42-668: "Fun"-damentals of MRI and Neuroimaging Analysis
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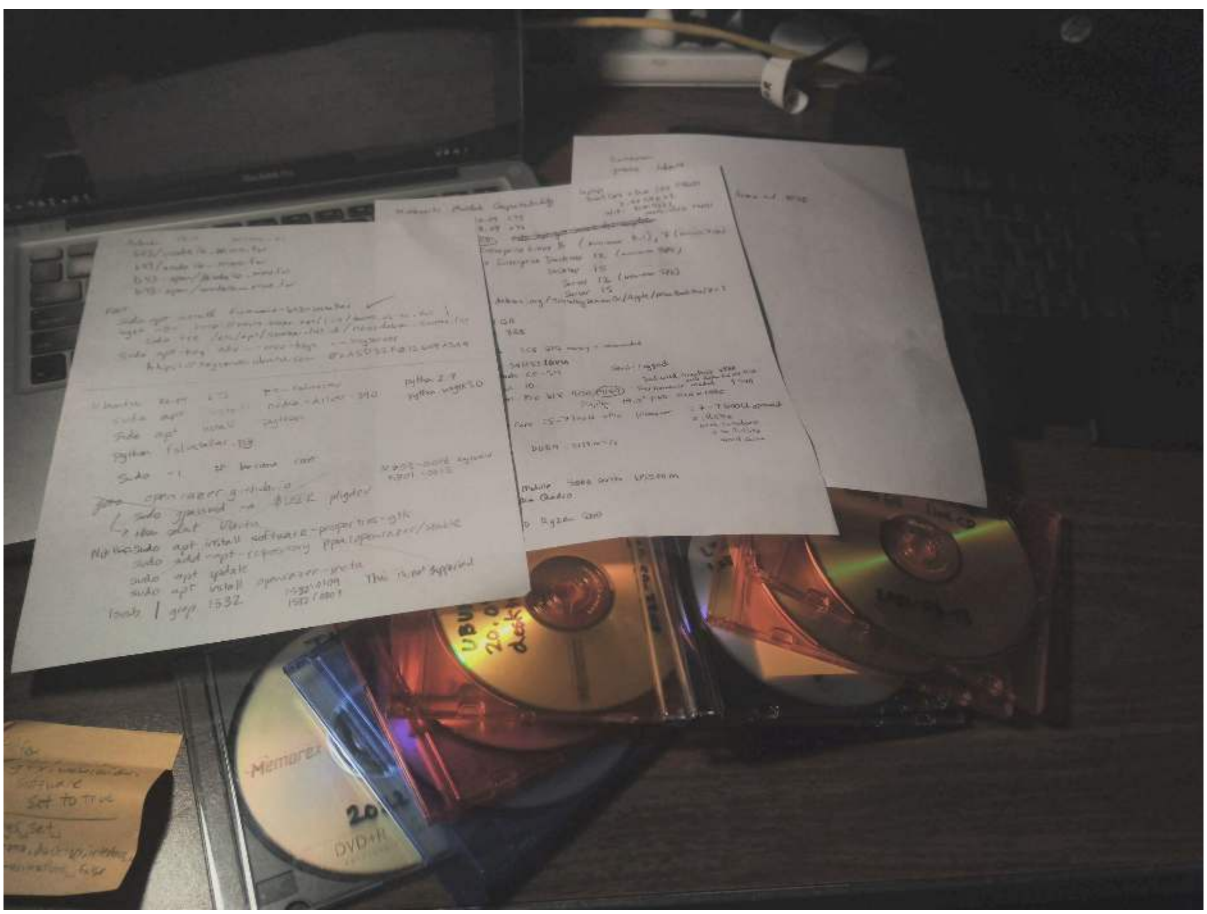
Started 2022 Mar 04, Completed 2022 Mar 16 (with 2 day grace period)

Project #1

0. CHALLENGES IN COMPLETING THIS ASSIGNMENT

I spent 40+ hours trying to get FSL to work on the CMU campus for future students, for which I am grateful for the assistance of Dr. Sossena Wood, Dr. Keith Cook, Maryia Rakach, D'Arcy A MacIsaac, and CMU IT-Help. In addition, I spent 30+ hours over Spring break with my 12+ year-old computers, trying 9 different Operating system configurations on 2 different computers, to find the right combination that would work with my WiFi, FSL, and Matlab requirements. Also, I have spent 20+ hours at the Wean Hall computer labs and at home over the past 3 days to generate this document. At school in the computer lab there are still opportunities for improvement. There is a 2 GB Linux size limit for all students. Once the 2 GB limit was reached I had to move files around. Google Drive does not permit a smooth workflow with multiple files. A workaround I had access to was moving files via a USB 1.0 drive with slow transfer speeds. IT-Help will not change this 2 GB size limit. The photo below is of my notes and the multiple operating systems tried.



For the purposes of this document, the reader can assume that I am referencing "Visual and audiovisual speech perception associated with increased functional connectivity between sensory and motor regions" [DATASET] or "Increased Connectivity among Sensory and Motor Regions during Visual and Audiovisual Speech Perception" [PUB] unless otherwise noted. A keen reader will note the similarities of order and intended meaning for my description of the experiments of the aforementioned dataset and publication. This was done as per my understanding of the written instructions of the assignment, and verbal instructions to rewrite in my own words the following sections, not as an attempt to plagiarize.

1. OBJECTIVE

It is common for people to attempt to use visual cues i.e. facial expressions, hand gestures, and lip-reading to gain additional meaning from audio-only signals e.g. speaking. The purpose of this study was to determine if there was a correlation in brain activity as measured by increased blood flow localizations with functional magnetic resonance imaging (fMRI) related to degraded auditory signals of people speaking. In other words, what parts of the brain are used when you can't hear what someone is saying? The sample size for the main experiment was 60 adult humans. The subjects were presented with words visually only, audio-only, and a combination of visual and audio. The words presented with both audio and visual were at low volume and also at different audio signal-to-noise ratios. In addition a single subject was selected for T1w and T2w SI Unit Tesla vs Voxel count comparison.

2. MATERIAL AND METHODS

2.1. Materials

There were seven lists with 50 words each. A female actor was recorded, with the camera focused on the "actor's head and shoulders", speaking individual words. The actor instructed the subject "along with a carrier phrase" to "Say the word _______". For consistency, the instructions were provided to the actor to "allow her mouth to relax to a slightly open and neutral position before each target word was spoken". For the experiment, the recordings "did not include a carrier phrase and were each 1.5 seconds long". The video was recorded with a "Canon Elura 85 digital video camera connected via IEEE 1394 connection to a Dell Precision 670". Adobe Premiere Elements was used for video editing. The video presented to the subjects was "in high quality .wmv files". Since audio volume and signal-to-noise ratio was a major component of the experiment, special care was taken so that audio was "leveled to ensure that each word had the same RMS amplitude using Adobe Audition".

> RMS stands for root mean square, is a metering tool that measures the average loudness of an audio track within a window of roughly 300 milliseconds. The value displayed is an average of the audio signal. The RMS value will give you a more accurate look at the perceived loudness of the music track for the average listener. Utilizing metering tools to visualize the average RMS will also help you avoid distortion, especially with loud music. [EMASTERED]

Where background noise was included, "RMS leveled six-talker babble" was "mixed and included in the final version of the file". 350 recordings were used in the study from a large selection of 970 recordings of "high frequency words originally selected from the 40,481 words listed in the English Lexicon Project".

Words were chosen for the lipreading visual only or the audio visual conditional test with different signal to noise ratios. These words that were selected for use in the main experiment were based on an prior experiment with the video only performance of each word from "149 participants (22-90 years old) who were tested using" the entire 40,481 words in the English Lexicon Project. The words chosen ranged from "10%–93% correct in the lipreading-only behavioral tests" and were "distributed among the six conditions that included visual information". The audio visual condition was Quiet, +5 SNR, 0 SNR, -5 SNR, -10, and then visual only. This was done so that the words would be "equivalent for lipreading difficulty". The words used in the A-only condition were selected from the remaining words.

