# Automated Olfactory Bulb Segmentation on High-Resolutional T2-Weighted MRI

Santiago Estrada[1], Ran Lu[1], Kersten Diers[1], Weiyi Zeng[1], Philipp Ehses[1], Tony Stöcker[1,2], Monique M.B Breteler[1,3], and Martin Reuter[1,4]
[1] German Center for Neurodegenerative Diseases (DZNE), Bonn, Germany
[2] Department of Physics and Astronomy, University of Bonn, Germany
[3] IMBIE, Faculty of Medicine, University of Bonn, Bonn, Germany
[4] Department of Radiology, Harvard Medical School, Boston MA, USA

## Introduction

- The olfactory bulb (OB) plays a crucial role in olfactory function.
- To date, there is a lack of an automatic processing method for OB segmentation in the neuroimage analysis community.
- Automatic OB segmentation is a challenging task due to its small size, location and poor visibility on traditional MRI scans.
- Here, we introduce the first publicly available deep learning pipeline to segment the OBs in sub-millimeter T2-weighted whole-brain MRI.
- The proposed pipeline is tested and validated in the Rhineland Study – a large prospective cohort study based in Bonn, Germany.

## Our Proposal

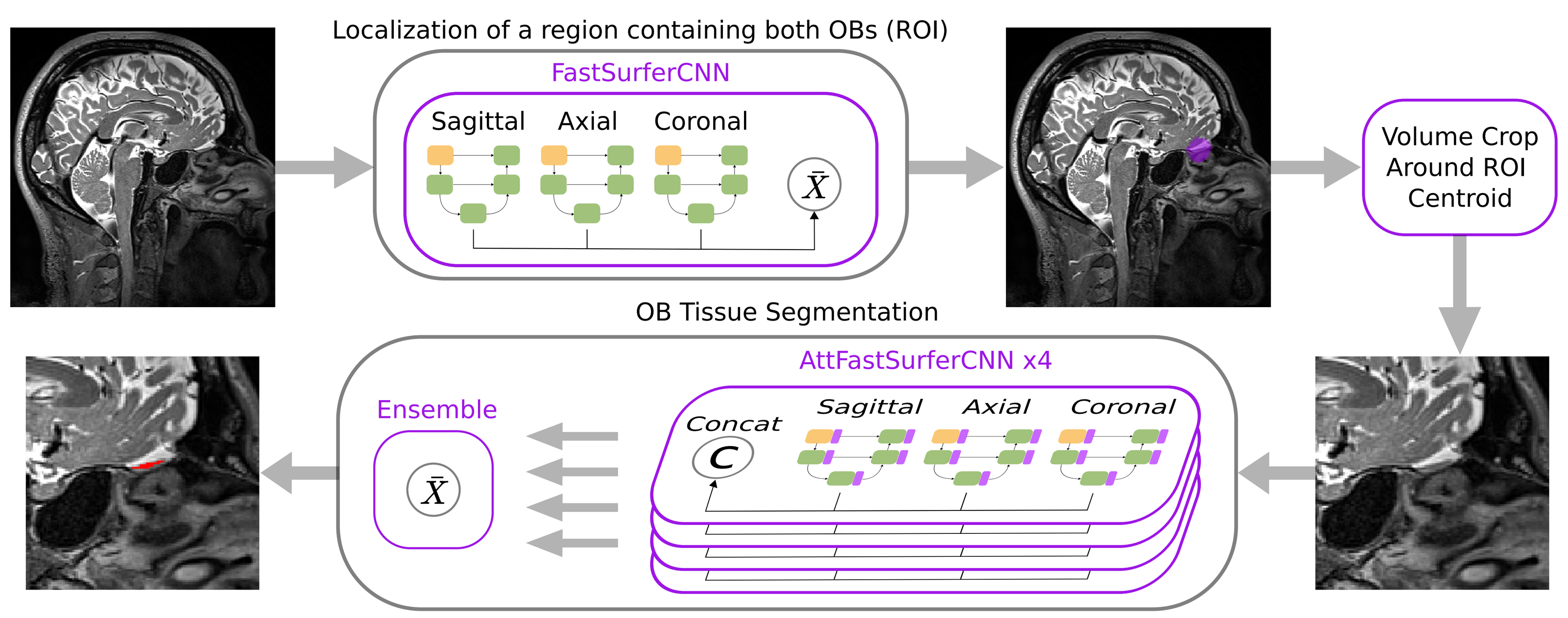



Fig 1. Proposed pipeline for OB segmentation. The pipeline is divided in three stages: First, localization of a ROI containing both OBs. Then, OB tissue segmentation within the localized volume, and finally, an ensemble of the predicted label maps.

