Supplementary Material

Fusion of Low-Level Descriptors of Digital Voice Recordings for Dementia Assessment

Supplementary Table 1. Full low-level descriptor CNN performance results. The full list of performance results for the CNN (convolutional neural network) that only utilized low-level descriptors (LLDs) on all three classification tasks. The LLDs included MFCCs, F0, Log HNR Jitter (local), Jitter (delta) and Shimmer (local) as inputs.

Metric	NC versus DE	MCI versus DE	NDE versus DE
Accuracy	0.766 ± 0.026	0.658 ± 0.031	**0.774 ± 0.035**
Balanced Accuracy	**0.739 ± 0.033**	0.623 ± 0.041	0.667 ± 0.043
Sensitivity	**0.641 ± 0.102**	0.461 ± 0.159	0.465 ± 0.128
Specificity	0.837 ± 0.062	0.785 ± 0.109	**0.869 ± 0.071**
Precision	**0.691 ± 0.087**	0.614 ± 0.094	0.535 ± 0.105
F1 Score	**0.654 ± 0.054**	0.500 ± 0.118	0.479 ± 0.080
Weighted F1 Score	0.763 ± 0.028	0.640 ± 0.041	**0.768 ± 0.028**
MCC	**0.489 ± 0.059**	0.270 ± 0.069	0.352 ± 0.075
Precision-recall AUC	**0.732 ± 0.081**	0.614 ± 0.057	0.522 ± 0.097
ROC AUC	**0.832 ± 0.034**	0.692 ± 0.031	0.765 ± 0.054

Supplementary Table 2. Full performance results for NC versus DE. For the classification task of NC versus DE, this table includes the full list of performance results for CNN models with inputs of LLDs and demographics (age, sex, education), LLDs and age, and LLDs only.

Metric	LLDs + Demo	LLDs + Age	LLDs
Accuracy	**0.772 ± 0.035**	0.768 ± 0.031	0.766 ± 0.026
Balanced Accuracy	0.747 ± 0.038	**0.750 ± 0.042**	0.739 ± 0.033
Sensitivity	0.666 ± 0.102	**0.677 ± 0.120**	0.641 ± 0.102
Specificity	0.828 ± 0.069	0.822 ± 0.062	**0.837 ± 0.062**
Precision	0.688 ± 0.081	0.680 ± 0.085	**0.691 ± 0.087**
F1 Score	**0.669 ± 0.060**	0.666 ± 0.069	0.654 ± 0.054
Weighted F1 Score	**0.770 ± 0.037**	0.767 ± 0.034	0.763 ± 0.028
MCC	0.502 ± 0.075	**0.502 ± 0.071**	0.489 ± 0.059
Precision-recall AUC	0.736 ± 0.060	**0.740 ± 0.079**	0.732 ± 0.081
ROC AUC	0.836 ± 0.035	**0.840 ± 0.025**	0.832 ± 0.034

Supplementary Table 3. Full performance results for MCI versus DE. For the classification task of MCI versus DE, this table includes the full list of performance results for CNN models with inputs of LLDs and demographics (age, sex, education), LLDs and age, and LLDs only.

Metric	LLDs + Demo	LLDs + Age	LLDs
Accuracy	**0.675 ± 0.043**	0.662 ± 0.048	0.658 ± 0.031
Balanced Accuracy	0.635 ± 0.039	**0.643 ± 0.044**	0.623 ± 0.041
Sensitivity	0.455 ± 0.116	**0.532 ± 0.120**	0.461 ± 0.159
Specificity	**0.815 ± 0.092**	0.753 ± 0.093	0.785 ± 0.109
Precision	**0.637 ± 0.080**	0.598 ± 0.084	0.614 ± 0.094
F1 Score	0.518 ± 0.079	**0.547 ± 0.078**	0.500 ± 0.118
Weighted F1 Score	**0.659 ± 0.045**	0.655 ± 0.050	0.640 ± 0.041
MCC	**0.299 ± 0.078**	0.295 ± 0.082	0.270 ± 0.069
Precision-recall AUC	0.611 ± 0.051	**0.616 ± 0.056**	0.614 ± 0.057
ROC AUC	**0.696 ± 0.037**	0.694 ± 0.049	0.692 ± 0.031

Supplementary Table 4. Full performance results for NDE versus DE. For the classification task of NDE versus DE, this table includes the full list of performance results for CNN models with inputs of LLDs and demographics (age, sex, education), LLDs and age, and LLDs only.