2.2. Participants

The participants or subjects consisted of "65 adults aged 18–34 years". Although 5 adults were excluded from the fMRI data. Hence, 60 participants remaining "ranged in age from 18–34 years (M = 22.42, SD = 3.24)".

For this document a single subject, sub01, was selected for review of structural brain anatomy via magnetic resonance imaging (MRI) data. [DATASET]

2.3. Procedure

A "behavioral lip-reading assessment" was performed by the participants, as well as a "MRI safety screening" and consent was obtained before the participant was evaluated in the fMRI machine. MRI safe earphones were inserted into the participants ear canals, and a mirror was used so that "two-sided projection screen" could be seen, which was located superior to the patients head along the bore axis of the MRI machine. Participants needing glasses were provided with MRI safe lenses to meet individualized visual requirements.

To record participant responses a box was provided and the participants were instructed to hold the box in a "comfortable position on their torso during testing". Of note, each sequence presented "included trials with recordings of audio, visual-only, audiovisual speech stimuli, or printed text via an image projected on the screen that was visible to the participant through the viewing mirror".

Accurate fMRI and MRI data can only be obtained with minimal movement of participants, hence a "camera positioned at the entrance to the scanner bore was used to monitor participant movement". Between each sequence, a "well-being check and short conversation occurred" and participants were "reminded to stay alert and asked to try to reduce movement during the session".

For the audio only condition, a black screen was shown and the audio was presented. Hence for the audio only condition there was in essence no visual stimulus. A block design was utilized and then "quasi-randomized so that no two blocks from the same condition were presented after the other and two null trials never occurred after another".

To compensate for distraction induced effects and to maintain attention of the participants "half of the experimental trials required a response from the participant", the trials consisted of a "set of two dots" which appeared on the screen via the mirror "after the audiovisual/audio presentation". The dot on the right of the screen was colored green and the dot on the left side was colored red. To record the confidence of the participants accurately, the participants were instructed to press the button in their right hand for yes, and the button in their left hand for no.

Each session consisted of seven sequences, for a duration of "approximately 5.5 minutes". Of the seven sequences, the "first six contained 98 trials each". The words, or stimuli, as either audio, visual, or audiovisual in "blocks of five experimental trials plus two null trials for each condition".

The resulting total consisted of 14 blocks in "70 experimental trials plus 28 null trials". For all trials, 800 ms of quiet without "visual presentation before the stimuli" was presented. The null trial included a "fixation cross for 1.5 seconds" protocol instead of the audio visual procedure.

Words appeared with common capitalization usage, and after the first six runs, a final run consisted of 60 trials presented on the screen. Both the audio and visual conditions used the same 50 words, where each word was shown on the "screen for 2.5 seconds". After each word was displayed two green dots were displayed for 2.5 seconds, a visual palate cleanser so to speak.

The participants were then instructed to speak the word while the dots were displayed on the screen thereby activating the short term or working memory. For validation there were ten null trials which were inserted into the sequence, which lasted 2.5 seconds and also included the fixation cross.

2.4. MRI data acquisition

The MRI images were obtained from a "Siemens Prisma 3T scanner using a 32 channel head coil". For increased signal resolution an gadolinium-based contrast agent (GBCA) is used for the most widely used "post-GBCA sequence" or MPRAGE which represents "an inversion recovery fast gradient recalled-echo sequence." [MPRAGE]

A "T1-weighted MPRAGE sequence" with a "voxel size of 1 x 1 x 1 mm" was to obtain the structural MRI images. Then functional images were obtained using a "multiband sequence" and an "acceleration factor of 8". A time of 0.770 s on average was required for each volume. A "sparse imaging paradigm" was utilized with a "repetition time of 3.07 s" which left 2.3 s for silence per trial. During the silent period words were presented and during the repeat blocks. Finally the participants were instructed to speak during the silent periods to "minimize the influence of head motion on the data" collection.

3. RESULTS

The results of the main experiment demonstrated that "audiovisual speech perception recruited both auditory and visual cortex, with some evidence for increased recruitment of premotor cortex in some conditions (including in substantial background noise)". The researchers then concluded that "investigated neural connectivity using psychophysiological interaction analysis with seed regions in both primary auditory cortex and primary visual cortex" and that connectivity "between auditory and visual cortices was stronger in audiovisual conditions than in unimodal conditions, including a wide network of regions in posterior temporal cortex and prefrontal cortex". Also during the "whole-brain analyses" a "region-of-interest analysis on the left posterior superior temporal sulcus (pSTS), implicated in many previous studies of audiovisual speech perception". [PUB, p. 435]

To summarize there is demonstrated "evidence for both activity and effective connectivity in pSTS for visual-only and audiovisual speech, although these were not significant in whole-brain analyses" These results "suggest a prominent role for cross-region synchronization in understanding both visual-only and audiovisual speech that complements activity in integrative brain regions like pSTS." [README]

Furthermore the findings demonstrated the "scaffolding of connectivity among auditory, visual, and premotor cortices that supports visual-only and audiovisual speech perception" and "suggest that the binding of multisensory information need not be restricted to heteromodal brain regions (e.g., pSTS) but may also emerge from coordinated unimodal activity throughout the brain". [PUB, p. 441]

See also section 4.4, page 22 of this document for "Visible Differences In The Segmentation".

4. ASSIGNMENT REQUIREMENTS

The assignment instructions are included in this document in slightly altered order for completeness.

Objective: The objective of this project is to have you, as students, work through the strategies that you have learned to date in this course. The topics that this project supports are segmentation and structural MRI. You will use an MR dataset from OpenNeuro with T1 and T2-weighted images.

In project #1, you will need to perform three strategies described in this document. Please perform each strategy with your tool and methodology of choice. It is important for you to describe the tool that you used for your analysis technique and describe how you developed your answer. You will submit project #1 as a report as if you were the researchers that conducted the patient information, MR protocol and MR image analysis. You will need to write the objective of the study, material and methods, and results section. Please reference sample MRI journal articles and distinguish how the MR protocol and image analysis sections are written.

Dataset: https://openneuro.org/datasets/ds003717/versions/1.0.0 . Use sub-01/anat/sub-01_T1w.json and sub-01/anat/sub-01-T2w.json.

Required Software Tools: FSL, MRIcron or ITKSnap. You can use any of these tools at your discretion to complete one of the tasks below.

Grading Rubric

It is alright if you work in groups, but you will need to submit this assignment on your own and abide by academic integrity included in the syllabus of this course.

The assignment will be graded with the following criteria in mind.

- The purpose of the study has been outlined
- The materials and methods section are well-defined to include
    - Patient recruitment
    - MR imaging protocol
    - MR imaging analysis
- The results section is explained in reference to the methodology used.

Please use proper units where necessary. Properly reference the datasets and tools used for your project.

4.1. Extract Image Acquisition Information from MR Dataset
Extract the image acquisition information from the MR dataset file. List the following: patient gender, magnetic field strength, slice thickness, echo time, repetition time, acquisition time, coil type, MR manufacturer.

