Effect of data leakage in brain MRI classification using 2D convolutional neural networks

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http://adni.loni.usc.edu/wp-ontent/uploads/how_to_apply/ADNI_Acknowledgement_List.pdf

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Short title: Data leakage in brain MRI

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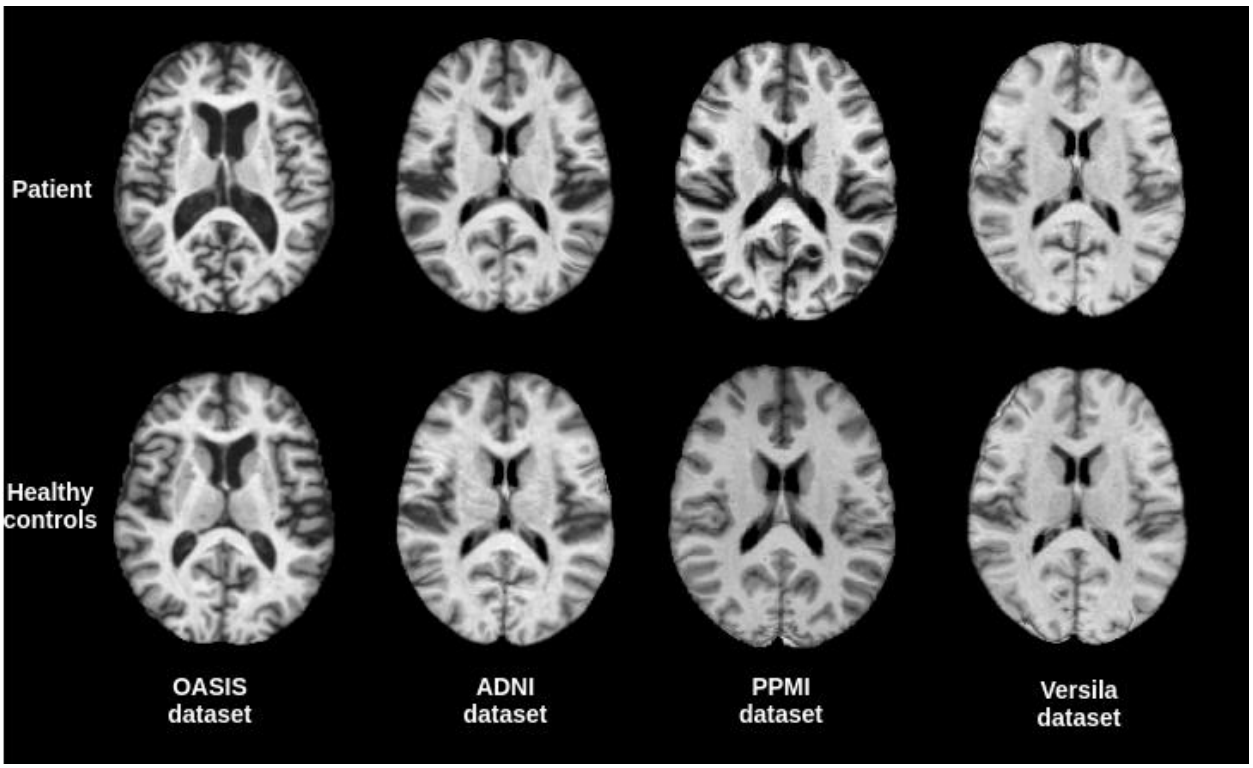
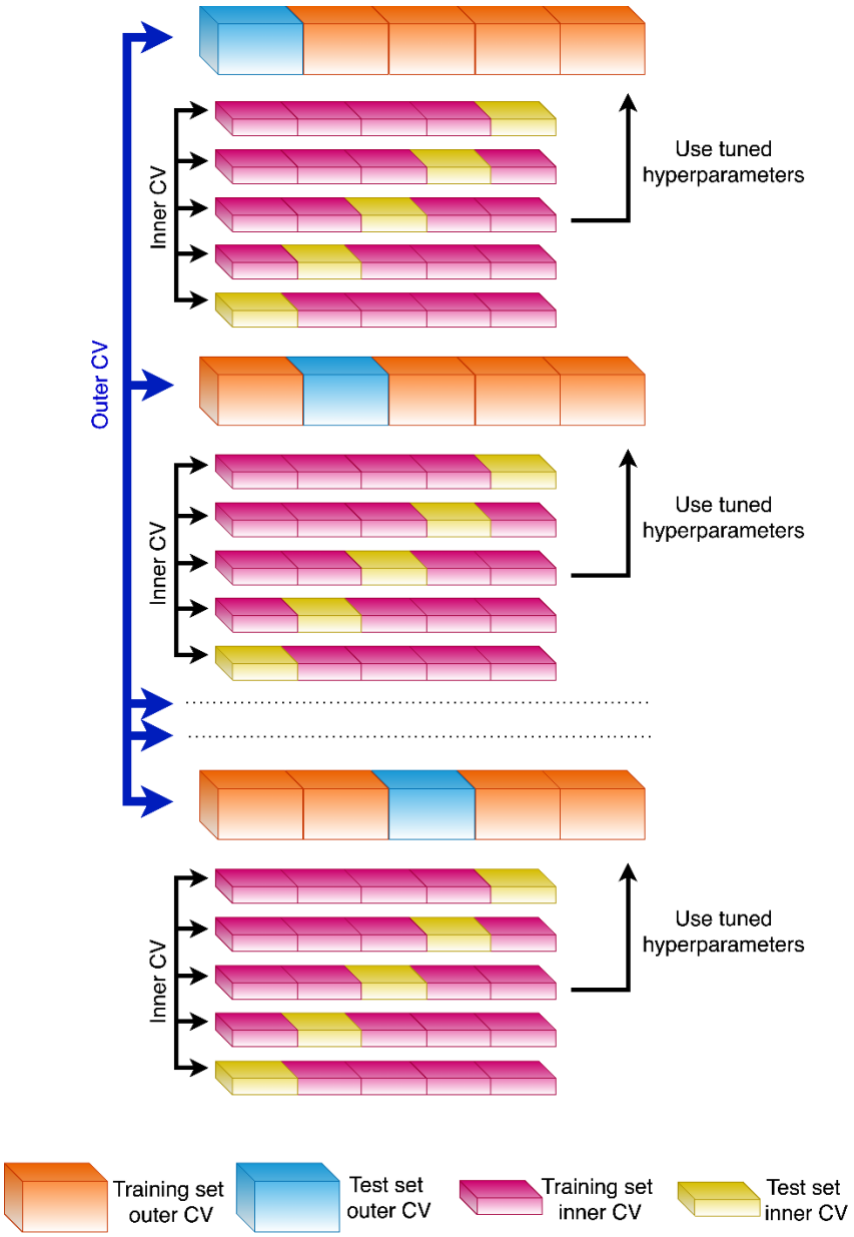
Supplementary Figure S1. Sample preprocessed T_1-weighted axial images from OASIS-200, ADNI, PPMI and Versilia datasets.



