Brain Extraction/Segmentation

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Brain Extraction 3 Different Attempts

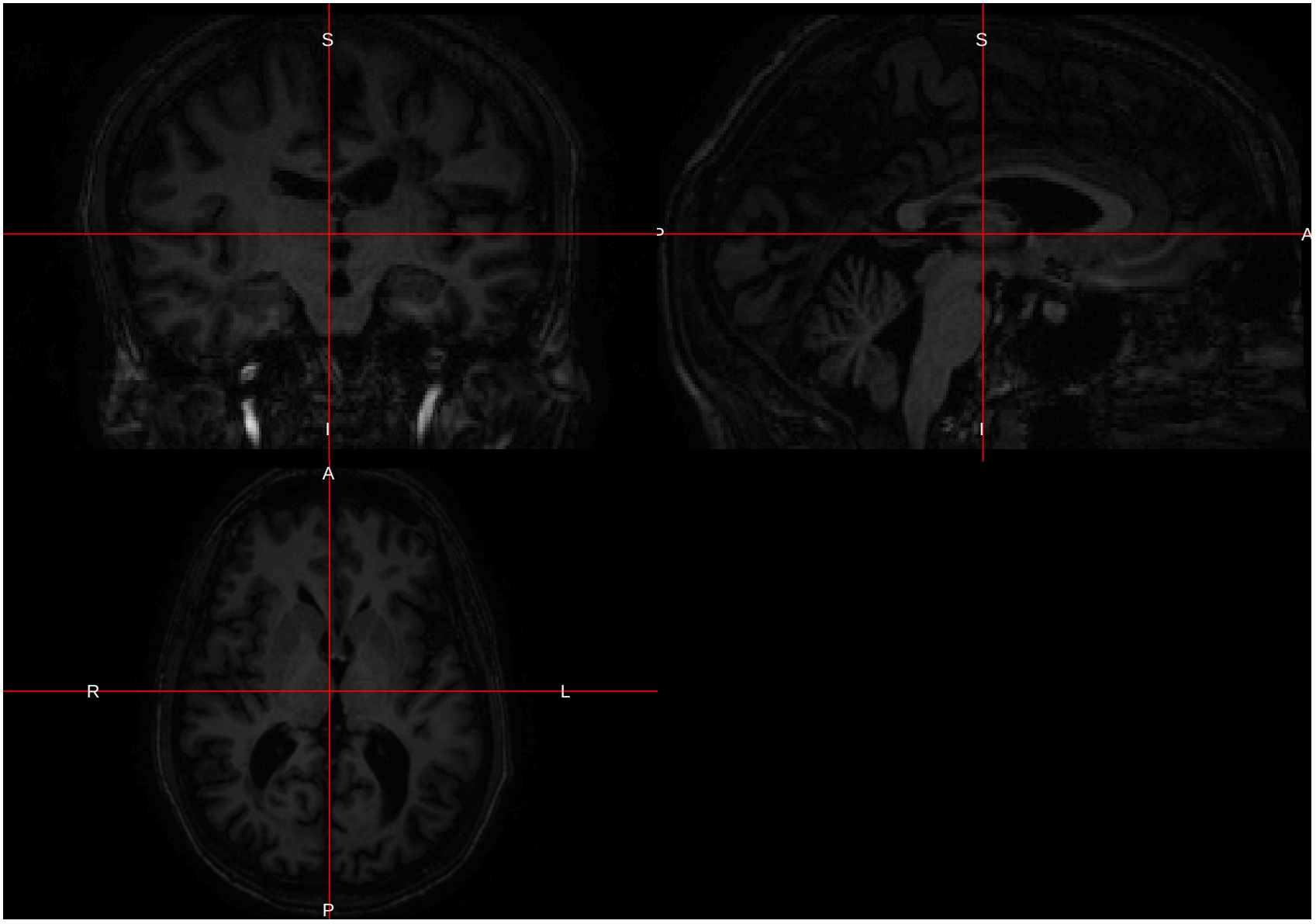
In this tutorial we will discuss performing brain segmentation using the brain extraction tool (BET) (Smith 2002) in `FSL` (Jenkinson et al. 2012), a robust version using a wrapper function in `extrantsr`, `fslbet_robust`, and a multi-atlas approach, called "multi-atlas label fusion" with the `malf` command.

Loading Data from `ms.lesion`

```
library(ms.lesion)
library(neurobase)
files = get_image_filenames_list_by_subject()$training01
t1_fname = files["MPRAGE"]
t1 = readnii(t1_fname)
red0.5 = scales::alpha("red", 0.5)
```