Dataset:
https://openneuro.org/datasets/ds003717/versions/1.0.0
Use sub-01/anat/sub-01_T1w.json and sub-01/anat/sub-01-T2w.json

65 adult subjects aged 18-34 years old, 5 subjects fMRI data was excluded, remaining 60 adult subjects remaining aged 18-34 years old with a median M = 22.42 years and standard deviation SD = 3.24 years. [README]

Patient Gender:
Subject 1: participant_id: sub-01; Patient Gender: **F, Female**; Patient age: 34; [PARTICIPANTS]

Magnetic Field Strength:
3T, 3 Tesla. [README]

Slice Thickness:
[sub-01_T1w.nii.gz] [sub-01_T2w.nii.gz]
From FSL overlay information:
Dimensions

- Number of dimensions: 3D
- dim1: 300
- dim2: 320
- dim3: 208
- pixdim1: 0.8 mm
- pixdim2: 0.8 mm
- pixdim3: **0.8 mm (Slice thickness is 0.8 mm)**
- Size: X=189 mm Y=259 mm Z=286 mm

Echo Time (TE):

- Echo Time (TE) = "Time between middle of exciting (e.g., 90°) RF pulse and middle of spin echo production. For multiple echos, use TE1, TE2, etc. When the RF spin echo and gradient echo are not coincident in time, TE refers to the time of the gradient spin echo." [GLOSSARY]
- "Time to Echo (TE) is the time between the delivery of the RF pulse and the receipt of the echo signal." [CASE]
- sub-01_**T1w**.json: Echo Time: **0.00222 s** [sub-01_T1w.json]
- sub-01_**T2w**.json: Echo Time: **0.563 s** [sub-01_T2w.json]

Repetition Time (TR):
- Repetition time (TR) = "Repetition time. The period of time between the beginning of a pulse sequence and the beginning of the succeeding (essentially identical) pulse sequence." [GLOSSARY]
- "Repetition Time (TR) is the amount of time between successive pulse sequences applied to the same slice." [CASE]
- Average: "repetition time of **3.07 s**" [README]
- sub-01_**T1w**.json: Repetition Time: **2.4 s** [sub-01_T1w.json]
- sub-01_**T2w**.json: Repetition Time: **3.2 s** [sub-01_T2w.json]

Acquisition Time:

"Image acquisition time. **Time required to carry out an MR imaging procedure comprising only the data acquisition time.** The total image acquisition time will be equal to the product of the repetition time, TR, the number of signals averaged, NSA, and the number of different signals (encoded for position) to be acquired for use in image reconstruction. The additional image reconstruction time will also be important to determine how quickly the image can be viewed. In comparing sequential plane imaging and volume imaging techniques, the equivalent image acquisition time per slice must be considered as well as the actual image acquisition time." [GLOSSARY]

"Seven sequences were presentenced during the session. Each one lasted approximately 5.5 minutes. The first six sequences contained 98 trails each. The stimuli were presented in blocks of five experimental trials plus two null trials for each condition. The total result was 14 blocks resulting in 70 experimental trials plus 28 null trials. All trials included 800 ms of quiet without a visual presentation before the stimuli began. During the null trials participants were presented with a fixation cross for 1.5 seconds instead of the audiovisual presentation. ... After the initial six runs, a final run of 60 trials was presented that included only orthographic words on the screen. The items were the same 50 words used for the behavioral V-only assessment. Each word stayed on the screen for 2.5 seconds. The words were followed by two green dots that appeared for 2.5 seconds. Participants were asked to say aloud the word that was presented during the period that the dots were on the screen. Ten null trials were randomly distributed throughout the sequence. Null trial lasted 2.5 seconds and included a fixation cross on the screen." [README]

Acquisition Time =

Repetition Time (TR) ✕ Number of signals averaged (NRA) ✕ number of different signals (encoded for position) to be acquired for use in image reconstruction

sub-01_**T1w**.json:
- Echo Time: **0.00222 s** [sub-01_T1w.json]
- Repetition Time: **2.4 s** [sub-01_T1w.json]
- **Acquisition Time: "Each volume took 0.770 s to acquire."** [README]

Cont...
sub-01_**T2w**.json:
- Echo Time: **0.563 s** [sub-01_T2w.json]
- Repetition Time: 3.2 s [sub-01_T2w.json]
- **Acquisition Time: "Each volume took 0.770 s to acquire."** [README]

Coil Type:
- "32 channel head coil" and the "Lower coil part can be combined with a Loop coil". [README] [HEADCOIL]
- Siemens Healthineers Magnetic Resonance Imaging 32-Channel Head Coil, with "iPAT-compatible coil for fast high-resolution and advanced neuro imaging". [HEADCOIL]
- The following is from Siemens. [HEADCOIL]
    - 32-element design with 32 integrated preamplifiers
    - Upper coil part removable, designed with 12 elements
    - Lower coil part usable without upper part (e.g. for highly claustrophobic patients), designed with 20 elements
    - Coil design with comfortable open view for visual stimulation experiments and reduction of claustrophobic response
    - Cushions (removable) for head stabilization
    - No coil tuning
    - iPAT-compatible
    - Detachable mirror assembly

MR manufacturer:
- **Siemens Healthineers** [SIEMENS-HEALTHINEERS]
- Siemens MAGNETOM Prisma 3T MRI scanner with 32 channel head coil
- "Siemens Prisma 3T scanner using a 32 channel head coil". [README]
- "3T MR scanner (Siemens MAGNETOM Prisma)" [WUSTL]

4.2. Brain Extraction through Segmentation

You can automatically or manually segment the full brain. Do this in your T1-weighted and T2-weighted image. Take a screenshot of what you see with the original image and segmented brain together.

Cont...

Tissue Type Segmentation T1

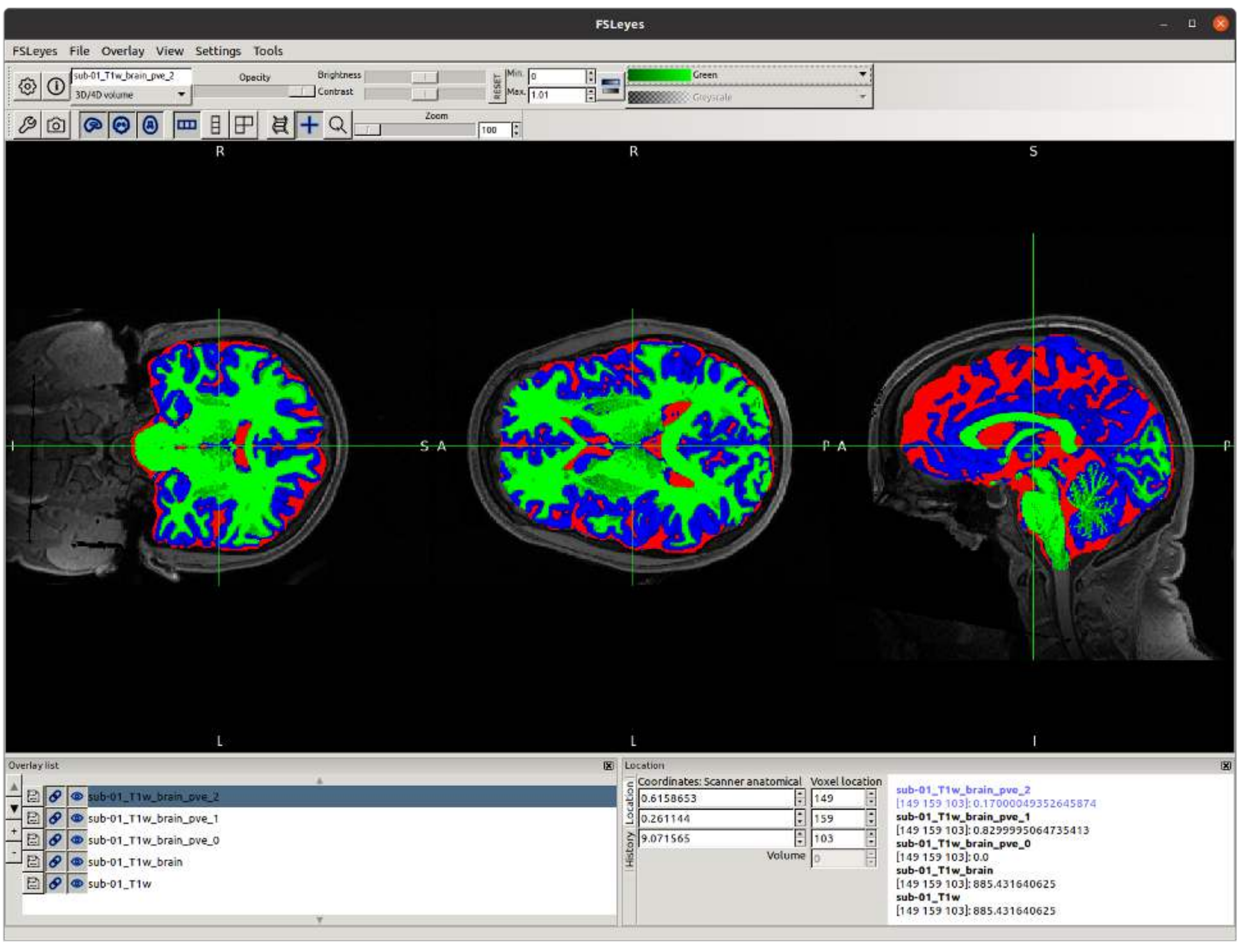
Tool: [FSL]