Supplementary Figure S2. A scheme of nested CV is represented: the inner CV loop is used to optimize hyperparameters, whereas the outer loop estimates the selected models' performance.



Supplementary Table S1. Summary of the previous studies performing classification of neurological disorders using MRI and with clear data leakage.

Reference	Description
Gunawardena et al., 2017[36]	*"The MRI scan produces a 3-dimensional (3D) model of the body. Performing image processing techniques in a 3D MRI film is hard. Therefore it is necessary to convert those 3D MRI films into a series of 2D images before doing any preprocessing […] Series of 2D images were pre-processed before feature extraction and classification […] Preprocessed images were further processed in order to achieve the best result. All the images which were to be input to the CNN model were resized into 160 x 160 dimension because different sizes may reduce the accuracy of the classification […] Afterward, the data set was shuffled. Then the data set has been divided (split) into training set and testing set with a ratio of 80/20 (80% for training and 20% for testing)."*
Hon & Khan, 2017[21]	*"Typically, from a 3D MRI scan, we have a large number of images that we can choose from. In most recent methods, the images to be used for training are extracted at random. Instead, in our porposed method, we extract the most informative slices to train the network. For this, we calculate the image entropy of each slice." [...]* *"We used our entropy-based sorting mechanism to pick the most informative 32 images from the axial plane of each 3D scan. That resulted in a total of 6400 training images, 3200 of which were AD and the other 3200 were HC." [...]* *"5-fold cross-validation was used to obtain the results, with an 80% - 20% split between training and testing." [...]* *"in our method, there are total 6,400 images; a 5-fold cross-validation (80% - 20%) split therefore results in a training size of 5,120)." […]*
Jain et al., 2019[37]	*"Brain MR images are in NIfTI format. NIfTI images are volumetric (3D) images, therefore images that we have after pre-processing are all of size 256x256x256. These images comprise of 2D images called slices. Hence, we have 256 slices corresponding to each NIfTI image […] image entropy based sorting mechanism is used to take most informative slices in which image entropy for each slice was calculated and top 32 slices based on entropy value were selected of each subject […] Above steps of data processing results in a balanced data-set of 4800 (150 subjects x 32 slices corresponding to each subject) slices which contains 1600 CE, 1600 MCI, and1600 CN slices" [...]* *"Our balanced dataset of 4800 images is shuffled and split into training and test set with split ratio 80:20."*
Khagi et al., 2019[38]	*"We have used 28 Normal controls (NC) and 28 Alzheimer's disease (AD) patients for classification, selecting 30 important slices from each patient. Once all the slices are collected, each model was trained, validated and tested in ratio of 6:2:2 on random selection basis."*
Sarraf et al., 2017[22]	*"The preprocessed rs-fMRI time series data were first loaded into memory using neuroimaging package Nibabel (http://nipy.org/nibabel/) and were*

	then decomposed into 2D (x,y) matrices along z and time (t) axes. Next, the 2D matrices were converted to lossless PNG format using the Python OpenCV (opencv.org). The last 10 slices of each time course were removed since they included no functional information. Also, any slices with sum of pixel intensities equal to zero were ignored. During the data conversion process, a total of 793,800 images were produced, including 270,900 Alzheimer's and 522,900 normal control PNG samples […] The random datasets were labeled for binary classification, and 75% of the images were assigned to the training dataset, while the remaining 25% were used for testing purposes." [...] *"The preprocessed MRI data were then loaded into memory using a similar approach to the fMRI pipeline and were converted from NII to lossless PNG format using Nibabel and OpenCV, which created two groups (AD and NC) × four preprocessed datasets (MRI 0,2,3,4). Additionally, the slices with zero mean pixels were removed from the data […] This step produced a total number of 62,335 images, with 52,507 belonging to the AD group and the remaining 9,828 belonging to the NC group per dataset […] Next, the model was trained and tested by 75% and 25% of the data"*
Wang et al., 2017[39]	Note that in addition to slice-level split, significant data leakage could come from the way augmentation is implemented in this paper. For example, a slice could end up in the training set and a slightly brighter copy of it in the test set. *"In this work, we employ the following data augmentation techniques: brightness augmentation, horizontal and vertical shifts, shadow augmentation and flipping." [...]* *"The selected dataset includes serial brain MRI scans from 400 individuals with MCI (age: 74.8±7.4years, 257 Male/143 Female), and 229 healthy elderly controls (age: 76.0±5.0years, 119 Male/110 Female)[…] After data augmentation, we obtain 8000 images including 4000 images of MCI and 4000 images of healthy control. We extract 5000 images for training, 1500 images for validation, 1500 images for testing."*
Puranik et al., 2018[40]	*"After the conversion of images to the JPEG format, the last 5 frame images from each time course were scraped as it didn't specifically denote any significant characteristic of the brain. Moreover, the images that were removed were complete black, and would only contribute as noise to the CNN. This generated 474,320 images in all of which 154,000 were Alzheimer disease prone images, 209,440 were normal and 110,880 comprised of EMCI images. These images were pooled together and then randomly shuffled for bifurcation into training and testing dataset in the ratio of 85% and 15% respectively"*
Basheera et al., 2019[41]	*"The CNN is used for classification. In our article, we used 224 x 224-sized gray segmented images as input to the CNN." [...]* *"Our total data set has 18,017 GM segmented images. We shuffled and split the data set in the ratio 80:20 as training and test data sets." [...]*