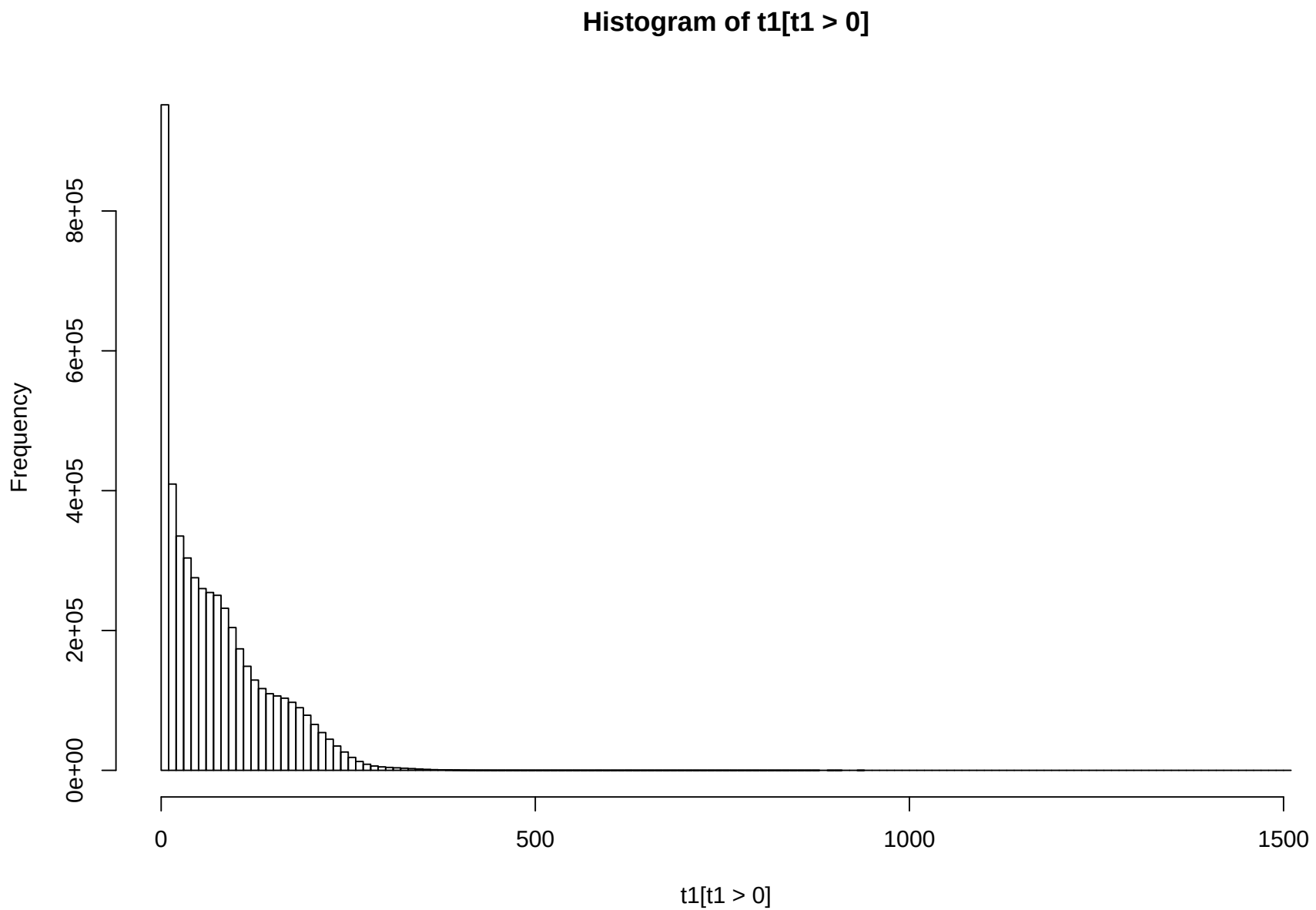
T1 image: high intensity values

```
ortho2(t1)
```



