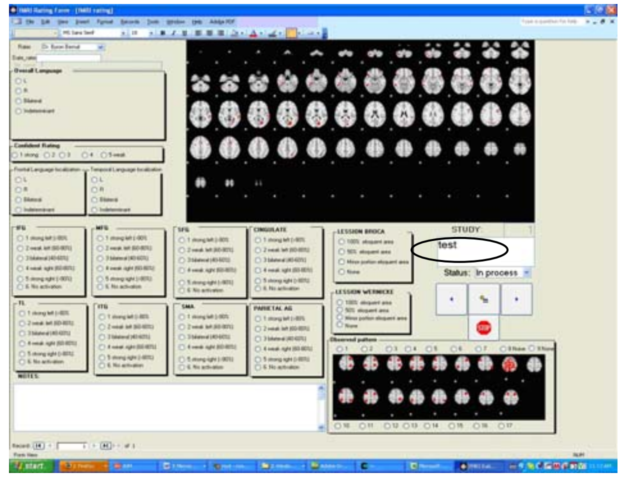
Figure 4 (b) depicts the rating GUI form. This form allows the user to define the rater id, to declare the level of confidence in the rating, and to systematically assess the features of interest that are observable on the activation map image displayed. While scrolling the different images, the rater can type comments related to its observations. After a rater finalizes his assessment on a given image, the rater might mark the status field of the record as "done" to help keep track of the studies already reviewed. In case this operation is not performed, the record status is kept as "In progress", as depicted in Figure 4 (b).

A total of 113 activation map images taken from the repository mri-cate.fiu.edu were rated by a brain radiology specialist from Miami Children Hospital using the proposed tool. Based on the expert experience, the process to rate a single activation map varies from 3 to 5 minutes using a regular Excel spreadsheet to record the findings. It was found that each institution used its own mechanism to record the ratings. The tool automatically saves the date and time when a record is saved and, based on that information; some statistical analysis is performed to identify the mean time and standard deviation of the rating time. The rating was done in 5 different sessions, and since the system records only the time of saving, there was no reference to assess the duration of 5 of the ratings. The average rating time recorded was 59 seconds, with a standard deviation of 16 seconds. Minimum and maximum rating times were 24 and 132 seconds, respectively. As compared to an average of 4 minutes as traditionally required by experienced radiologists to rate an activation map image, this system might present a reduction up to 25% of the average rating time claimed by the specialists, This is a considerable achievement taking in consideration that an average study involves the rating of over a hundred images by multiple raters. It was also noted by the clinicians that many times the rater needs to revisit the image and adjust the rating even when the specific image had already been rated. This revisiting process was not considered in the timing analysis presented here.

The first page of the descriptive statistics report for the 113 images is shown in Figure 5. This report is generated from the configuration component of the GUI and summarizes the assessment on all the images of the study. For each feature scored, it counts how many studies present similar characteristics, as well as the percentage represented by them in the whole population that is analyzed. The report is generated for each of the raters in the system. At this moment, no inter-observer analysis is performed.



(a)



(b)

Figure 4. GUI snapshots: (a) GUI configuration component to import images, editing, and reporting descriptive statistics, with an arrow showing the button to access the rating GUI. (b) GUI image rating component for medical image rating using a systematic approach (for better observation by the reader, the case status is marked with an ellipse) .

7. CONCLUSIONS

This research has described a novel multimedia tool for the assessment of fMRI brain activation maps. The tool provides a fast and systematic approach to rate images as opposed to the traditional approach that is time consuming and costly, and at the same time subjective since it relies on the human rater expertise for feature selection and assessment, which can change from rater to rater. An improvement of up to 75% in rating speed over "the traditional rating method" was reached.

The tool has been also carefully designed and implemented for easy to use, while keeping fully operational its intended functionalities. This user friendly interface provides physicians additional means for software selection, user-system interaction with considerable time saving and rating efficiency.

An extension of this rating tool would consider the inclusion of Kappa statistics analysis, where not only the descriptive statistics results for each rater are presented, but also the inter-observer agreement statistical significance would be evaluated via the Kappa coefficient.

This innovative tool has been welcomed by the rater experts who have used it thus far.

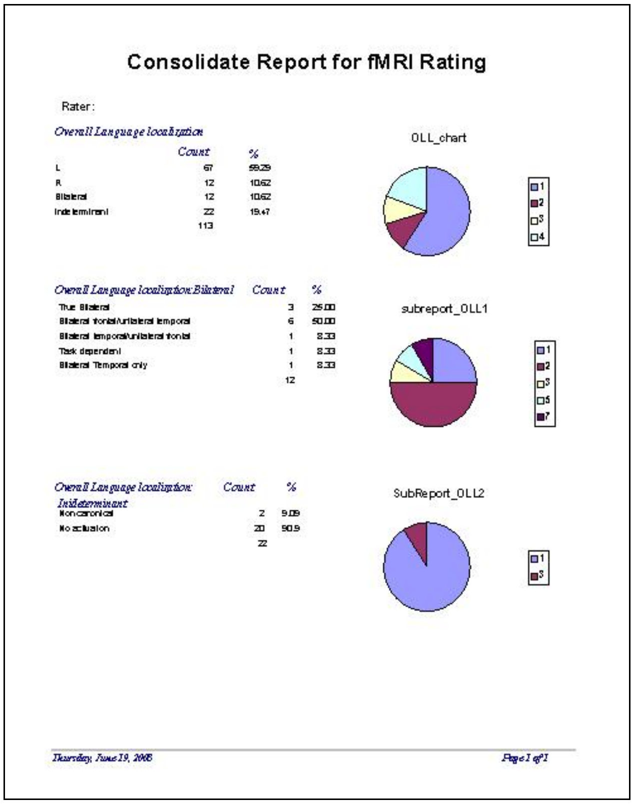


Figure 5. Descriptive statistics for consolidating all features assessed during image rating.

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