Nawaz et al., 2020[42]	*"Every 3D MRI image contains 256 256 166 slices per volume which cannot be fed to a 2D CNN model. Therefore, we have rescaled each 3D MRI volume and have converted it into 2D slices each of size 300 300 with a single channel for each plane (axial, coronal, sagittal). Each patient contains around 690± 2D slices which can be further fed to train the 2D-CNN model. The pre-processed slices of 3D images are shown in Fig. 1 during different stages." [...]* *"In this paper, we have used 3D structural MRI scans of 160 patients (52 NC, 62 MCI, and 45 AD) to train our 2D-CNN model. The unbalanced (a total of 67413) 2D images are used as a dataset which includes 20972 images for AD class, 26192 images for MCI, and 18513 for NC class. Networks are trained from scratch on data for 70 epochs with a batch size of 100. Experiments are performed using 60% data for training, 20 % for testing, and 20% for the validation set."* Please note that in Table 1 the number of images has been reported.

Supplementary Table S2. Summary of the previous studies performing classification of neurological disorders using MRI and suspected to have potential data leakage.

Reference	Description
Farooq et al., 2017[43]	*"MRI scans are provided in the form of 3D Nifti volumes. At first, skull stripping and gray matter (GM) segmentation is carried out on axial scans through spatial normalization, bias correction and modulation using SPM-8* tool. GM volumes are then converted to JPEG slices using Python Nibabel package. Slices from start and end which contain non information are discarded from the dataset".* Paragraph III.A. *"A subject is scanned at different point of times in different visits, i.e., baseline, after on two and three years. Each such scan is considered as a separate subject in this work. The dataset consists of 33 AD, 22 LMCI, 39 MCI patients and 45 healthy controls which makes a total 355 MRI volumes. Augmentation is done by simply flipping the image along horizontal axis. The balances set includes a total of 9506 images for each class, and a total of 38024 images for all classes". [...]* *"All experiments are performed by splitting data into 25% as test and 75% as train data. 10% data from train set is used as validation set".*
Ramzan et al., 2019[44]	*"After applying the preprocessing methods on fMRI data, preprocessed 64×64x48x140 4D fMRI scans are obtained in which each scan contains 64×64x48 3D volumes per time course (140 s). These 4D scans are then converted to 2D images along with image height and time axis. This results in 6720 images of size 64x64 per fMRI scan. The first and last three slices are removed as they contain no functional information. Therefore, from each scan information from 44 slices is used. Hence, 6160 2D images are obtained from each fMRI scan and are saved in portable network graphics (PNG) format. The data acquired from ADNI is processed and converted to 2D images by using the aforementioned pre-processing methods. In this way, we have created a dataset that was used for training deep learning networks." [...]* "*In the dataset, there are 138 4D scans and 850,080 2D images. For the evaluation, we split the dataset into a training dataset, validation dataset and testing dataset with 70%, 20%, and 10% split ratio, respectively as described in Table 6. The dataset was randomly shuffled before splitting.*" Please note that in Table 6, the number of images rather than the number of subjects has been reported for the training, validation, and testing dataset.
Raza et al., 2019[45]	*"We used the AlexNet model that takes a 2-d image as an input whereas our brain MRI data is 3-d. Data permutation is used in which multiple slices (Central 20 slices) are extracted from MRI brain data to increase training samples." [...]* *"split ratio for training and test data is set to 0.8 in the experiment. In each plane of OASIS dataset, the number of images for training and testing the classifier are 6656 and 1664 respectively. Similarly, for each plane in ADNI dataset, the number of images for training and testing the classifier is 34912 and 8728 respectively."*

Pathak et al., 2020[46]	*"In our work, we have converted MRI samples into JPEG slices in MATLAB tool. Pixel size of each sample is reduced to 8-bit from 14-bit size by rescaling to 255." [...]* *"Dataset consists of 110 AD, 105 MCI and 51 NC subjects, where each subject contains 44–50 sample of images. Out of which 110 AD subjects are collected from Horizon imaging center [17]. There are total of 9540 images used for training the network and 4193 images for testing. Data augmentation on images is done with rescale operation." [...]* *"We have conducted four experiments of our dataset. For two experiments, as shown in Table 4, 70% of the data was used for training and 30% for validation."* Please note that in Table 4 the number of images rather than the number of subjects has been reported for training and validation. *"Remaining two experiments are conducted with our dataset by removing some blank and unwanted images. In this, 75% of the reduced data was used for training and 25% for validation for remaining two experiments are shown in Table 5."* Please note that also in Table 5 the number of images rather than the number of subjects has been reported for training and validation.
Libero et al., 2015[47]	We suspect that feature selection was performed on the whole dataset, before the application of the ML validation scheme. *"Nineteen high-functioning adults with ASD (15 males/4 females; mean age: 27.1 years) and 18 typically developing (TD) peers (14 males/4 females; mean age: 24.6 years) participated in this multimodal neuroimaging study (see Table 1 for demographic information)." […]* *"Groups were compared on the resulting cortical thickness values using ANCOVAs conducted using SPSS 22.0 software. Age was used as a covariate for all between-group analyses, as well as average hemispheric cortical thickness." […]* *"1H-MRS ratios were compared using ANCOVA, covarying for age, and GM content." […]* *"To compare the ASD and TD groups on FA, RD, MD, and AD, t- tests were conducted point-wise along each fiber tract for 100 points. A permutation based multiple comparison correction was applied to determine statistical significance (Nichols & Holmes, 2002), $p < .05$."* *"Leave-one-subject-out cross validation was performed for both regression and classification." […]* *"The data points included were the significant resulting values of the statistical analyses of separate neuroimaging modalities."*
Zhou et al., 2014[48]	We suspect that feature selection was performed on the whole dataset, before the application of the ML validation scheme. *"To reduce possible classifier overfitting and improve generalization, feature selection was performed in two steps. First, principal component analysis was used to decompose the covariance matrix of the imaging features using the singular value decomposition program in Matlab (release 2010b; MathWorks, Natick, Mass) [33] after variance normalization. Then the number of sorted components based on singular values that contained*