T1 image has long tails

```
hist(t1[ t1 > 0], breaks = 200)
```

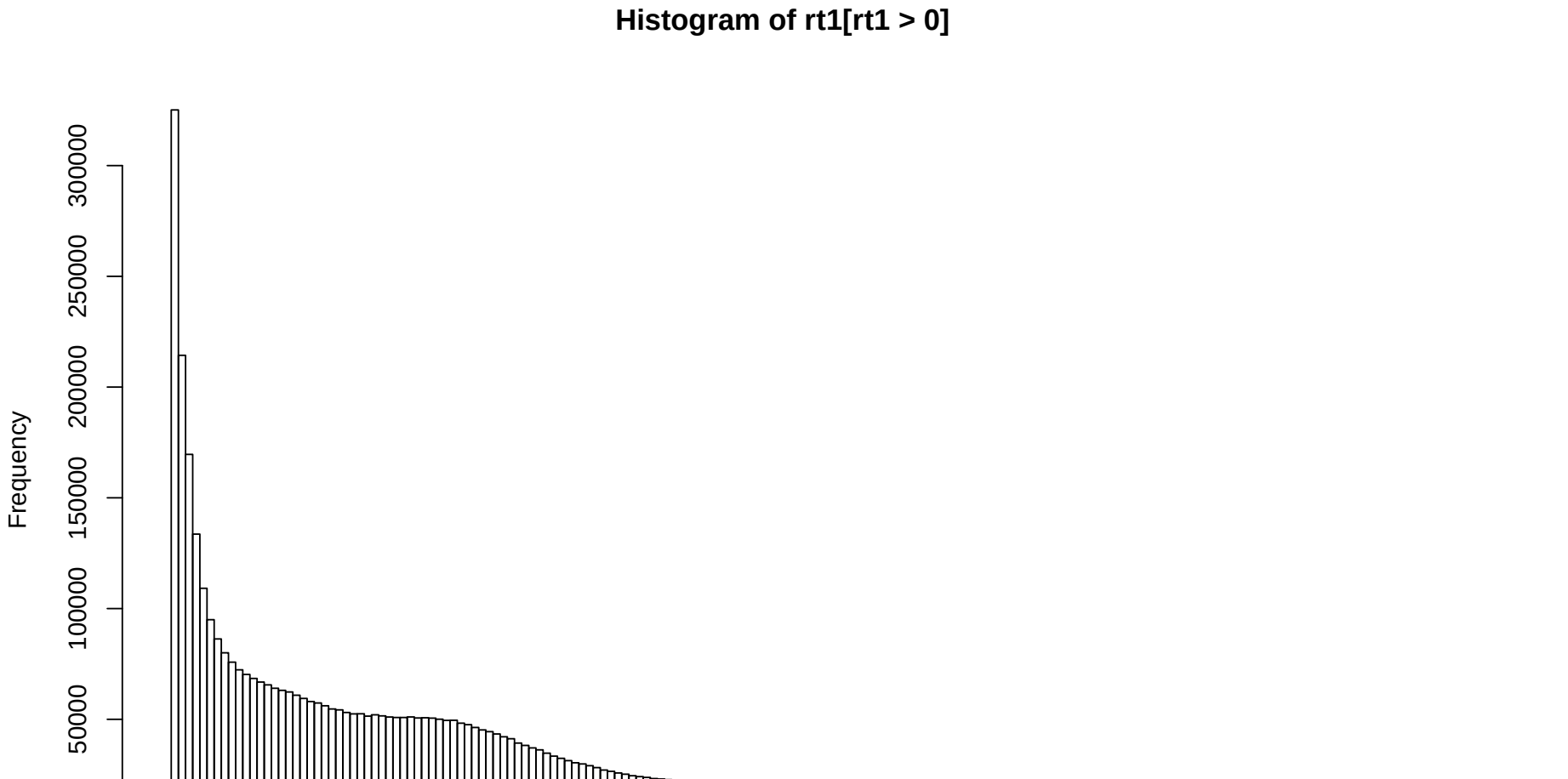


Limiting extreme values

`robust_window` essentially performs Winsorizing to limit extreme values

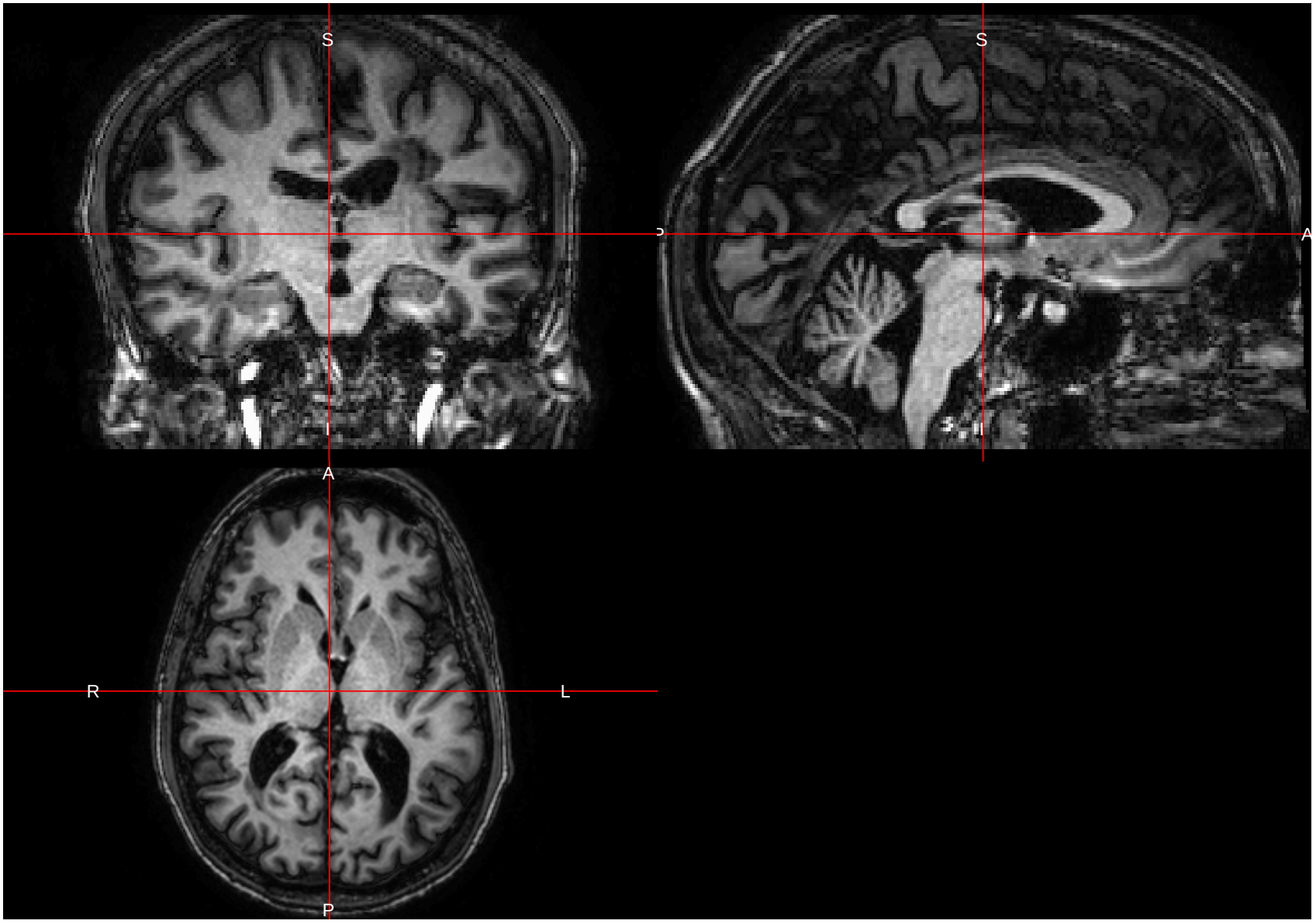
- sets them to 99.9^{th} quantile

```
rt1 = robust_window(t1); hist(rt1[ rt1 > 0], breaks = 200)
```



Re-plotting the image

```
ortho2(rt1)
```



Attempt 1: Brain Extraction of T1 image using BET

Here we will use FSL's Brain Extraction Tool (BET) to extract the brain tissue from the rest of the image (general overview):

- 2nd and 98th percentiles are calculated. (98th - 2nd) * 10% + 2nd percentile used to threshold out background
- From non-thresholded voxels - calculate center of gravity (COG)
- Calculate radius of brain and median intensity of all points within "spherical brain"
- Perform region growing and iterating to get brain surface
- Smooth surface
- Use median intensity to shrink surface to the "real" surface

