

Toward Deeper Insights into Brain Ageing: Modelling with Explainable Vision Transformers

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Introduction

Machine learning, particularly through advanced imaging techniques such as three-dimensional Magnetic Resonance Imaging (MRI), has significantly enhanced medical diagnostics—especially in analyzing complex conditions like brain ageing. In this study, we introduce **Triamese-ViT** [1], an innovative tri-structured Vision Transformer (ViT) architecture with built-in interpretability. Triamese-ViT offers structure-aware explainability, enabling the identification and visualization of key features or regions that contribute to its predictions. By integrating information from three complementary perspectives, it enhances the accuracy of brain age estimation while maintaining interoperability with existing methods. When evaluated, Triamese-ViT demonstrated superior performance and produced informative attention maps. These maps were applied to analyze natural ageing and sex differences, and

their interpretability was further validated using the traditional explainable AI (XAI) technique of occlusion analysis.

Materials and methods

Figure 1 depicts the architecture of our model, 'Triamese-ViT'. This model processes brain MRI images from three distinct perspectives utilizing the vision transformer to extract unique features. These features are then integrated within a Multi-Layer Perceptron (MLP) framework to generate age predictions. A built-in interpretability function generates 3D-like images to explain different brain regions influence during prediction.

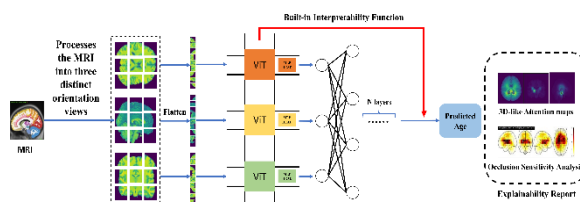


Figure 1. Structure of Triamese-ViT.

Results

The built-in interpretability results (Figure 2) aligned with those from occlusion analysis, identifying the Cingulum,

Rolandic Operculum, Thalamus, and Vermis as important regions in normal ageing (Figure 3). And they also revealed pronounced hemispheric asymmetries, especially in females, where left-hemisphere regions were predominantly youth-preserving and right-hemisphere regions—particularly the visual cortex and precuneus, showed age-accelerating effects. In contrast, males exhibited more bilateral and diffuse ageing patterns, with age-accelerating regions notably concentrated in the cerebellum (Figure 4). Over half of the analyzed regions displayed opposite effects between sexes.

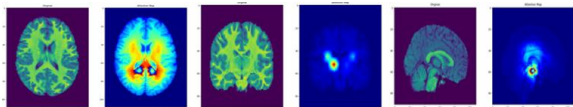


Figure 2. Our built-in interpretability function provides explanations.

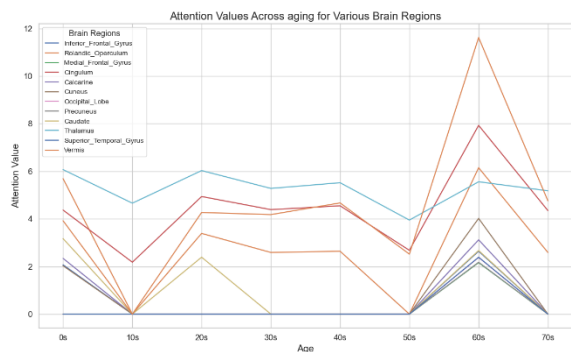


Figure 3. The attention trend lines for the most important regions throughout natural ageing based on the built-in interpretation.

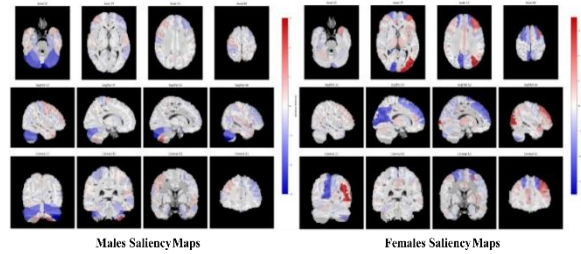


Figure 4. The significant gender difference in different brain regions during ageing.

Discussion

This aspect of our findings paves the way for further research and highlights the profound and reliable insights offered by Tri-ViT. It establishes Tri-ViT as an invaluable tool for advancing our comprehension of brain ageing. Future research could focus on validating these findings in clinical trials, exploring the use of Tri-ViT in personalized treatment plans, and further enhancing its interpretability to better support healthcare professionals in their decision-making processes.

References

- 1) Z. Zhang, V. Aggarwal, P. Angelov and R. Jiang, "Modeling Brain Ageing with Explainable Triamere ViT: Towards Deeper Insights into Autism Disorder," in *IEEE Journal of Biomedical and Health Informatics*, 2025, 2025 May 27:PP. doi: 10.1109/JBHI.2025.3574366.

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