	99% or 95% of the information from the covariance matrix of all features was determined. Finally, an advanced feature selection algorithm, based on mutual-information and integration of both mRMR criteria [34], was used to select imaging features based on the number of features (components) determined via principal component analysis."
Sivaranjini, et al., 2019[26]	*"The image dataset with 80% of the input data is used for training and the remaining 20% is used for testing. The number of images from each subject given to the deep learning model is averaged to be 40 ± 5 slices based on the selection criterion as shown in Table 2. These images are given to the subsequent convolution layers."* Please note that also in Table 2 the number of images rather than the number of subjects has been reported for training and testing.
Lui et al., 2014[49]	We suspect that feature selection was performed on the whole dataset, before the application of the ML validation scheme. *"All original features are normalized by removing the mean of each feature and dividing by its SD. We used the feature selection procedure, mRMR,24 to incrementally choose the most representative subset of imaging features, to increase relevance, and decrease redundancy." […]* *"We used 5 types of mainstream classifiers on the features chosen by mRMR: support vector machine (SVM), naive Bayesian, Bayesian network, radial basis network, and multilayer perceptron […] We also applied the above methodology to evaluate the achievable performance of different classifiers using the single best feature alone and for mRMR selected features."*
Hasan et al., 2019[50]	*"Hasan and Meziane [2] refined these texture measures by ignoring the irrelevant features using analysis of variance method (ANOVA) and reduced to eleven texture measures for each co-occurrence matrix, namely, the contrast, the dissimilarity, the correlation, the sum of square variance, the sum variance, he sum average, the difference entropy, the inverse difference normalized (IDN), the information measure of correlation I (IMC1), the inverse difference moment normalized (IDMN) and the weighted distance in addition to the cross correlation. The total number of texture measures was reduced from 190 to 100 feature measures after using ANOVA." […]* *"In this study, a total of 6000 MRI axial slices from 600 patients (300 normal, and 300 abnormal) were collected […] The number of slices for each MRI scan is about 75 slices. […] The collected MRI dataset is adopted to validate the proposed method. Support vector machine (SVM) with 10-fold cross validation method are applied for accuracy rate estimation of the proposed method. The dataset is divided randomly into 10 folds that are roughly of equal size. Each MRI slice in the given dataset was normalized with 'zero- center' before submission to CNN."*

Supplementary Table S3. Summary of the previous studies performing classification of neurological disorders using MRI and that provide insufficient information to assess data leakage.

Reference	Description
Al-Khuzaie et al., 2021[51]	Section 3 *"Table 1 demonstrates the number of MRI slices."* Section 4 "*The training data set was 75% and the validation data set was 25%."* Please note that also in Figure 3 the input is *"MRI slices dataset".*
Wu et al., 2018[23]	*"Then, from among about 160 slices of raw MR scans of each subject, we discarded the first and last 15 slices without anatomical information, resulting in about 130 slices for each subject. Next, we selected 48 different slices randomly from the remaining slices with the interval of 4, and thus generated 16 RGB color images for each subject. Third, the selected slices were converted into portable network graphics (PNG) format. Finally, all of the RGB color images were resized to 256×256 pixels and converted to the Lightning Memory-Mapped Database (LMDB) for high throughput of the CaffeNet deep learning platform. To ensure the robustness of the model, five random datasets were created to repeat the training and testing of the CNN classifiers (5-fold cross-validation). The flow chart for this is shown as in Figure 4." [...]* *"Differential diagnosis of MCI" "According to aforementioned data augmentation, all baseline MR data were expanded to up to 7,200 slices (4,800 for training, 2,400 for testing) for 150 NC subjects, 7,200 slices (4,800 for training, 2,400 for testing) for 150 patients with sMCI, and 7,536 slices (5,024 for training, 2,512 for testing) for 157 patients with cMCI. During the training model, embedded five-fold cross validation was employed to train a robust model."*

Supplementary Table S4. OASIS-200 is sub-sampled ten times by selecting 34 subjects (17 healthy controls (label=0) and 17 Alzheimer disease patients (label=1)) to produce 10 different OASIS_34 small datasets. The subject IDs and the demographic data associated with each subject are given below. Age is in years. F, female; M, male, OASIS, Open Access Series of Imaging Studies.