Attempt 1: Brain Extraction of T1 image using BET

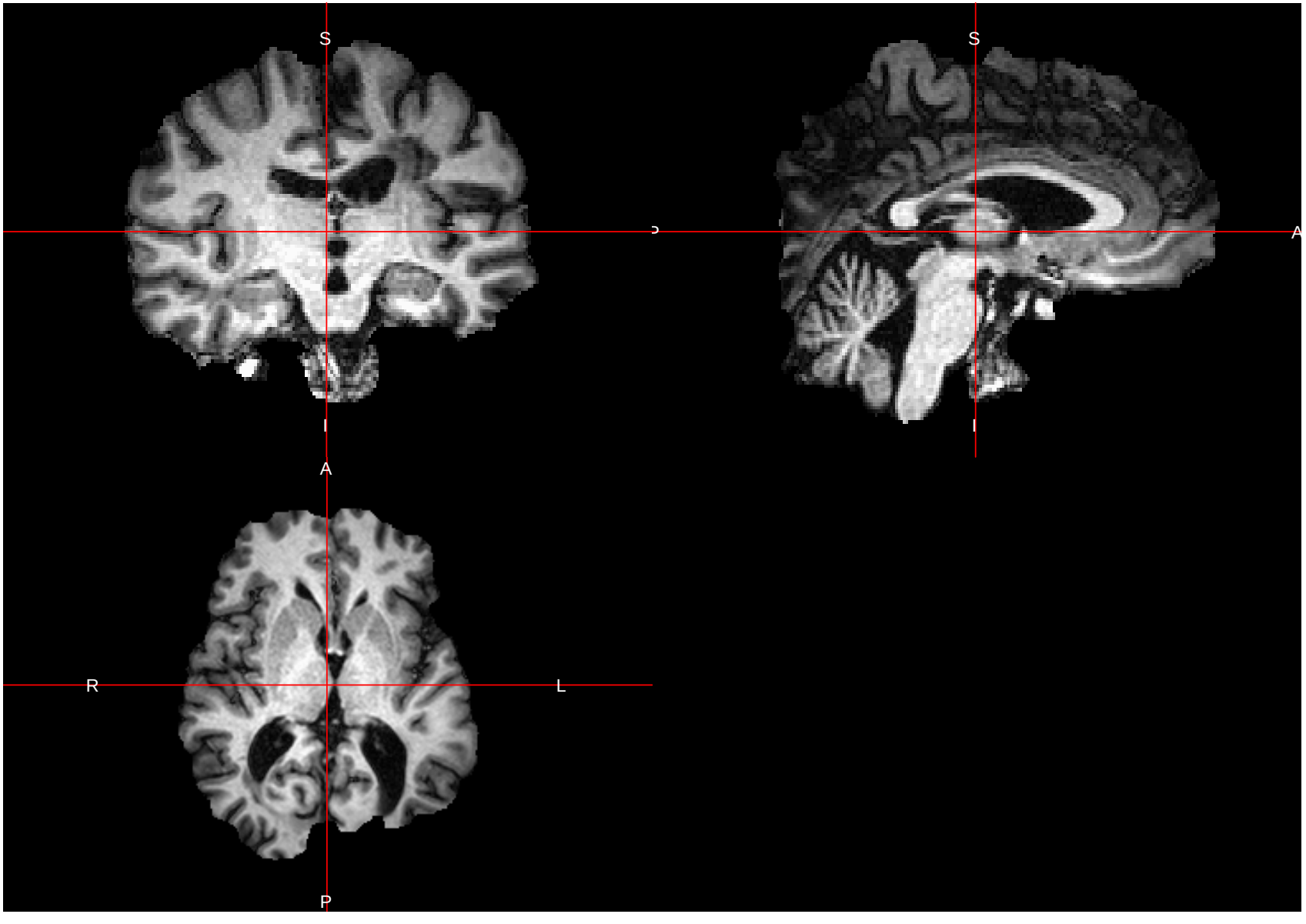
`fslr::fslbet` - takes in a filename/nifti

- additional options can be passed to FSL command in using `opts`

```
library(fslr)
ss = fslbet(infile = t1_fname)
```

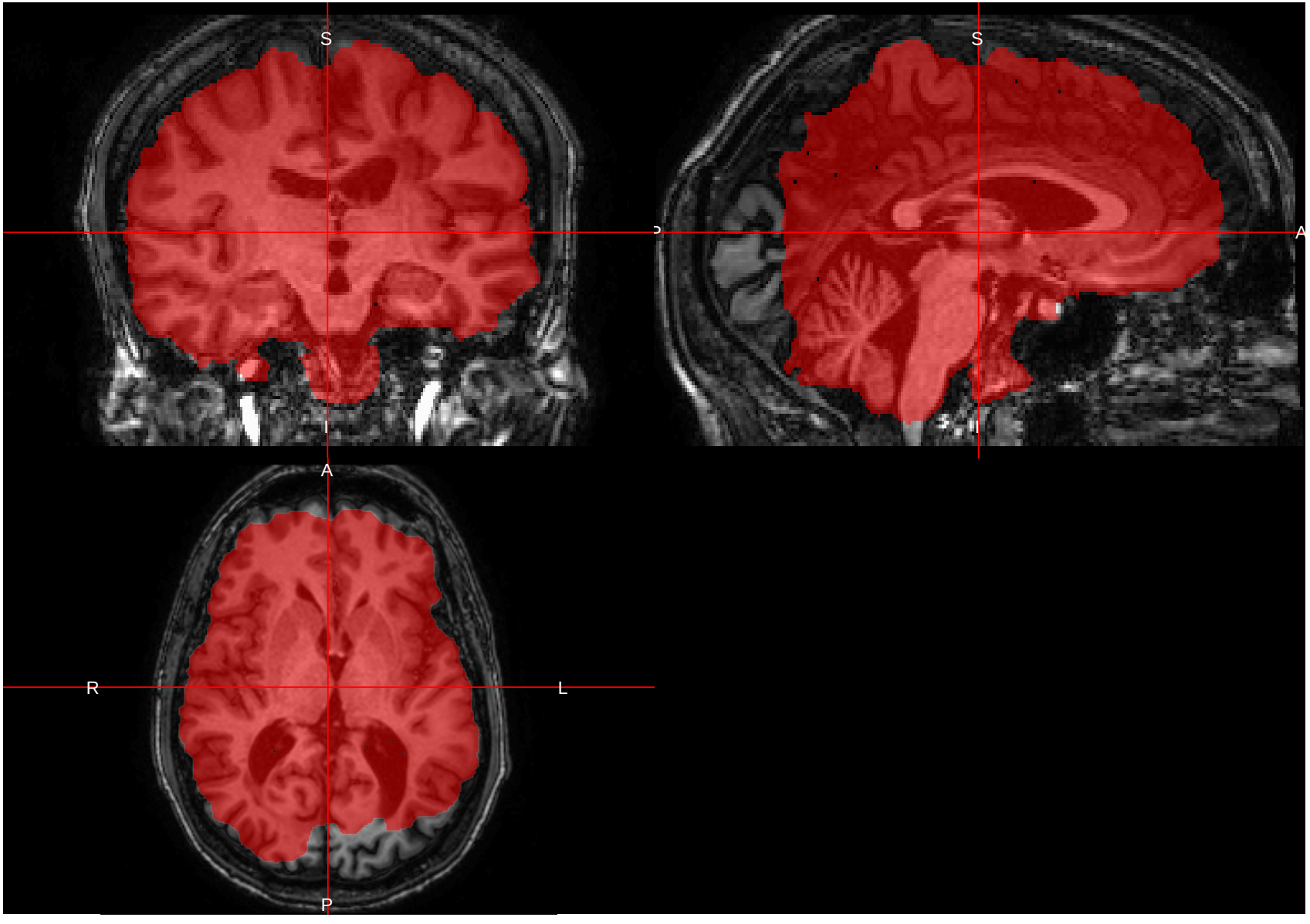
FSL BET Results - Missing Brain Tissues (Posterior)

```
ortho2(robust_window(ss))
```