Brain extraction first.
```
bet sub-01_T1w sub-01_T1w_brain -f 0.5 -g 0
```

Then segmentation.
```
fast -t 1 -n 3 -H 0.1 -I 4 -l 20.0 -o sub-01_T1w_brain
sub-01_T1w_brain
```

fsleyes > File > Add from file > sub-01_T1w, sub-01_T1w_brain, sub-01_T1w_brain, sub-01_T1w_brain_pve_0, sub-01_T1w_brain_pve_1, sub-01_T1w_brain_pve_0

Change sub-01_T1w_brain_pve_0 color map to Red
Change sub-01_T1w_brain_pve_1 color map to Blue
Change sub-01_T1w_brain_pve_2 color map to Green



Tissue Type Segmentation T2

Tool: [FSL]

Brain extraction first.

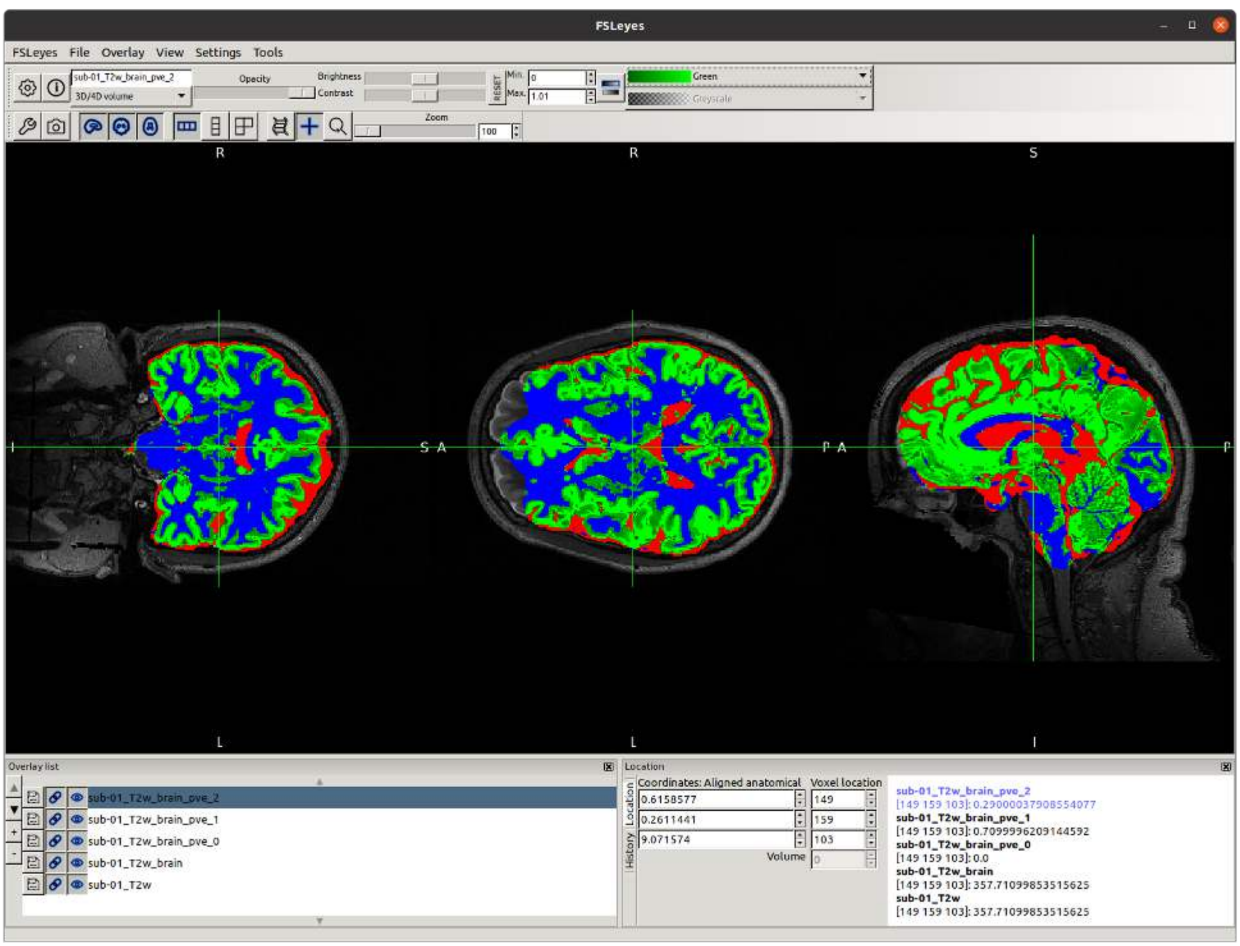
```
bet sub-01_T2w sub-01_T2w_brain -f 0.5 -g 0
```

Then segmentation.

```
fast -t 1 -n 3 -H 0.1 -I 4 -l 20.0 -o sub-01_T2w_brain
sub-01_T2w_brain
```

fsleyes > File > Add from file > sub-01_T2w, sub-01_T2w_brain, sub-01_T2w_brain, sub-01_T2w_brain_pve_0, sub-01_T2w_brain_pve_1, sub-01_T2w_brain_pve_0

Change sub-01_T2w_brain_pve_0 color map to Red
Change sub-01_T2w_brain_pve_1 color map to Green
Change sub-01_T2w_brain_pve_2 color map to Blue



4.3. Measurement of Relaxation quantities in Grey Matter

Measure T1-weighted and T2-weighted quantities in the grey matter of the brain. This will require that you segment the grey matter tissue. These values can be obtained by looking at the histogram but can be averages by segmenting the tissue and finding the mean value of the T1 and T2 in the grey matter. Take a screenshot of what you see and your segmentation. Report the mean and standard deviation of the grey matter T1, T2 for each dataset.

Cont...

