

A Unified Framework for Estimating Brain Age and Aging Velocity from MRI Data



Yuanwang Zhang ✉ ywzhang3@seas.upenn.edu, Hongming Li ✉ Hongming.Li@pennmedicine.upenn.edu, Yong Fan ✉ Yong.Fan@pennmedicine.upenn.edu

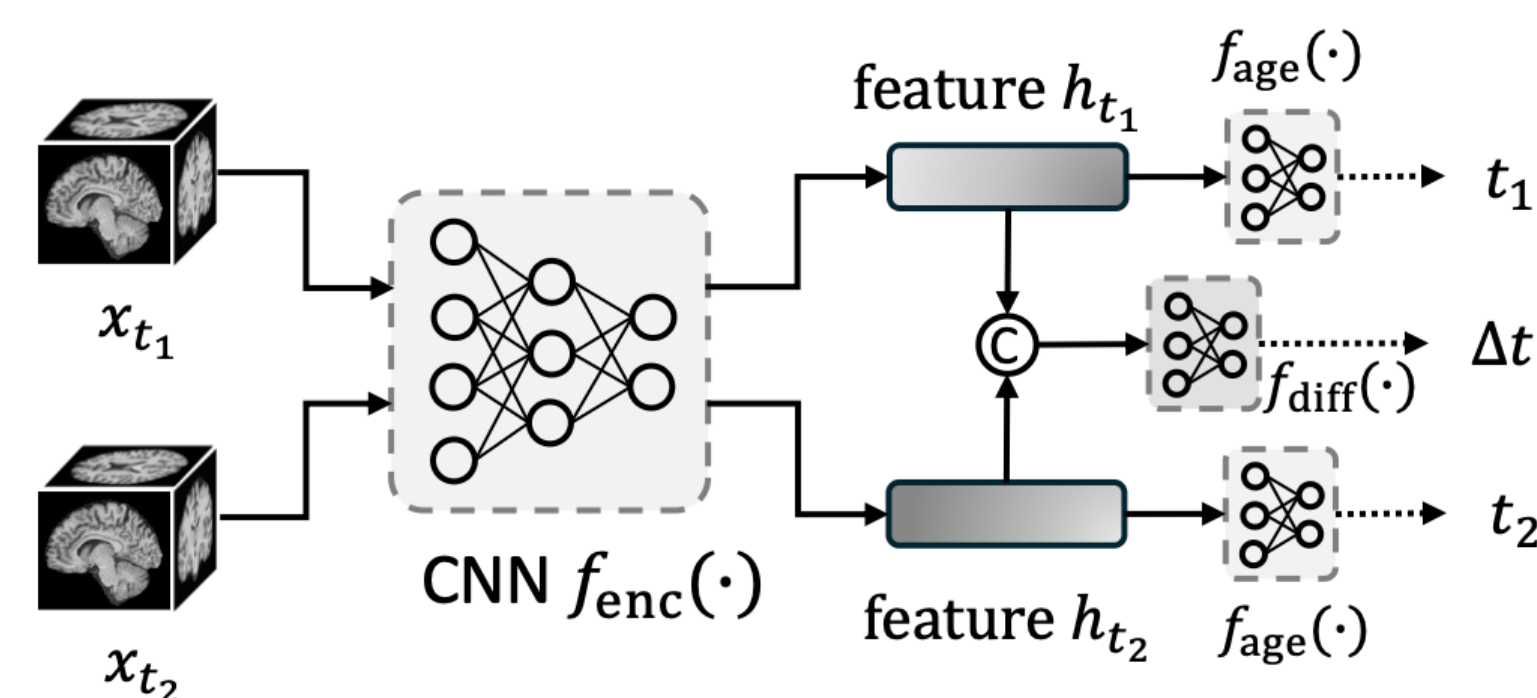
AI2D, Center for Biomedical Image Computing and Analytics (CBICA), Perelman School of Medicine, University of Pennsylvania

Brain age delta and aging speed estimated from MRI data are promising biomarkers of brain health. Brain age delta captures cross-sectional brain status, while aging speed captures ongoing temporal structural change. A single unified deep learning model is proposed, which estimates both biomarkers from T1-weighted MRI data with improved performance.