FSL BET Results not Satisfactory

```
ortho2(rt1, ss > 0, col.y = red0.5)
```



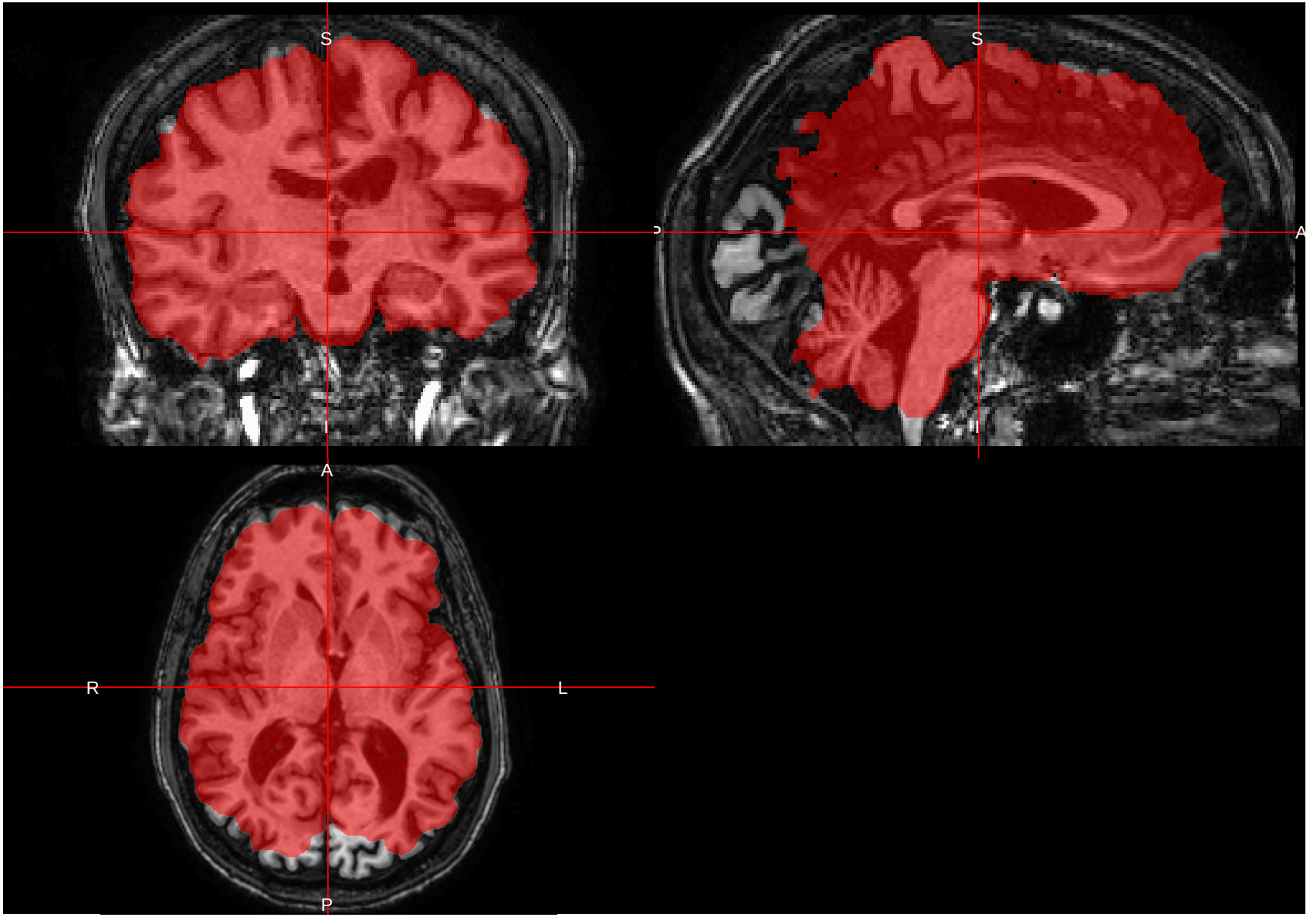
Attempt 2: Bias Correct before BET (recommended)

Before doing skull-stripping/brain extraction, we would do bias correction:

```
library(extrantsr)
bc_img = bias_correct(file = t1, correction = "N4")
```

BET on N4 Corrected Image Unsatisfactory

```
bc_bet = fslbet(bc_img); ortho2(bc_img, bc_bet > 0, col.y =
```



Attempt 3: Brain Extraction of T1 image using MALF

Figure from Doshi et al. (2013):

Attempt 3: Brain Extraction of T1 image using MALF

Multi-Atlas Fusion:

- Register templates to an image using the T1 for that subject
- Apply transformation to the label/mask
- Average each voxel over all templates
- there are "smarter" (e.g. weighted) ways
- `malf.templates` package has templates provided by Neuromorphometrics, Inc. (`http://Neuromorphometrics.com/`) form MICCAI 2012 Challenge on Multi-atlas Labelling (Bennett Allan Landman et al. 2012)
- hand segmentations of the brain and brain structures