Sub-sample 1				Sub-sample 2				Sub-sample 3				Sub-sample 4				Sub-sample 5				Sub-sample 6				Sub-sample 7				Sub-sample 8				Sub-sample 9				Sub-sample 10			
id	label	sex	age	id	label	sex	age	id	label	sex	age	id	label	sex	age	id	label	sex	age	id	label	sex	age	id	label	sex	age	id	label	sex	age	id	label	sex	age	id	label	sex	age
27	0	F	82	8	0	F	89	97	0	F	60	9	0	M	89	95	0	M	61	75	0	F	69	4	0	F	90	24	0	F	83	39	0	F	78	88	0	M	64
40	0	F	78	54	0	F	73	58	0	F	73	74	0	M	69	77	0	M	68	71	0	M	70	59	0	F	73	89	0	F	64	38	0	F	78	8	0	F	89
63	0	M	71	97	0	F	60	68	0	M	71	15	0	M	87	15	0	M	87	39	0	F	78	44	0	F	75	33	0	M	80	37	0	F	80	85	0	F	65
24	0	F	83	65	0	F	71	74	0	M	69	53	0	M	74	7	0	F	90	14	0	F	88	55	0	F	73	31	0	M	81	72	0	F	70	14	0	F	88
50	0	F	74	13	0	F	88	2	0	F	91	46	0	M	75	6	0	F	90	84	0	F	65	33	0	M	80	55	0	F	73	33	0	M	80	26	0	F	82
53	0	M	74	37	0	F	80	46	0	M	75	28	0	F	81	68	0	M	71	1	0	F	93	41	0	F	77	67	0	F	71	97	0	F	60	90	0	F	63
78	0	M	68	12	0	F	88	88	0	M	64	91	0	M	62	46	0	M	75	90	0	F	63	37	0	F	80	66	0	F	71	86	0	M	65	4	0	F	90
21	0	M	84	43	0	F	76	26	0	F	82	25	0	F	83	34	0	F	80	24	0	F	83	71	0	M	70	83	0	F	65	49	0	F	74	28	0	F	81
80	0	F	67	58	0	F	73	56	0	F	73	75	0	F	69	44	0	F	75	67	0	F	71	9	0	M	89	98	0	F	59	80	0	F	67	57	0	F	73
89	0	F	64	27	0	F	82	18	0	M	86	76	0	F	69	26	0	F	82	61	0	F	72	86	0	M	65	88	0	M	64	60	0	F	72	59	0	F	73
71	0	M	70	30	0	F	81	19	0	F	85	97	0	F	60	81	0	F	67	87	0	F	64	2	0	F	91	40	0	F	78	55	0	F	73	9	0	M	89
29	0	F	81	64	0	F	71	49	0	F	74	61	0	F	72	73	0	F	69	89	0	F	64	34	0	F	80	51	0	F	74	73	0	F	69	80	0	F	67
23	0	F	84	2	0	F	91	75	0	F	69	13	0	F	88	98	0	F	59	72	0	F	70	66	0	F	71	7	0	F	90	25	0	F	83	82	0	F	66
85	0	F	65	89	0	F	64	87	0	F	64	66	0	F	71	71	0	M	70	43	0	F	76	81	0	F	67	86	0	M	65	23	0	F	84	19	0	F	85
59	0	F	73	53	0	M	74	72	0	F	70	51	0	F	74	40	0	F	78	34	0	F	80	1	0	F	93	68	0	M	71	32	0	F	80	62	0	M	72
49	0	F	74	80	0	F	67	61	0	F	72	50	0	F	74	22	0	M	84	70	0	F	70	25	0	F	83	95	0	M	61	19	0	F	85	61	0	F	72
91	0	M	62	85	0	F	65	0	0	F	94	27	0	F	82	52	0	M	74	77	0	M	68	61	0	F	72	54	0	F	73	54	0	F	73	66	0	F	71
135	1	F	80	188	1	M	68	173	1	F	72	182	1	M	70	146	1	M	78	176	1	F	71	168	1	M	73	156	1	M	75	125	1	M	81	176	1	F	71
148	1	F	77	138	1	M	79	176	1	F	71	115	1	M	84	134	1	F	80	129	1	F	80	137	1	M	79	117	1	F	83	153	1	M	76	162	1	F	73
128	1	M	81	194	1	M	66	188	1	M	68	138	1	M	79	179	1	F	71	111	1	M	86	196	1	M	64	164	1	F	73	129	1	F	80	157	1	F	75
191	1	F	67	163	1	M	73	127	1	F	81	132	1	F	80	170	1	F	72	196	1	M	64	178	1	M	71	148	1	F	77	180	1	M	71	149	1	F	77
192	1	F	66	161	1	M	74	116	1	F	83	154	1	F	76	122	1	M	82	143	1	M	78	130	1	M	80	159	1	M	75	140	1	F	78	104	1	M	90
198	1	F	63	162	1	F	73	197	1	M	64	117	1	F	83	149	1	F	77	100	1	F	96	134	1	F	80	155	1	F	75	177	1	M	71	165	1	F	73
144	1	F	78	169	1	F	73	198	1	F	63	124	1	F	81	165	1	F	73	139	1	F	79	157	1	F	75	187	1	M	69	138	1	M	79	123	1	M	82
163	1	M	73	113	1	F	84	118	1	F	83	111	1	M	86	183	1	M	70	122	1	M	82	100	1	F	96	124	1	F	81	167	1	F	73	191	1	F	67
104	1	M	90	189	1	F	67	168	1	M	73	198	1	F	63	172	1	F	72	186	1	F	69	195	1	F	65	129	1	F	80	189	1	F	67	138	1	M	79
140	1	F	78	187	1	M	69	134	1	F	80	161	1	M	74	141	1	F	78	135	1	F	80	116	1	F	83	193	1	F	66	169	1	F	73	130	1	M	80
186	1	F	69	198	1	F	63	147	1	F	78	160	1	F	74	175	1	F	72	178	1	M	71	192	1	F	66	163	1	M	73	195	1	F	65	199	1	F	62
197	1	M	64	192	1	F	66	106	1	M	88	135	1	F	80	154	1	F	76	165	1	F	73	177	1	M	71	132	1	F	80	100	1	F	96	178	1	M	71
187	1	M	69	179	1	F	71	157	1	F	75	106	1	M	88	112	1	F	84	195	1	F	65	101	1	F	92	162	1	F	73	196	1	M	64	148	1	F	77
130	1	M	80	119	1	F	83	107	1	F	87	101	1	F	92	150	1	M	77	114	1	M	84	151	1	F	77	194	1	M	66	132	1	F	80	164	1	F	73
172	1	F	72	101	1	F	92	146	1	M	78	125	1	M	81	195	1	F	65	173	1	F	72	159	1	M	75	169	1	F	73	127	1	F	81	106	1	M	88
157	1	F	75	121	1	F	83	196	1	M	64	129	1	F	80	168	1	M	73	174	1	F	72	126	1	F	81	190	1	M	67	197	1	M	64	126	1	F	81
152	1	M	77	183	1	M	70	181	1	M	70	152	1	M	77	124	1	F	81	161	1	M	74	164	1	F	73	127	1	F	81	101	1	F	92	109	1	F	86

Supplementary Table S5. Thirty-four subjects (17 AD and 17 HC) have been randomly sampled ten times to produce sub-sampled OASIS-34 datasets. The demographic features of each sub-sampled dataset are listed. Differences between AD and HC groups were assessed through a t-test and a χ^2-test for age and gender, respectively. The p-values are also reported.