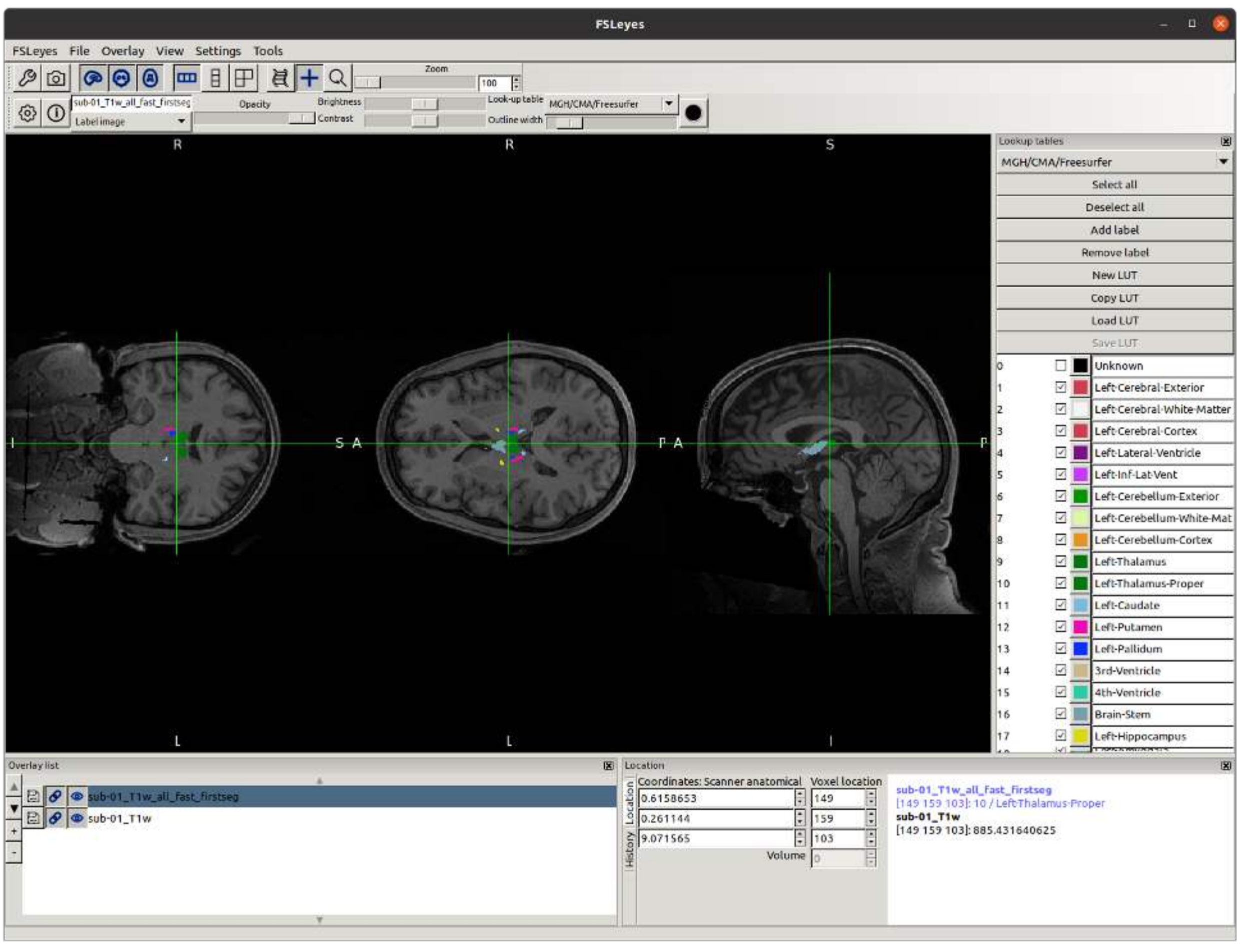
Deep Gray Matter Structure Segmentation sub-01_T1w

Tool: [FSL]

```
run_first_all -i sub-01_T1w -o sub-01_T1w
```

fsleyes > File > Add from file > sub-01_T1w, sub-01_T1w_all_fast_firstseg

Select sub-01_T1w_all_fast_firstseg from overlay list
Change overlay list to Label image
Change Look-up table to MGH/CMA/Freesurfer
Settings > Ortho View 1 > Lookup Tables
Lookup tables > MGH/CMA/Freesurfer

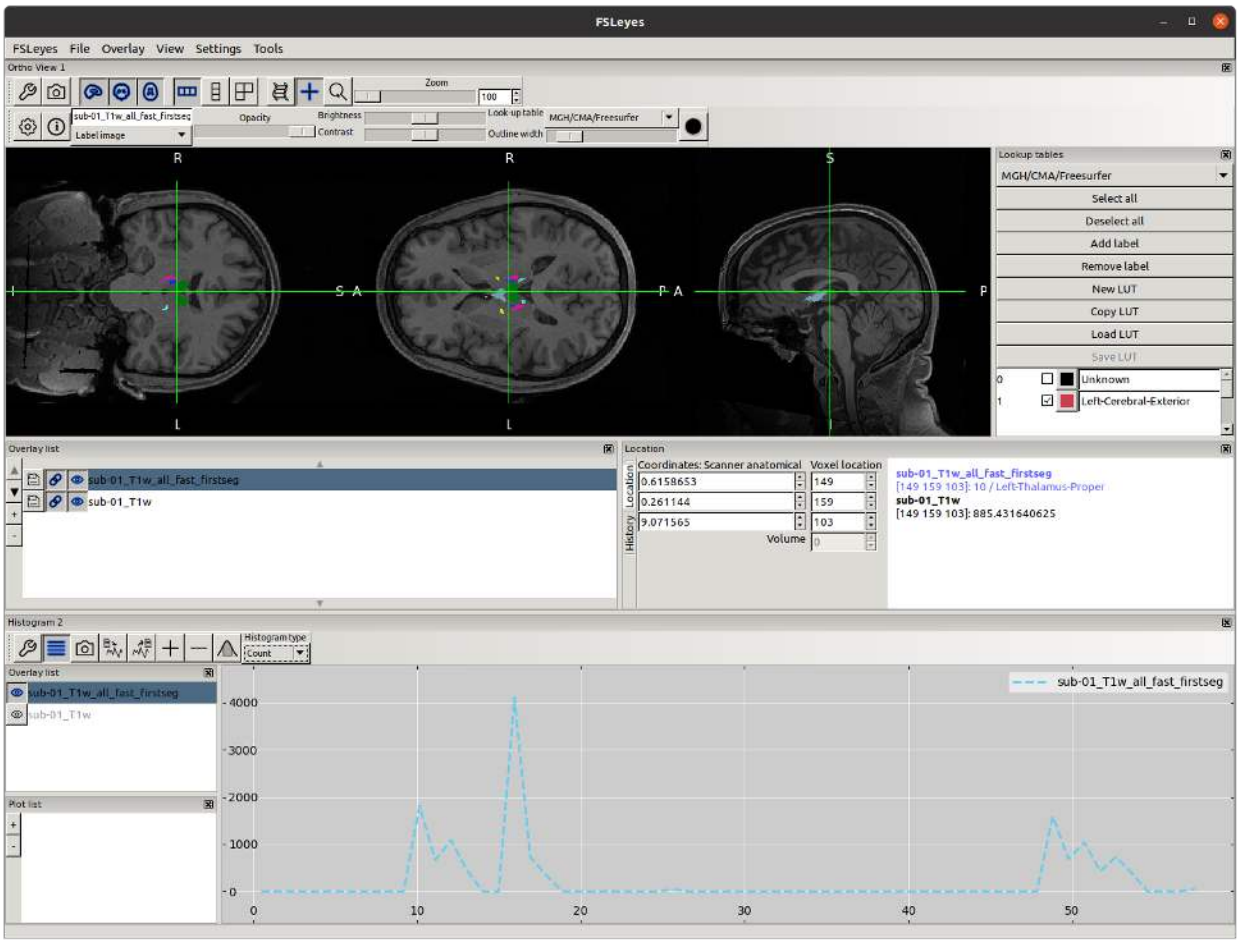


Cont...

Deep Gray Matter Structure Segmentation sub-01_T1w Cont.

Tool: [FSL]

fsleyes > View > Histogram > Histogram type: Count > Export data series to a text file. > Export the X axis data as the first column? > Yes > dataseries-sub-01_T1w.txt > Save



Google Sheets > File > Import > Upload > dataseries-sub-01_T1w.txt > Import Location> Insert new sheet(s) > Separator type: Custom > Custom separator: [space character]

You should have two columns of data, delete the empty ones.