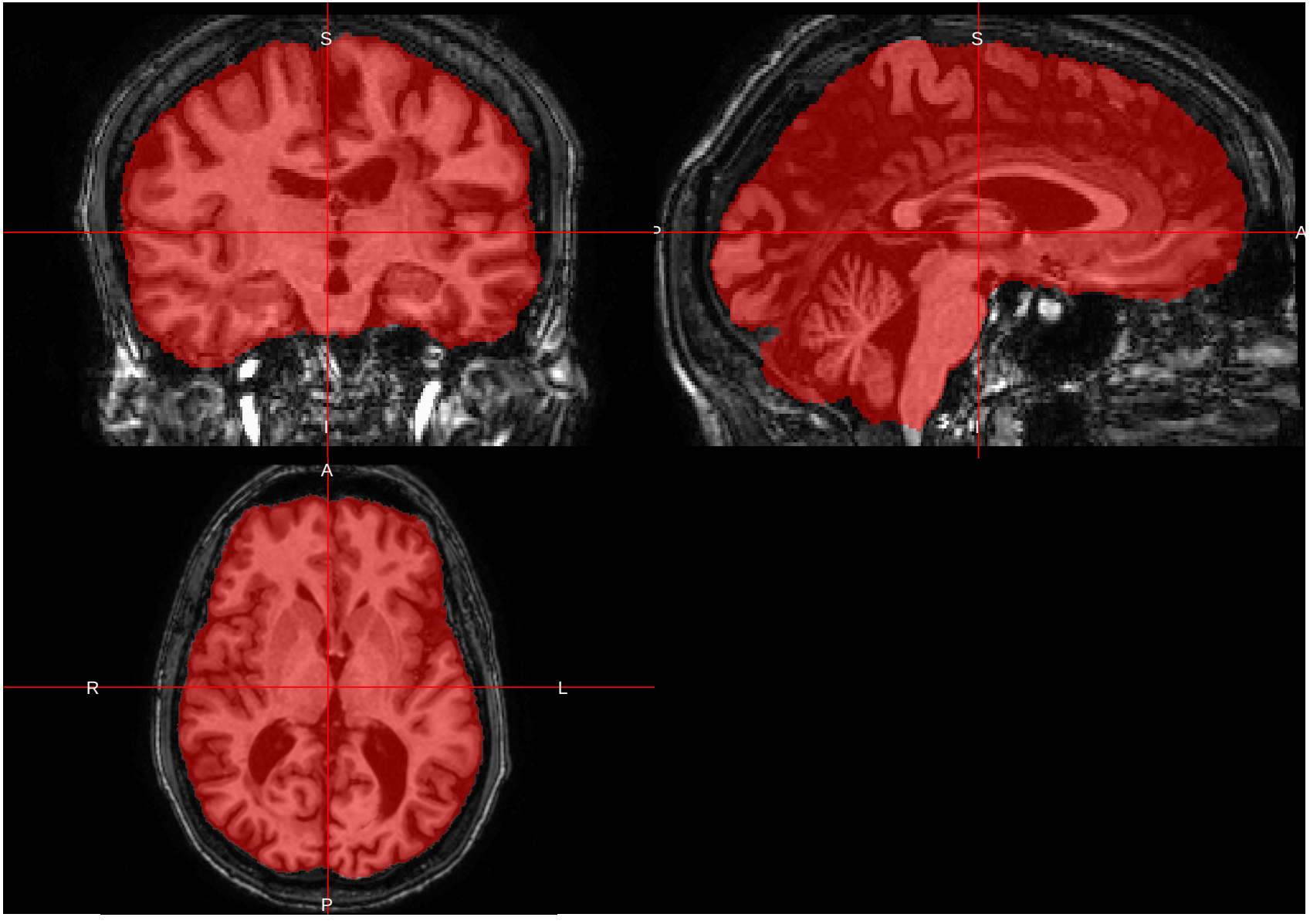
MALF - use extrantsr::malf

- Function requires arguments: `template.images` (T1-weighted images in this case) and `template.structs` (labels/structures/masks, brain masks here)
- Performs non-linear registration using Symmetric Normalization (`SyN`) (B. B. Avants et al. 2008), a form of diffeomorphic registration:

```
library(malf.templates) # load the data package
library(extrantsr)
timgs = mass_images(n_templates = 5) # let's register 5 te
ss = extrantsr::malf(
  infile = bc_img,
  template.images = timgs$images,
  template.structs = timgs$masks,
  keep_images = FALSE # don't keep the registered images
)
```

MALF performs well

```
ortho2(bc_img, ss > 0, col.y = red0.5)
```



Processed Results Available in `ms.lesion`

In the `ms.lesion` package, we have the brain masks for each subject located in the `coregistered` folder. You can access this data using the `type = "coregistered"`

```
files = get_image_filenames_list_by_subject(
  type = "coregistered")$training01
files["Brain_Mask"]
```

```
[1] "library/ms.lesion/extdata/coregistered/training01/brai
```

Conclusions from the MS data

- FSL BET can perform brain extraction (we will show when it works)
- it did not work sufficiently here
- there are options you can change for performance
- Bias-correction before brain extraction is a good idea
  - especially if the method depends on intensities
- MALF/MASS is a good option, but needs templates and is computationally expensive
  - weighted templates or local weighting is done in other software (not discussed)

Additional Example

FSL BET did not work in the previous data set. It works in many cases, though. We will look at a subject from the kirby21 dataset (Bennett A Landman et al. 2011).