OASIS subsample		**AD patients**	**Healthy controls**	**p-value**
Sample-1	Age (range, years)	62 – 84	63 - 90	
	Age (mean ± SD, years)	73.7 ± 7.0	74.0 ± 6.9	0.72
	Gender (women/men)	11/6	10/7	0.45
Sample-2	Age (range, years)	60 – 91	63 – 92	
	Age (mean ± SD, years)	76.0 ± 9.1	73.7 ± 7.6	0.02
	Gender (women/men)	16/1	10/7	0.22
Sample-3	Age (range, years)	60 – 94	63 - 88	
	Age (mean ± SD, years)	74.8 ± 9.3	75.1 ± 7.7	0.47
	Gender (women/men)	12/5	10/7	0.45
Sample-4	Age (range, years)	60 – 89	63 – 92	
	Age (mean ± SD, years)	75.2 ± 8.3	79.2 ± 6.6	0.49
	Gender (women/men)	11/6	9/8	0.07
Sample-5	Age (range, years)	59 – 90	65 – 84	
	Age (mean ± SD, years)	75.2 ± 9.0	75.3 ± 4.8	0.29
	Gender (women/men)	9/8	12/5	0.49
Sample-6	Age (range, years)	63 – 93	64 – 96	
	Age (mean ± SD, years)	73.1 ± 8.4	76.2 ± 7.8	0.05
	Gender (women/men)	15/2	10/7	0.15

	Age (range, years)	65 – 93	64 – 96	
Sample-7	Age (mean ± SD, years)	78.1 ± 8.3	76.5 ± 8.4	0.27
	Gender (women/men)	13/4	10/7	0.29
	Age (range, years)	59 – 90	66 – 83	
Sample-8	Age (mean ± SD, years)	71.9 ± 8.2	74.5 ± 5.2	1.00
	Gender (women/men)	11/6	11/6	0.15
	Age (range, years)	60 – 85	64 – 96	
Sample-9	Age (mean ± SD, years)	74.7 ± 6.8	75.9 ± 8.7	0.05
	Gender (women/men)	15/2	10/7	0.34
	Age (range, years)	63 – 90	62 – 90	
Sample-10	Age (mean ± SD, years)	75.8 ± 9.4	76.7 ± 7.1	0.24
	Gender (women/men)	14/3	11/6	0.38

AD = Alzheimer's disease; HC = Healthy controls; OASIS = Open Access Series of Imaging Studies; SD = standard deviation.

Supplementary Table S6. Subject IDs and associated demographics for OASIS_200 dataset. The first 100 subjects are from the healthy control group (label = 0) and the last 100 subjects belong to Alzheimer disease patient group (label = 1). Age is in years. F, female; M, male; OASIS, Open Access Series of Imaging Studies.

OASIS_IDs	NIFTI_IDs	labels	sex	age
221	0	0	F	94
270	1	0	F	93
284	2	0	F	91
65	3	0	M	90
83	4	0	F	90
299	5	0	F	90
301	6	0	F	90
445	7	0	F	90
19	8	0	F	89
32	9	0	M	89
197	10	0	F	89
271	11	0	F	89
169	12	0	F	88
176	13	0	F	88
342	14	0	F	88
260	15	0	M	87
363	16	0	M	87
157	17	0	F	86
317	18	0	M	86
201	19	0	F	85
254	20	0	F	85
110	21	0	M	84
186	22	0	M	84
428	23	0	F	84
75	24	0	F	83
113	25	0	F	83
146	26	0	F	82
426	27	0	F	82
13	28	0	F	81
106	29	0	F	81
228	30	0	F	81
337	31	0	M	81
33	32	0	F	80
138	33	0	M	80
180	34	0	F	80
244	35	0	F	80

330	36	0	F	80
446	37	0	F	80
206	38	0	F	78
259	39	0	F	78
280	40	0	F	78
64	41	0	F	77
338	42	0	M	77
195	43	0	F	76
220	44	0	F	75
234	45	0	M	75
423	46	0	M	75
1	47	0	F	74
10	48	0	M	74
165	49	0	F	74
212	50	0	F	74
241	51	0	F	74
354	52	0	M	74
365	53	0	M	74
62	54	0	F	73
279	55	0	F	73
326	56	0	F	73
355	57	0	F	73
369	58	0	F	73
404	59	0	F	73
139	60	0	F	72
237	61	0	F	72
332	62	0	M	72
170	63	0	M	71
203	64	0	F	71
216	65	0	F	71
255	66	0	F	71
341	67	0	F	71
398	68	0	M	71
449	69	0	F	71
85	70	0	F	70
256	71	0	M	70
371	72	0	F	70
112	73	0	F	69
199	74	0	M	69
293	75	0	F	69
422	76	0	F	69
130	77	0	M	68
343	78	0	M	68

356	79	0	F	68
68	80	0	F	67
303	81	0	F	67
438	82	0	F	66
30	83	0	F	65
133	84	0	F	65
322	85	0	F	65
358	86	0	M	65
78	87	0	F	64
135	88	0	M	64
292	89	0	F	64
70	90	0	F	63
114	91	0	M	62
457	92	0	F	62
109	93	0	F	61
455	94	0	F	61
456	95	0	M	61
72	96	0	F	60
200	97	0	F	60
289	98	0	F	59
372	99	0	M	59
278	100	1	F	96
400	101	1	F	92
447	102	1	F	92
226	103	1	M	90
247	104	1	M	90
273	105	1	F	89
31	106	1	M	88
137	107	1	F	87
179	108	1	F	87
28	109	1	F	86
351	110	1	M	86
440	111	1	M	86
35	112	1	F	84
161	113	1	F	84
223	114	1	M	84
304	115	1	M	84
53	116	1	F	83
122	117	1	F	83
123	118	1	F	83
286	119	1	F	83
290	120	1	M	83
380	121	1	F	83

16	122	1	M	82
23	123	1	M	82
84	124	1	F	81
158	125	1	M	81
164	126	1	F	81
352	127	1	F	81
441	128	1	M	81
21	129	1	F	80
42	130	1	M	80
134	131	1	M	80
166	132	1	F	80
267	133	1	M	80
329	134	1	F	80
335	135	1	F	80
373	136	1	F	80
60	137	1	M	79
263	138	1	M	79
339	139	1	F	79
52	140	1	F	78
185	141	1	F	78
217	142	1	F	78
268	143	1	M	78
287	144	1	F	78
308	145	1	F	78
399	146	1	M	78
425	147	1	F	78
233	148	1	F	77
238	149	1	F	77
315	150	1	M	77
388	151	1	F	77
405	152	1	M	77
15	153	1	M	76
402	154	1	F	76
82	155	1	F	75
205	156	1	M	75
272	157	1	F	75
424	158	1	M	75
452	159	1	M	75
240	160	1	F	74
418	161	1	M	74
3	162	1	F	73
124	163	1	M	73
210	164	1	F	73