INTRODUCTION

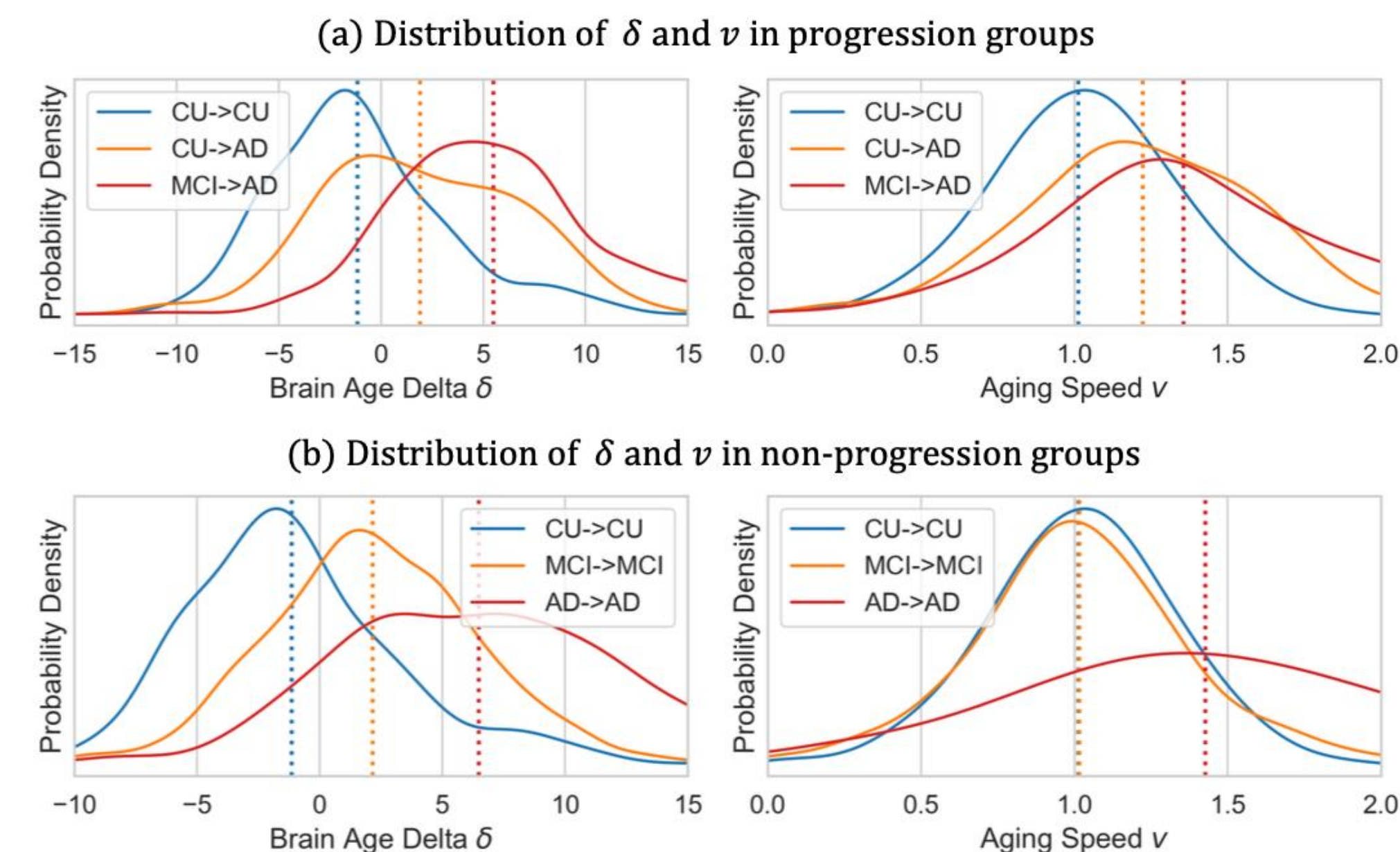
Brain age estimated from cross-sectional MRI provides a snap-shot of brain health relative to chronological age, and the derived brain age delta has emerged as a promising biomarker of brain aging. However, cross-sectional models primarily capture cumulative aging effects at a single time point and do not characterize ongoing aging velocity. Longitudinal models estimate age differences between scan pairs, many existing works overlook baseline effects, limiting their interpretability and generalizability. This study introduces a novel unified framework that jointly models cross-sectional brain age and longitudinal aging velocity.

METHOD



4,417 T1-weighted MRI scans from 1,156 cognitive unimpaired (CU) subjects were collected across ADNI, OASIS-3 and AIBL to train the proposed deep learning model to estimate normative brain age and age differences. Mean absolute error was used as the loss function. The trained model was then applied to subjects with mild cognitive impairment (MCI) and dementia. Two biomarkers were derived: brain age delta, estimated as brain age minus chronological age, and aging velocity, estimated as brain age difference divided by chrono-logical age difference.

RESULTS



The model achieves a mean absolute error (MAE) of 3.44 years and an average R^2 of 0.77 for brain age estimation, and an MAE of 0.92 years with an average R^2 of 0.79 for brain age difference estimation. Subjects with clinical progression, e.g., from CU to MCI or AD, exhibited significantly higher aging velocity than those in the non-progression group, while subjects diagnosed with MCI or AD consistently showed increased brain age delta regardless of progression status.

CONCLUSIONS

Brain age delta and aging velocity provide complementary information of brain health, with brain age delta reflecting cross-sectional status and aging velocity characterizing temporal structural change. The joint modeling of these two biomarkers not only improves prediction accuracy but also enhances clinical utility, regardless of whether longitudinal scans are available.

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