The x axis represents SI unit Tesla values and the y axis represents the number of voxels (count). Select second column to represent Y-axis for =AVERAGE(B1:B) and =STDEV(B1:B)

sub-01_T1w_all_fast_firstseg
Mean = 236.15
Standard Deviation: 641.9262808

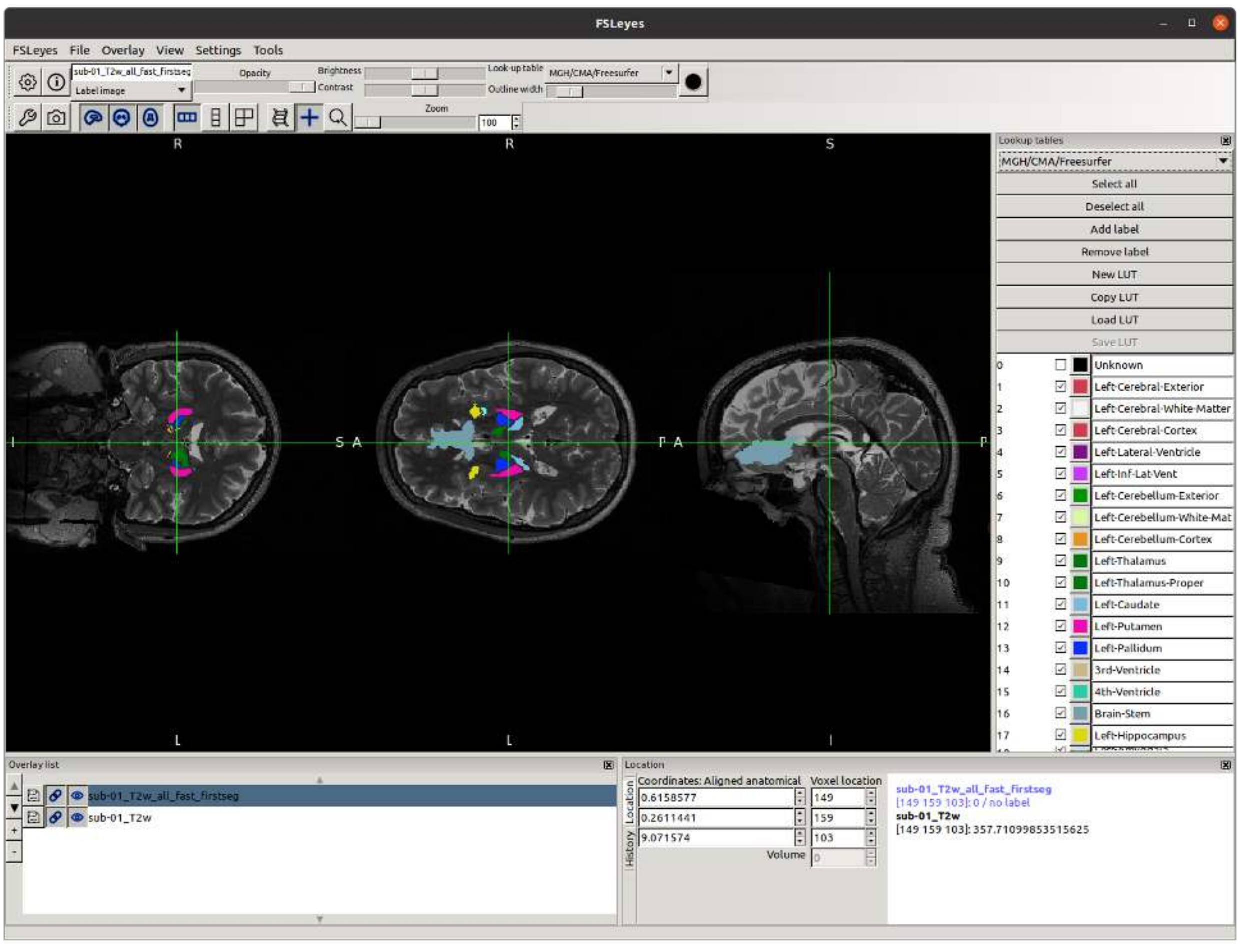
Deep Gray Matter Structure Segmentation sub-01_T2w

Tool: [FSL]

run_first_all -i sub-01_T2w -o sub-01_T2w

fsleyes > File > Add from file > sub-01_T2w, sub-01_T2w_all_fast_firstseg

Select sub-01_T2w_all_fast_firstseg from overlay list
Change overlay list to Label image
Change Look-up table to MGH/CMA/Freesurfer
Settings > Ortho View 1 > Lookup Tables
Lookup tables > MGH/CMA/Freesurfer



Cont...

Deep Gray Matter Structure Segmentation sub-01_T2w Cont.

fsleyes > View > Histogram > Histogram type: Count > Export data series to a text file. > Export the X axis data as the first column? > Yes > dataseries-sub-01_T2w.txt > Save

Google Sheets > File > Import > Upload > dataseries-sub-01_T2w.txt > Import Location> Insert new sheet(s) > Separator type: Custom > Custom separator: [space character]

You should have two columns of data, delete the empty ones.

The x axis represents SI unit Tesla values and the y axis represents the number of voxels (count). Select second column to represent Y-axis for =AVERAGE(B1:B) and =STDEV(B1:B)

sub-01_T2w_all_fast_firstseg
Mean = 1024.266667
Standard Deviation: 3661.19572

4.4. Single-Tissue Segmentation of Caudate Structure
You will need to segment the caudate from the T1-weighted and T2-weighted image. Note if there are any visible differences in the segmentation.

Tool: [FSL]

fsleyes > File > Add from file > sub-01_T1w, sub-01_T1w_all_fast_firstseg, sub-01_T2w, sub-01_T2w_all_fast_firstseg

Select sub-01_T1w_all_fast_firstseg from overlay list
Change overlay list to Label image
Change Look-up table to MGH/CMA/Freesurfer
Settings > Ortho View 1 > Lookup Tables
Lookup tables > MGH/CMA/Freesurfer
Lookup tables > Deselect all > Select Left-Caudate and Right Caudate

Select sub-01_T2w_all_fast_firstseg from overlay list
Change overlay list to Label image
Change Look-up table to MGH/CMA/Freesurfer
Settings > Ortho View 1 > Lookup Tables
Lookup tables > MGH/CMA/Freesurfer
Lookup tables > Deselect all > Select Left-Caudate and Right Caudate

NOTE: I considered using ITKSnap, since I had already done this with the hippocampus on another assignment, I wanted to challenge myself to learn how to do it with FSL.