Kirby21

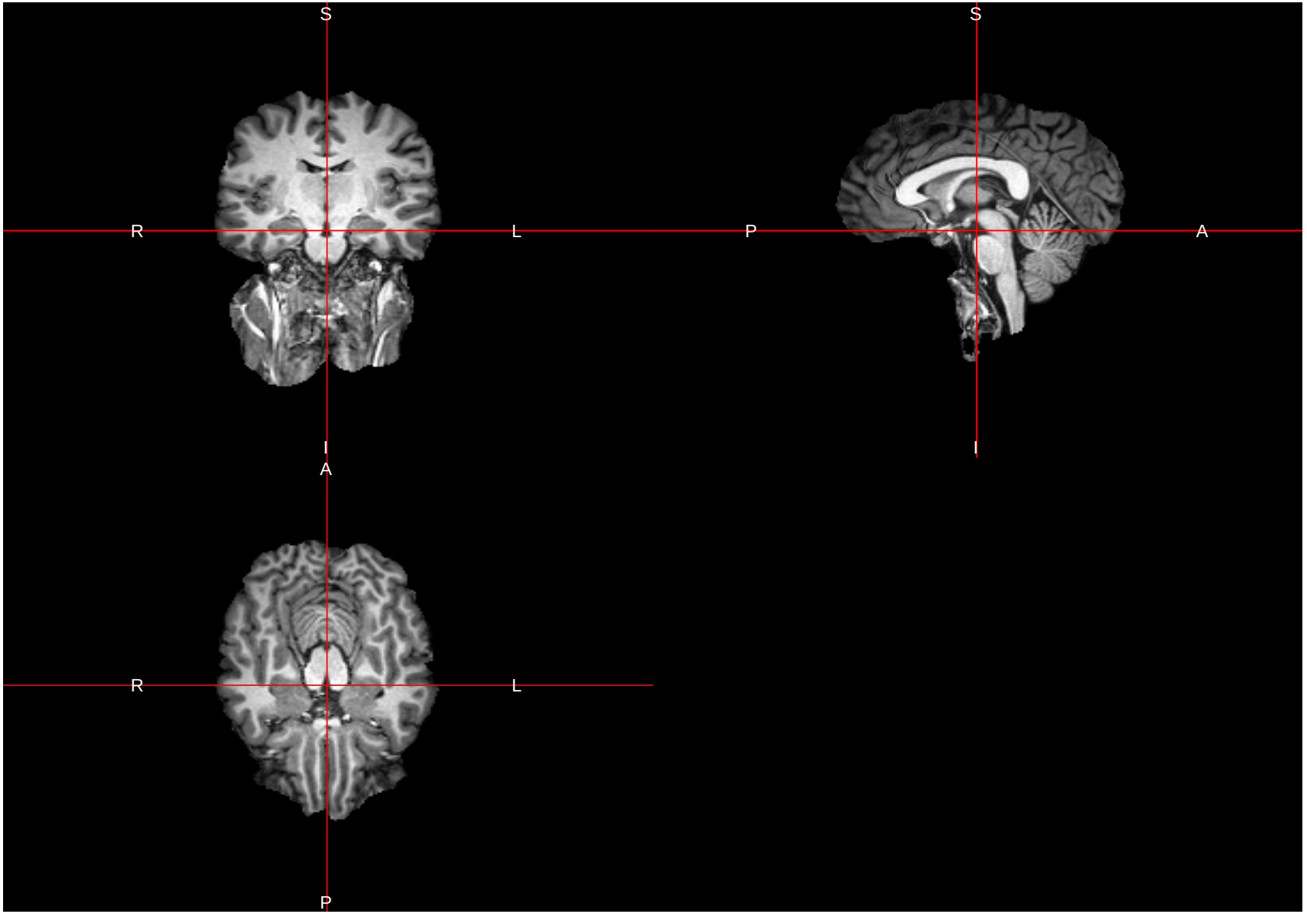
```
library(kirby21.t1)
t1_fname = get_t1_filenames()[1]
t1 = readnii(t1_fname)
```

T1 image has the neck!

```
ortho2(robust_window(t1))
```

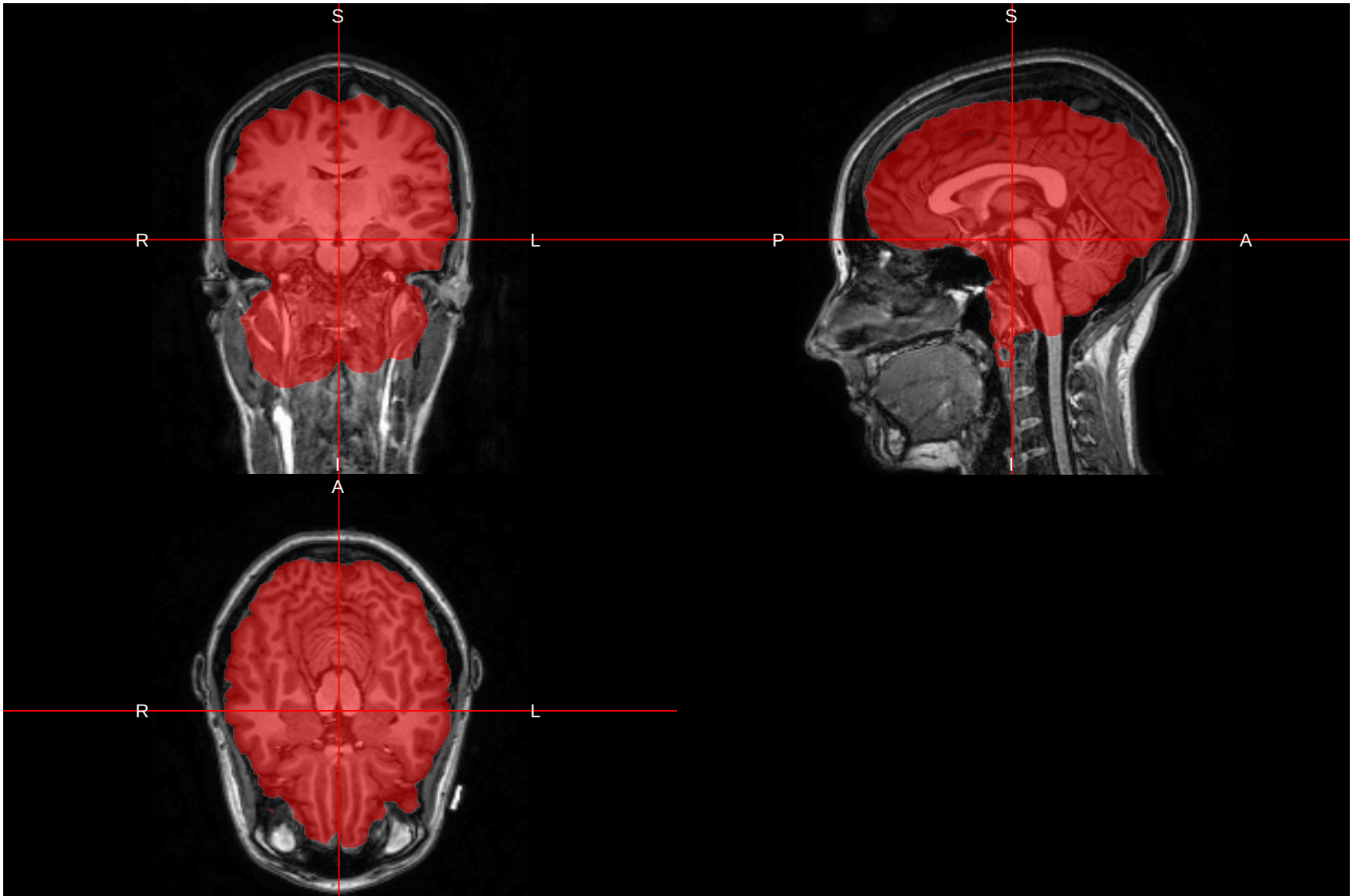
Neck messes up BET

```
ss = fslbet(infile = t1_fname); ortho2(robust_window(ss))
```