- We modify our *FastSurferCNN*[1] to focus on the OB.
- To improve performance for small structures, we suitably included the self-attention mechanism proposed by Zhang et al.[2] into *FastSurferCNN.*
- The new architecture termed *AttFastSurferCNN* promotes attention to spatial information by improving the modeling of local and global-range dependencies, which in turn increases semantic consistency.
- The pipeline combines the prediction of four *AttFastSurferCNNs,* ensuring that only OB voxels with a high inter-model agreement are segmented.

## Ground Truth Dataset Characteristics

| Usage | Cohort | N | Age Range | Women, n (%) |
|---|---|---|---|---|
| Training set | The Rhineland Study | 357 | 30-85 | 204 (57.1%) |
| Testing set | | 203 | 30-87 | 114 (56.2%) |
| Generalizability set | Human Connectome Project (HCP)[3] | 30 | 22-35 | 14 (46.6%) |

## Validation in the Rhineland Study (N=203)

### - OB Segmentation Accuracy

| Network | Dice Mean (SD) | AVD Mean (SD) |
|---|---|---|
| *AttFastSurferCNN* | **0.8525 (0.0561)*** | 0.2692 (0.1913) |
| *FastSurferCNN* | 0.8506 (0.0577) | **0.2667 (0.1860)** |
| Inter-rater variability | 0.8211 (0.0590) | 0.3057 (0.2685) |