291	165	1	F	73
312	166	1	F	73
374	167	1	F	73
451	168	1	M	73
454	169	1	F	73
56	170	1	F	72
115	171	1	M	72
269	172	1	F	72
298	173	1	F	72
316	174	1	F	72
432	175	1	F	72
67	176	1	F	71
155	177	1	M	71
288	178	1	M	71
411	179	1	F	71
430	180	1	M	71
39	181	1	M	70
120	182	1	M	70
142	183	1	M	70
453	184	1	F	70
22	185	1	F	69
73	186	1	F	69
390	187	1	M	69
300	188	1	M	68
98	189	1	F	67
307	190	1	M	67
382	191	1	F	67
66	192	1	F	66
94	193	1	F	66
143	194	1	M	66
184	195	1	F	65
46	196	1	M	64
243	197	1	M	64
362	198	1	F	63
41	199	1	F	62

Supplementary Table S7. Subject IDs and associated demographics for ADNI dataset. The first 100 subjects are from the Alzheimer disease group (label = 1) and the last 100 subjects belong to the healthy control group (label = 0). Age is in years. ADNI, Alzheimer's Disease Neuroimaging Initiative; F, female; M, male.

ADNI_IDs	NIFTI_IDs	label	age	sex
5275	0	1	78	F
5006	1	1	68	F
4252	2	1	87	F
4338	3	1	81	M
4990	4	1	75	F
4756	5	1	84	M
5029	6	1	80	M
4954	7	1	61	M
4774	8	1	86	M
4195	9	1	62	M
4124	10	1	72	M
4672	11	1	67	M
5163	12	1	67	M
4615	13	1	87	M
5149	14	1	84	M
5087	15	1	65	F
5027	16	1	76	M
4537	17	1	77	F
4039	18	1	56	M
4625	19	1	64	M
4879	20	1	80	F
5162	21	1	69	M
4732	22	1	77	M
4993	23	1	72	F
5013	24	1	68	F
4968	25	1	79	M
5206	26	1	85	M
4845	27	1	68	F
5016	28	1	64	F
4280	29	1	80	M
5090	30	1	59	M
5184	31	1	73	F
4024	32	1	56	F
4001	33	1	89	F
4905	34	1	73	F
4894	35	1	61	F

5070	36	1	71	M
5138	37	1	61	M
5205	38	1	59	F
4153	39	1	79	M
4728	40	1	82	M
5146	41	1	73	F
4982	42	1	58	F
4258	43	1	76	M
5208	44	1	69	M
4192	45	1	82	M
4740	46	1	88	M
4589	47	1	75	F
5019	48	1	63	F
5240	49	1	63	F
4949	50	1	78	F
5210	51	1	86	M
4853	52	1	71	F
5106	53	1	74	M
4223	54	1	76	M
5015	55	1	78	F
5071	56	1	76	M
4641	57	1	74	F
4172	58	1	76	M
4770	59	1	76	M
4783	60	1	83	M
4971	61	1	77	M
5123	62	1	73	F
4863	63	1	70	M
4730	64	1	81	F
4719	65	1	79	F
4657	66	1	72	F
4549	67	1	79	M
4692	68	1	83	M
4997	69	1	61	F
4906	70	1	76	F
5054	71	1	74	F
4820	72	1	86	F
5252	73	1	57	M
4827	74	1	71	M
5005	75	1	78	M
4501	76	1	79	M
4912	77	1	69	F
4867	78	1	75	M

4546	79	1	71	M
4526	80	1	80	M
5241	81	1	88	M
5017	82	1	84	M
4110	83	1	79	F
4733	84	1	75	M
4792	85	1	80	M
4696	86	1	73	F
4209	87	1	78	F
5074	88	1	75	F
5231	89	1	74	F
4477	90	1	82	F
4660	91	1	77	F
4859	92	1	72	M
5037	93	1	67	M
5112	94	1	75	F
4755	95	1	72	M
4772	96	1	79	F
5018	97	1	73	M
5059	98	1	72	M
4994	99	1	85	M
4075	100	0	73	M
4266	101	0	70	F
4348	102	0	66	F
56	103	0	78	F
4388	104	0	67	M
89	105	0	71	M
4739	106	0	65	M
4071	107	0	85	M
4150	108	0	74	M
416	109	0	82	F
4262	110	0	73	F
4083	111	0	85	M
4080	112	0	79	F
4545	113	0	67	F
23	114	0	78	M
4643	115	0	65	F
4382	116	0	76	F
59	117	0	79	F
257	118	0	86	F
4093	119	0	70	F
4616	120	0	85	M
4345	121	0	70	M

677	122	0	81	M
4389	123	0	81	M
4393	124	0	74	M
4399	125	0	78	F
4313	126	0	77	F
4577	127	0	85	M
4032	128	0	70	F
4021	129	0	67	M
4082	130	0	76	M
4060	131	0	85	M
4339	132	0	84	M
4349	133	0	71	F
4277	134	0	72	F
4340	135	0	67	F
4208	136	0	78	M
4278	137	0	75	M
4391	138	0	75	M
4856	139	0	65	F
4357	140	0	74	F
4158	141	0	84	M
4304	142	0	75	M
4104	143	0	72	M
4580	144	0	70	F
4448	145	0	64	F
4270	146	0	75	F
4795	147	0	61	M
842	148	0	79	M
4264	149	0	74	F
311	150	0	83	F
4086	151	0	82	M
4010	152	0	71	F
4367	153	0	65	F
4222	154	0	82	F
4386	155	0	85	F
5023	156	0	64	F
4218	157	0	81	M
4878	158	0	73	F
4120	159	0	82	F
4076	160	0	73	F
685	161	0	95	F
21	162	0	79	F
4257	163	0	79	M
4291	164	0	76	F

4612	165	0	69	F
4559	166	0	67	F
4308	167	0	74	M
4762	168	0	74	M
454	169	0	89	F
4196	170	0	79	M
4084	171	0	68	F
555	172	0	87	M
4552	173	0	63	M
4505	174	0	80	F
4410	175	0	69	F
4200	176	0	70	F
4576	177	0	71	F
4320	178	0	71	F
4164	179	0	73	M
4173	180	0	70	F
4424	181	0	66	F
4043	182	0	82	M
4026	183	0	74	M
4453	184	0	66	M
4028	185	0	64	F
4642	186	0	58	F
69	187	0	81	M
4092	188	0	82	F
4511	189	0	70	M
4491	190	0	84	M
473	191	0	83	M
210	192	0	83	F
4041	193	0	78	F
4014	194	0	81	M
751	195	0	77	M
4225	196	0	70	M
498	197	0	80	M
4037	198	0	76	M
4337	199	0	72	M

Supplementary Table S8. Subject IDs and associated demographics for PPMI dataset. The first 100 subjects are from the Parkinson's disease patient group (label = 1) and the last 100 subjects belong to the healthy control group (label = 0). Age is in years. F, female; M, male, PPMI, Parkinson's Progression Markers Initiative.