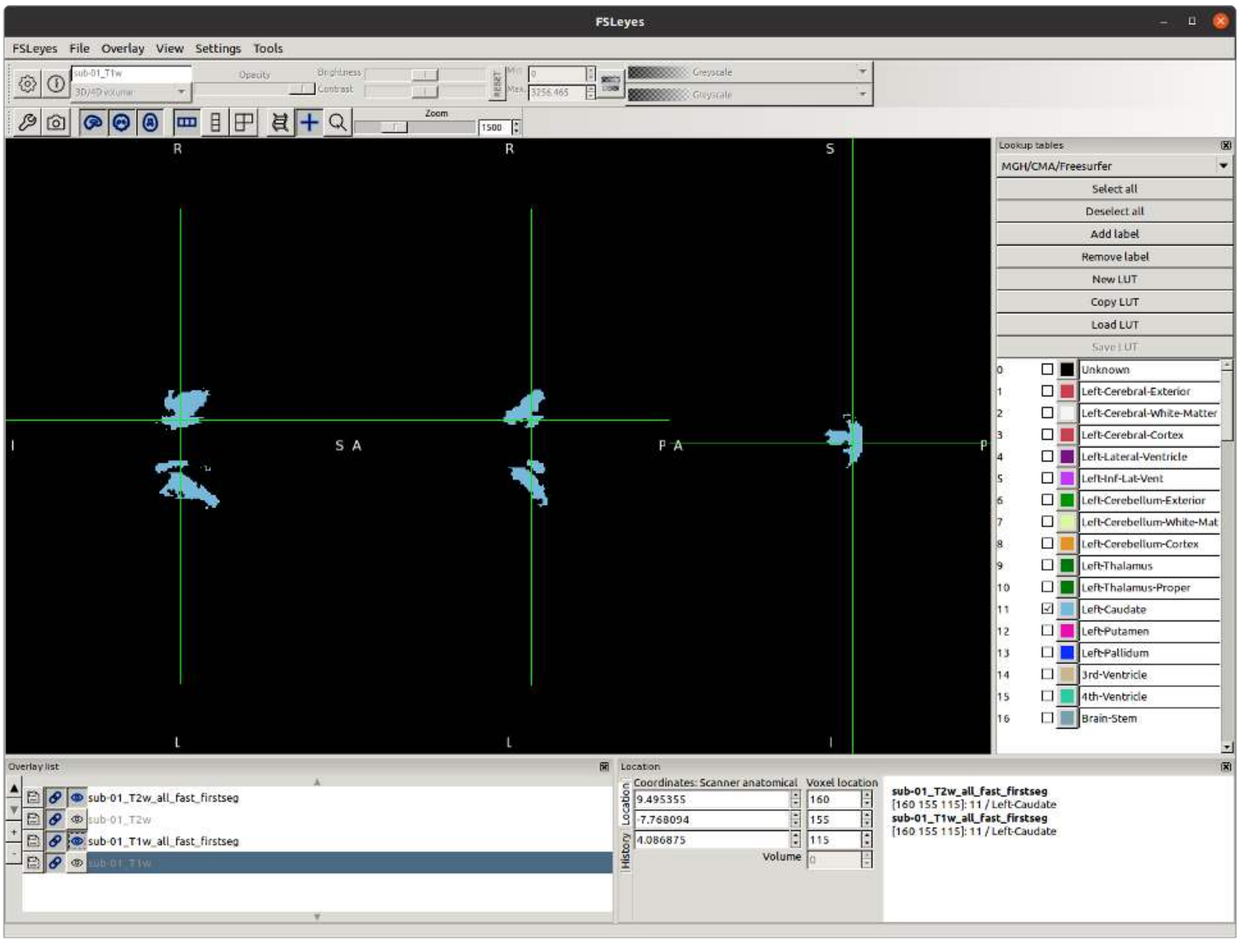
Cont...

Segment Caudate Cont.

Zoom to 1500

Select the eye in the Overlay List to hide sub-01_T1w and sub-01_T2w, then select sub-01_T1w

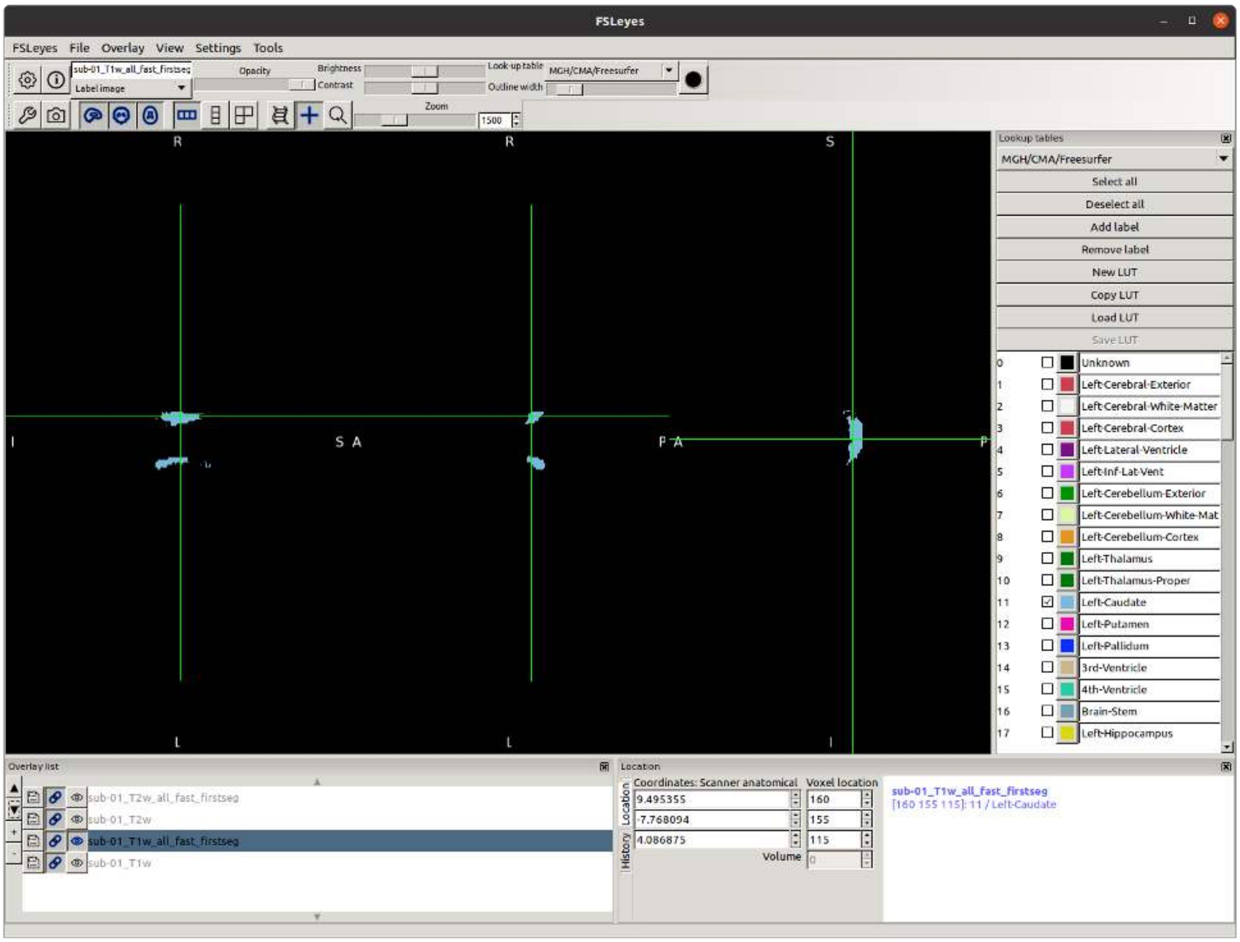
Use the mouse to select a Voxel Location where both sub-01_T1w_all_fast_firstseg and sub-01_T2w_all_fast_firstseg show Left-Caudate. In this case Voxel Location: 160, 155, 115



Cont...

Segment Caudate Cont.