Significance : * $p < 0.05$, paired Wilcoxon signed-rank test

### - Replication of known age and sex effect on OB volumes

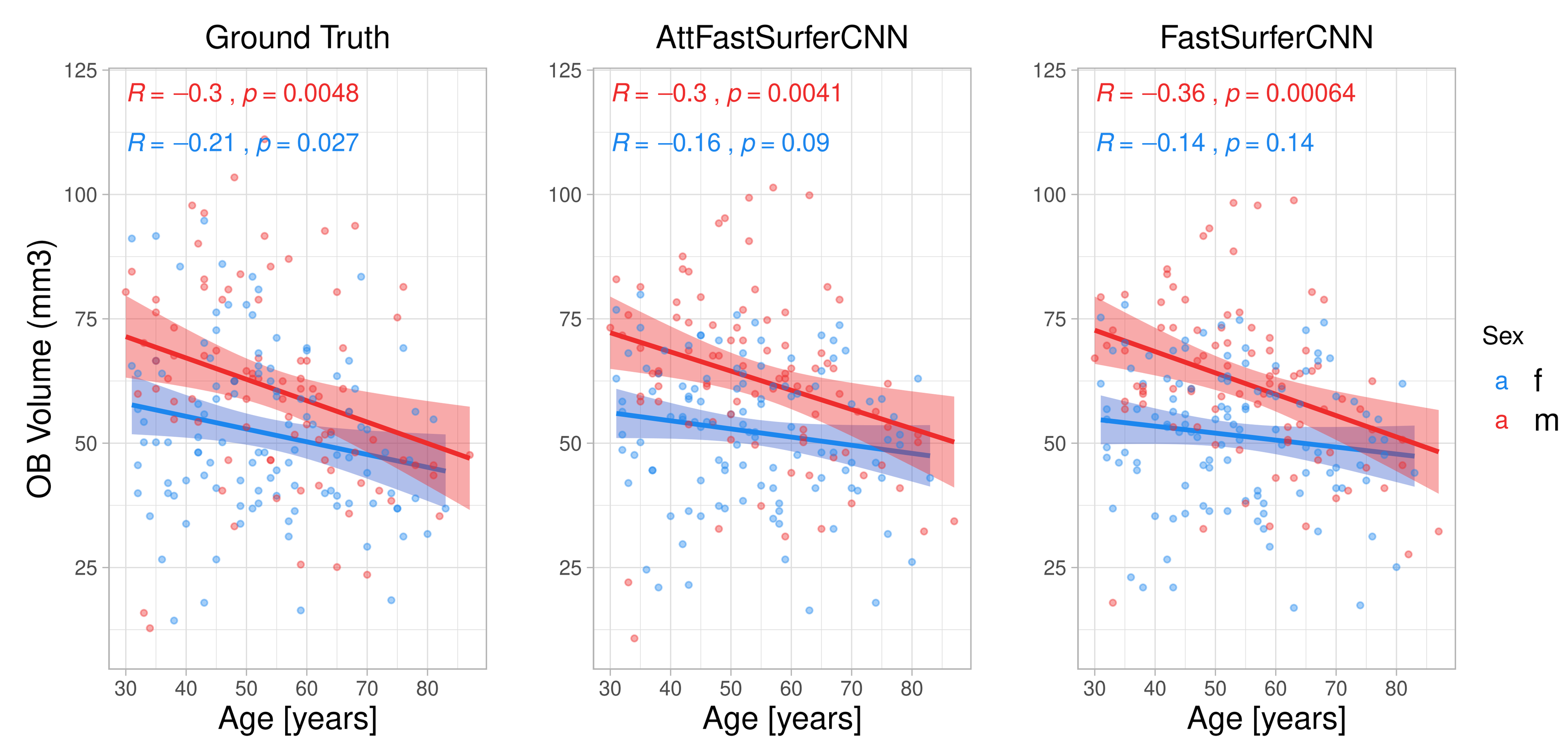
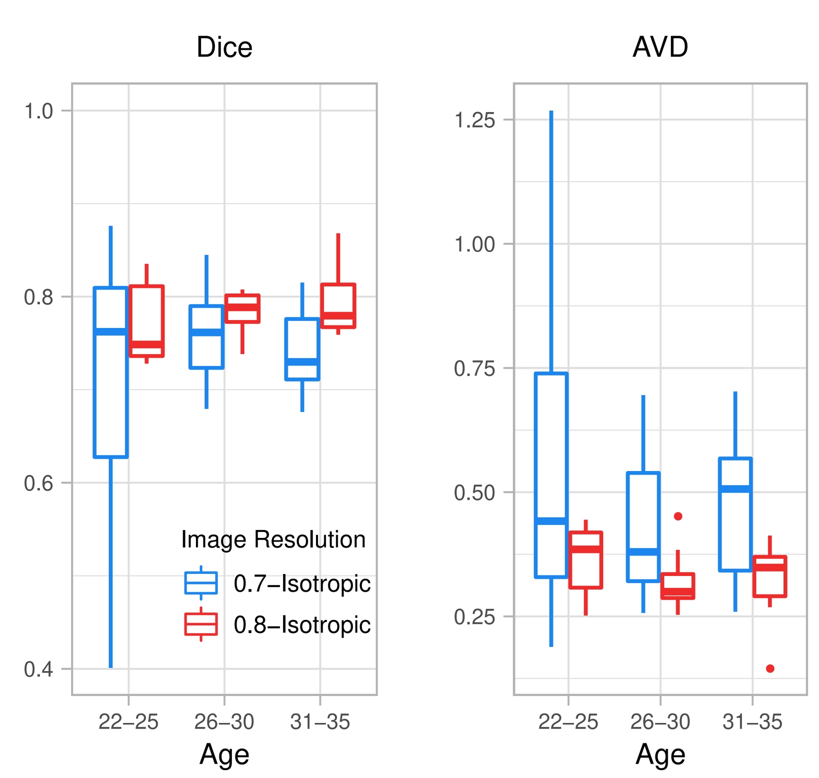



Fig 2. Association between age and olfactory bulb volumes in men and women for the ground truth (manual labels) and automated methods.

- The predicted OB volumes are significantly decreased with age (*AttFastSurferCNN*: ($\beta$ =-0.230, $p<0.01$), and *FastSurferCNN* :($\beta$ =-0.203, $p<0.01$)) , following the behaviour of the manual data ($\beta$=-0.319, $p<0.01$) and other studies[4,5].
- *AttFastSurferCNN* presents an improvement in the modeling of the age effects compared to the standard *FastSurferCNN* ($R^2$ : **0.205** vs 0.193).

## Generalizability in the HCP dataset (N=30)




- Segmentation results are more stable at original training resolution ( 0.8 mm isotropic).
- Accuracy decreases at native HCP resolution, specifically for ages outside the training range (22 to 25).
- HCP consist of de-faced scans, never encounter during training.

Fig 3. Segmentation similarity scores from the HCP dataset stratified by age category, as well as comparison of the pipeline's performance at native HCP resolution (0.7 mm isotropic) and at the networks original training resolution (0.8 mm isotropic).