PPMI_IDs	NIFTI_IDs	label	sex	age
3625	0	1	F	67
3060	1	1	M	75
3577	2	1	M	68
3830	3	1	F	52
3709	4	1	M	69
3591	5	1	M	63
3154	6	1	F	73
3814	7	1	M	67
3056	8	1	M	56
3327	9	1	F	54
3176	10	1	M	62
3229	11	1	M	73
3770	12	1	F	55
4099	13	1	F	60
4102	14	1	M	69
4038	15	1	F	71
4071	16	1	M	58
3575	17	1	M	61
3771	18	1	F	75
3003	19	1	F	57
3364	20	1	F	39
3608	21	1	M	46
3116	22	1	M	65
3522	23	1	M	54
3288	24	1	F	47
3632	25	1	M	55
3309	26	1	F	54
3150	27	1	F	57
3970	28	1	M	67
3638	29	1	M	66
3232	30	1	F	68
3454	31	1	F	57
3616	32	1	M	78
3455	33	1	M	67
3023	34	1	F	71
3083	35	1	F	66
3325	36	1	F	67
3218	37	1	M	64
3429	38	1	M	65
3653	39	1	F	80
3514	40	1	M	71
3119	41	1	M	64
3752	42	1	M	52
4022	43	1	M	48
4122	44	1	M	64
3436	45	1	M	51

3207	46	1	F	58
3439	47	1	M	57
3067	48	1	M	74
3066	49	1	F	64
3290	50	1	M	63
3230	51	1	M	70
3787	52	1	M	49
4115	53	1	M	67
3311	54	1	M	75
3634	55	1	M	43
3077	56	1	M	63
3417	57	1	M	57
3822	58	1	M	56
4092	59	1	F	77
3021	60	1	F	64
4034	61	1	F	55
3958	62	1	M	76
4113	63	1	F	34
3630	64	1	F	61
3588	65	1	F	49
3621	66	1	F	54
3473	67	1	F	55
3584	68	1	M	43
3102	69	1	M	64
3819	70	1	F	53
3442	71	1	M	63
3472	72	1	M	61
4035	73	1	M	60
3815	74	1	M	62
3432	75	1	M	64
3838	76	1	F	61
4077	77	1	M	48
3282	78	1	F	62
3190	79	1	M	82
3307	80	1	M	66
3710	81	1	M	56
3462	82	1	F	44
3802	83	1	M	70
3433	84	1	F	82
3128	85	1	F	60
3132	86	1	M	50
3080	87	1	M	80
3186	88	1	F	62
4078	89	1	M	70
3589	90	1	F	75
3666	91	1	M	52
3001	92	1	M	65
3631	93	1	F	68
3205	94	1	M	73
3006	95	1	F	58
3434	96	1	M	54
3220	97	1	F	74
3461	98	1	M	63

3961	99	1	M	37
3515	100	0	F	74
3468	101	0	M	57
3809	102	0	F	53
3277	103	0	M	66
4010	104	0	M	42
3216	105	0	F	52
3350	106	0	M	79
3390	107	0	M	66
3544	108	0	M	70
3527	109	0	M	62
3851	110	0	F	54
3959	111	0	M	73
3464	112	0	M	51
3767	113	0	F	53
3257	114	0	F	53
3480	115	0	F	72
3952	116	0	F	69
3967	117	0	M	57
3270	118	0	M	55
3424	119	0	F	64
4116	120	0	M	65
3000	121	0	F	69
3016	122	0	M	57
3779	123	0	M	56
3813	124	0	M	65
3806	125	0	F	59
3029	126	0	M	66
3526	127	0	M	61
3619	128	0	F	32
3151	129	0	M	58
3114	130	0	F	64
3301	131	0	M	52
4004	132	0	F	65
3479	133	0	M	58
3570	134	0	M	72
3853	135	0	M	47
3636	136	0	M	64
3161	137	0	M	45
3310	138	0	M	65
3201	139	0	F	65
3013	140	0	F	79
4104	141	0	M	66
3074	142	0	M	31
3053	143	0	M	69
3611	144	0	F	42
3478	145	0	M	77
3169	146	0	M	57
3215	147	0	F	70
4079	148	0	M	63
3157	149	0	F	64
4090	150	0	M	57
3428	151	0	F	58

3206	152	0	F	31
3368	153	0	F	53
3355	154	0	M	32
3405	155	0	F	64
3160	156	0	M	80
3361	157	0	F	56
3613	158	0	F	56
3320	159	0	M	56
3411	160	0	M	41
3519	161	0	M	74
3008	162	0	F	82
3969	163	0	F	81
3358	164	0	M	49
3362	165	0	F	42
3219	166	0	M	70
3759	167	0	F	54
4085	168	0	M	67
4032	169	0	M	68
3551	170	0	M	64
4118	171	0	F	68
3615	172	0	M	66
3965	173	0	M	83
3064	174	0	F	60
3057	175	0	F	60
3807	176	0	F	73
3075	177	0	M	76
4139	178	0	M	81
3466	179	0	M	48
3410	180	0	M	74
3523	181	0	M	64
3768	182	0	M	60
3651	183	0	M	77
3004	184	0	M	59
3115	185	0	M	61
3855	186	0	F	49
3156	187	0	M	70
3453	188	0	F	60
3525	189	0	M	56
3852	190	0	M	77
3071	191	0	M	72
3521	192	0	M	65
3955	193	0	M	54
3656	194	0	M	79
3554	195	0	M	75
4105	196	0	M	67
3859	197	0	M	60
3817	198	0	M	74
3457	199	0	F	63