Recommend to Bias Correct first: not fixed

```
bc_img = bias_correct(t1, correction = "N4"); bc_bet = fslb
ortho2(robust_window(t1), bc_bet > 0, col.y = red0.5)
```



BET with neck removal

We use the modification of BET in `extrantsr`, which is called through `fslbet_robust`. `fslbet_robust`:

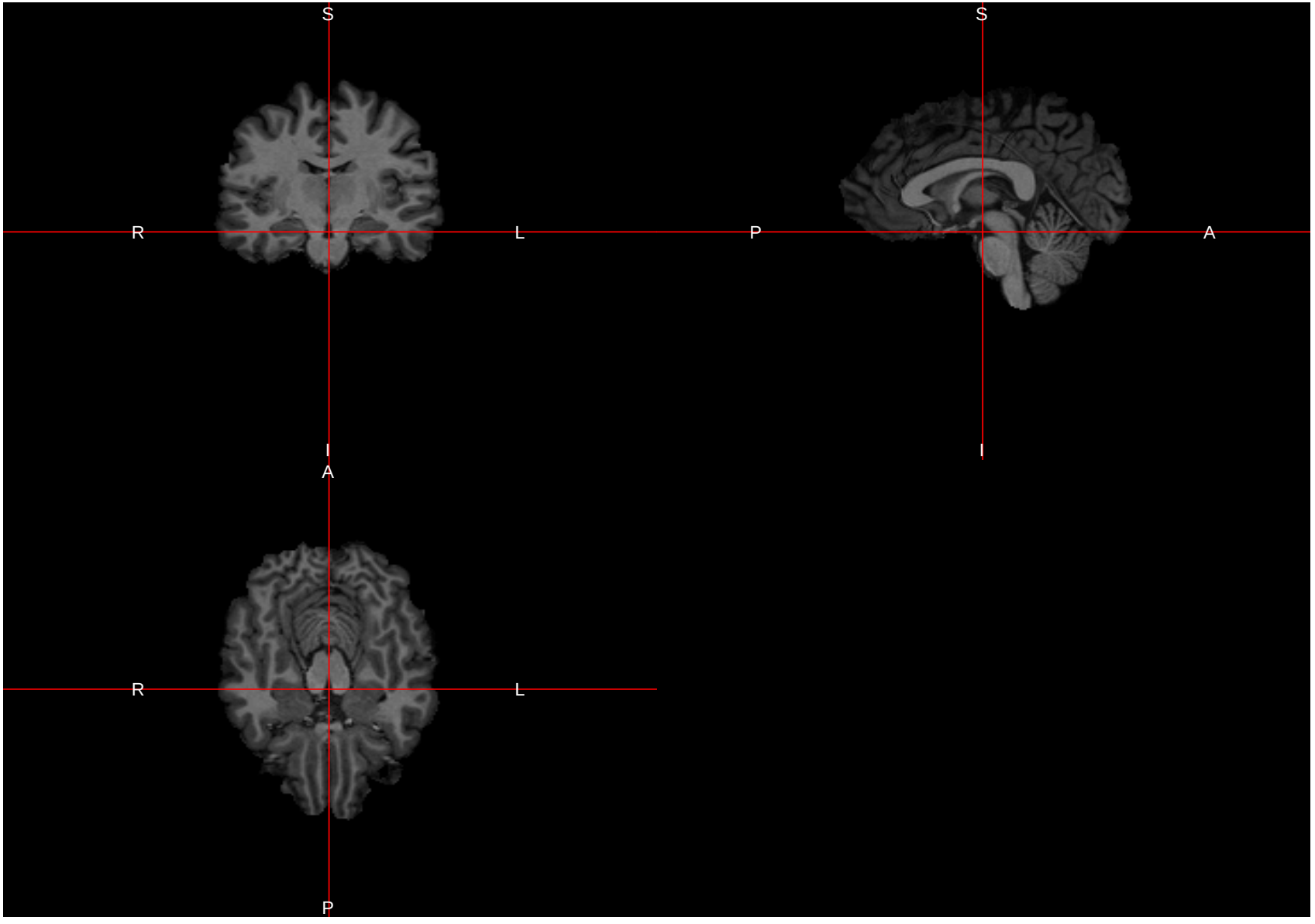
- bias correct image
- remove neck (`double_remove_neck` performs 2 registration steps, more robust than one (which is the default).)
- run BET
- estimate center of gravity (COG)
- run BET again with new COG

fslbet_robust syntax

```
ss = extrantsr::fslbet_robust(
  t1,
  remover = "double_remove_neck",
  correct = TRUE,
  correction = "N4",
  recog = TRUE)
```

BET with neck removal - works well!

```
ortho2(ss)
```



Conclusions

- Brain extraction allows you to analyze the brain only
- Important for tissue segmentation/registration
- BET can work well (look at your data!)
- Should bias correct first
- May need to remove neck
- High values may affect results - may need to remove/Winsorize them

References

Avants, B. B., C. L. Epstein, M. Grossman, and J. C. Gee. 2008. "Symmetric Diffeomorphic Image Registration with Cross-Correlation: Evaluating Automated Labeling of Elderly and Neurodegenerative Brain." *Medical Image Analysis*, Special issue on the third international workshop on biomedical image registration - WBIR 2006, 12 (1): 26–41. doi:10.1016/j.media.2007.06.004.

Doshi, Jimit, Guray Erus, Yangming Ou, Bilwaj Gaonkar, and Christos Davatzikos. 2013. "Multi-Atlas Skull-Stripping." *Academic Radiology* 20 (12). Elsevier: 1566–76.

Jenkinson, Mark, Christian F. Beckmann, Timothy E. J. Behrens, Mark W. Woolrich, and Stephen M. Smith. 2012. "FSL." *NeuroImage* 62 (2): 782–90. doi:10.1016/j.neuroimage.2011.09.015.

Landman, Bennett A, Alan J Huang, Aliya Gifford, Deepti S Vikram, Issel Anne L Lim, Jonathan AD Farrell, John A Bogovic, et al. 2011. "Multi-Parametric Neuroimaging Reproducibility: A 3-T Resource Study." *Neuroimage* 54 (4). Elsevier: 2854–66.

`https://www.nitrc.org/projects/multimodal/`.