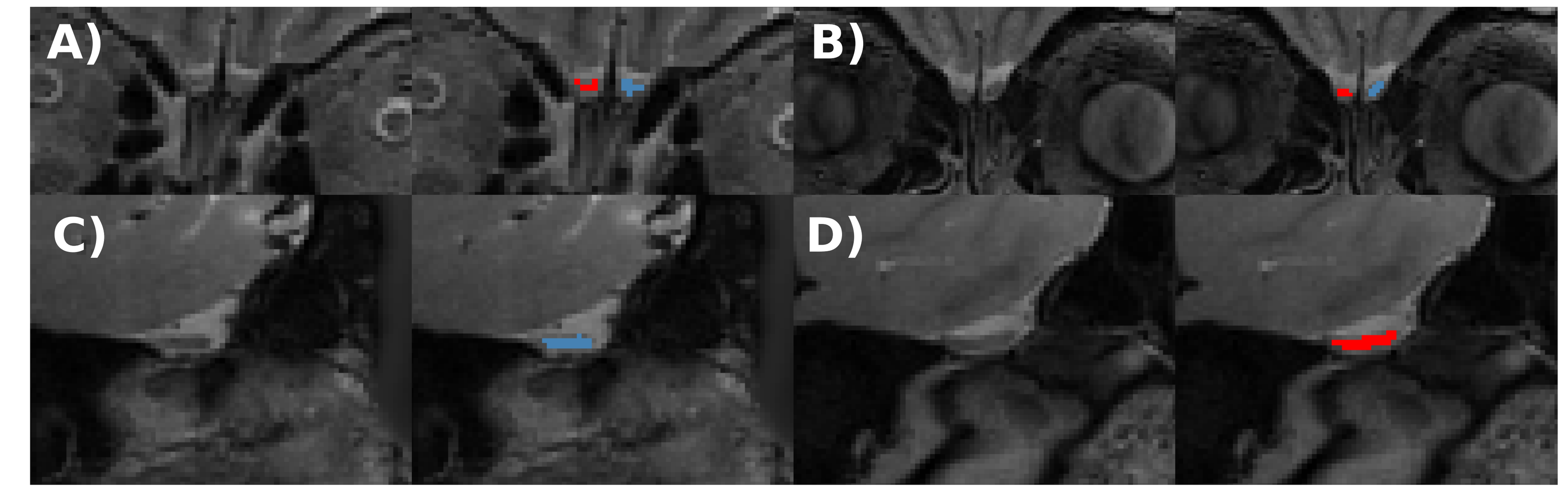



Fig 4. Examples of the pipeline results in the Rhineland Study (A-B) and HPC dataset (C-D). Accurate automatic segmentation of total OB on a heterogenous population (blue : left OB and red : right OB).

## Conclusion

- The proposed pipeline provides a robust and reliable solution for assessing OB volumes in a large cohort study.
- *AttFastSurferCNN* recovers OB significantly better than the standard *FastSurferCNN* and outperforms manual inter-rater scores.
- *AttFastSurferCNN* shows an improvement when evaluating volume associations despite the slight changes at the image metric level.
- The pipeline shows good generalizability to an independent dataset (HCP) with different acquisition parameters and demographics.
- The pipeline is rigorous validated in terms of segmentation accuracy, as well as sensitivity to replicate known OB volume associations.

## Contact and tool

Email : santiago.estrada@dzne.de
Webpage : deep-mi.org
Tool : github.com/Deep-MI/olf_bulb_segmentation
Follow us on twitter : @deepmilab

## References

[1] L. Henschel, S. Conjeti, S. Estrada, K. Diers, B. Fischl, M. Reuter, Fastsurfer-a fast and accurate deep learning based neuroimaging pipeline, NeuroImage 219 (2020) 117012.
[2] H. Zhang, I. Goodfellow, D. Metaxas, A. Odena, Self-attention generative adversarial networks, in: International conference on machine learning, PMLR, 2019, pp. 7354–7363.
[3] D. C. Van Essen, K. Ugurbil, E. Auerbach, D. Barch, T. E. Behrens, R. Bucholz, A. Chang, L. Chen, M. Corbetta, S. W. Curtiss, et al., The human connectome project: a data acquisition perspective, Neuroimage 62 (2012) 2222–2231.
[4] D. Buschhuter, M. Smitka, S. Puschmann, J. C. Gerber, M. Witt, N. Abolmaali, T. Hummel, Correlation between olfactory bulb volume and olfactory function, Neuroimage 42 (2008) 498–502.
[5] T. Hummel, A. Urbig, C. Huart, T. Duprez, P. Rombaux, Volume of olfactory bulb and depth of olfactory sulcus in 378 consecutive patients with olfactory loss, Journal of neurology 262 (2015) 1046–1051.