In Overlay List Hide sub-01_T2w_all_fast_firstseg



This shows only the Left and Right Caudate for sub-01_T1w_all_fast_firstseg

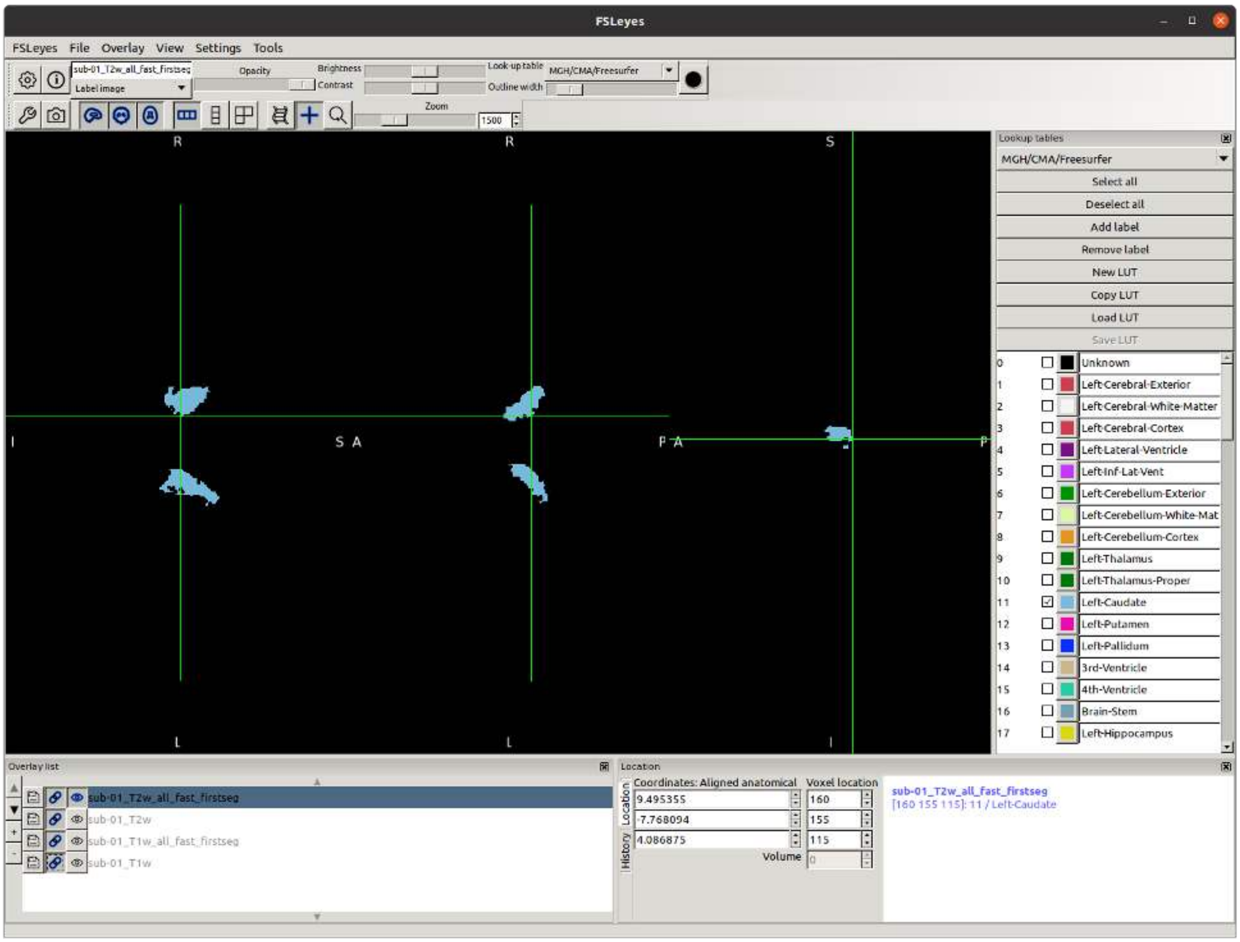
Cont...

Segment Caudate Cont.

In Overlay List Hide sub-01_T1w_all_fast_firstseg

In Overlay List Hide sub-01_T2w_all_fast_firstseg

In Overlay List Select sub-01_T2w_all_fast_firstseg



This shows only the Left and Right Caudate for sub-01_T2w_all_fast_firstseg

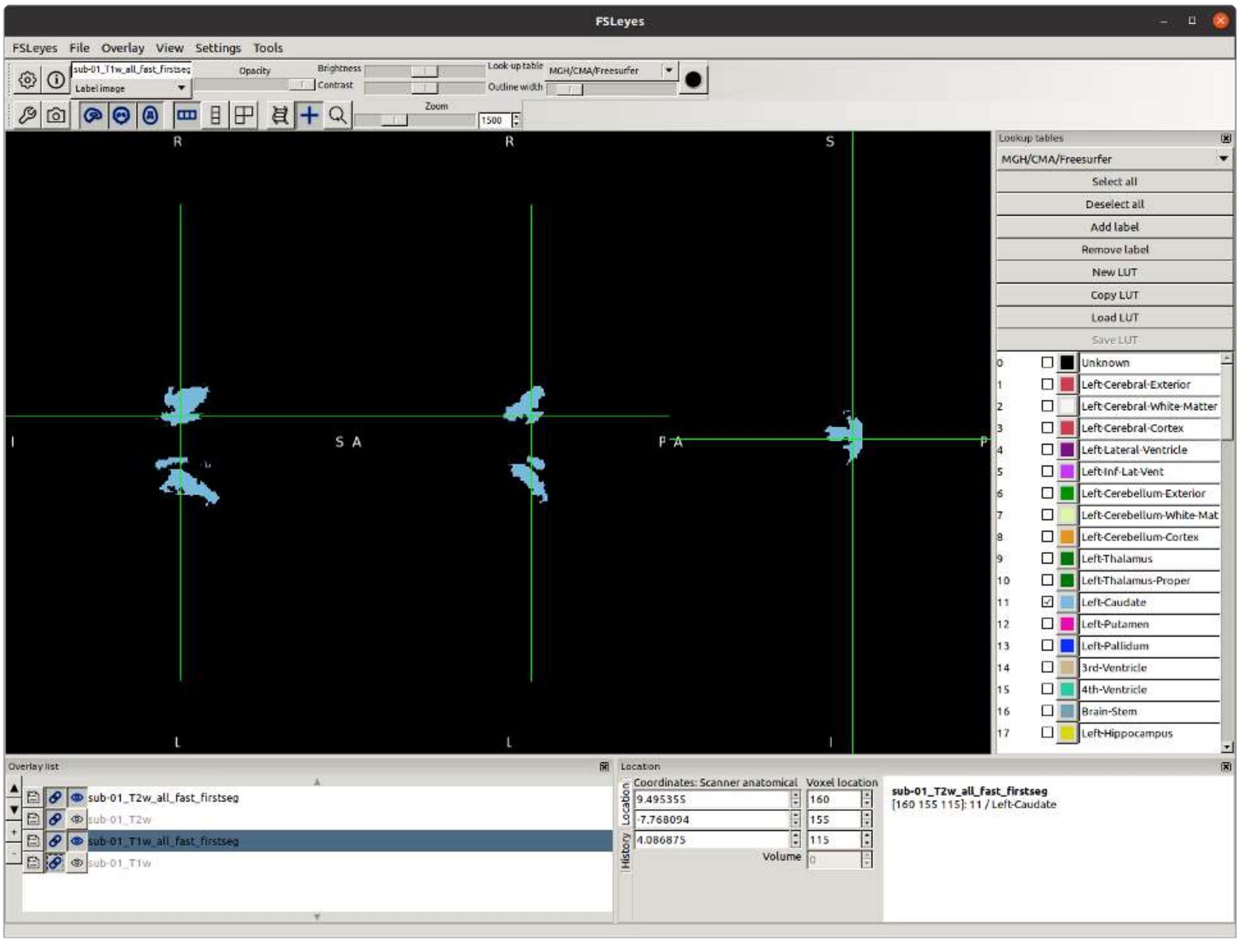
Cont...

Segment Caudate Cont.

In Overlay List Show sub-01_T1w_all_fast_firstseg

In Overlay List Show sub-01_T2w_all_fast_firstseg

In Overlay List **Select** sub-01_**T1**w_all_fast_firstseg



This shows **both** the Left and Right Caudate for sub-01_T2w_all_fast_firstseg

Visible Differences In The Segmentation

T1w shows Left and Right Caudate of a lesser amount. T2w shows Left and Right Caudate of a greater amount. Which indicates different T1w and T2w responses to the magnetic resonance signal due to the different constituent parts of the anatomy.

5. REFERENCES

[ASSIGNMENT] Wood S. Project 1 Instructions. 42-668 Fundamentals of MRI and Neuroimaging Analysis, Spring 2022, Carnegie Mellon University, Pittsburgh, PA. 2022 Mar 12. Available from: https://canvas.cmu.edu/courses/27919/assignments/467469.

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