Metric	LLDs + Demo	LLDs + Age	LLDs
Accuracy	0.765 ± 0.023	**0.783 ± 0.027**	0.774 ± 0.035
Balanced Accuracy	0.648 ± 0.052	0.656 ± 0.046	**0.667 ± 0.043**
Sensitivity	0.434 ± 0.141	0.422 ± 0.120	**0.465 ± 0.128**
Specificity	0.862 ± 0.055	**0.890 ± 0.049**	0.869 ± 0.071
Precision	0.492 ± 0.106	**0.550 ± 0.099**	0.535 ± 0.105
F1 Score	0.446 ± 0.103	0.464 ± 0.084	**0.479 ± 0.080**
Weighted F1 Score	0.758 ± 0.019	**0.771 ± 0.026**	0.768 ± 0.028
MCC	0.309 ± 0.019	0.345 ± 0.080	**0.352 ± 0.075**
Precision-recall AUC	0.485 ± 0.085	**0.529 ± 0.083**	0.522 ± 0.097
ROC AUC	0.754 ± 0.033	**0.770 ± 0.042**	0.765 ± 0.054

Supplementary Table 5. Full performance results for NC versus DE. For the classification task of NC versus DE, this table includes the full list of performance results for random forest models with inputs of openSMILE functionals (Funct) and demographics (age, sex, education), openSMILE functionals and age, openSMILE functionals only, demographics only, and age only.

Metric	Funct + Demo	Funct + Age	Funct	Demo	Age
Accuracy	**0.776 ± 0.025**	0.762 ± 0.016	0.766 ± 0.022	0.676 ± 0.027	0.698 ± 0.040
Balanced Accuracy	**0.729 ± 0.028**	0.712 ± 0.018	0.717 ± 0.024	0.629 ± 0.027	0.655 ± 0.043
Sensitivity	**0.565 ± 0.059**	0.541 ± 0.042	0.549 ± 0.036	0.469 ± 0.047	0.505 ± 0.073
Specificity	**0.892 ± 0.024**	0.883 ± 0.027	0.885 ± 0.030	0.789 ± 0.036	0.804 ± 0.026
Precision	**0.742 ± 0.047**	0.718 ± 0.050	0.723 ± 0.063	0.549 ± 0.052	0.583 ± 0.044
F1 Score	**0.639 ± 0.040**	0.615 ± 0.027	0.623 ± 0.035	0.504 ± 0.040	0.540 ± 0.059
Weighted F1 Score	**0.767 ± 0.027**	0.753 ± 0.017	0.757 ± 0.022	0.669 ± 0.027	0.692 ± 0.044
MCC	**0.493 ± 0.052**	0.459 ± 0.038	0.468 ± 0.054	0.269 ± 0.058	0.320 ± 0.084
Precision-recall AUC	0.712 ± 0.036	**0.724 ± 0.030**	0.704 ± 0.043	0.572 ± 0.055	0.590 ± 0.031
ROC AUC	0.827 ± 0.007	**0.832 ± 0.008**	0.827 ± 0.012	0.715 ± 0.022	0.757 ± 0.032

Supplementary Table 6. Full performance results for MCI versus DE. For the classification task of MCI versus DE, this table includes the full list of performance results for random forest models with inputs of openSMILE functionals (Funct) and demographics (age, sex, education), openSMILE functionals and age, openSMILE functionals only, demographics only, and age only.

Metric	Funct + Demo	Funct + Age	Funct	Demo	Age
Accuracy	0.663 ± 0.040	0.662 ± 0.035	**0.674 ± 0.044**	0.562 ± 0.034	0.603 ± 0.038
Balanced Accuracy	0.622 ± 0.042	0.615 ± 0.021	**0.631 ± 0.035**	0.530 ± 0.038	0.545 ± 0.042
Sensitivity	0.422 ± 0.064	0.385 ± 0.028	0.413 ± 0.055	0.366 ± 0.063	0.237 ± 0.094
Specificity	0.823 ± 0.036	0.844 ± 0.030	0.848 ± 0.027	0.694 ± 0.037	**0.853 ± 0.072**
Precision	0.611 ± 0.079	0.624 ± 0.023	**0.644 ± 0.040**	0.441 ± 0.072	0.529 ± 0.125
F1 Score	0.498 ± 0.066	0.476 ± 0.025	**0.502 ± 0.051**	0.397 ± 0.061	0.312 ± 0.108
Weighted F1 Score	0.648 ± 0.043	0.641 ± 0.035	**0.656 ± 0.048**	0.553 ± 0.037	0.556 ± 0.063
MCC	0.268 ± 0.089	0.261 ± 0.048	**0.293 ± 0.073**	0.062 ± 0.079	0.117 ± 0.099
Precision-recall AUC	0.621 ± 0.040	**0.626 ± 0.032**	0.611 ± 0.040	0.456 ± 0.061	0.489 ± 0.063
ROC AUC	0.701 ± 0.049	**0.708 ± 0.040**	0.705 ± 0.055	0.573 ± 0.048	0.575 ± 0.035

Supplementary Table 7. Full performance results for NDE versus DE. For the classification task of NDE versus DE, this table includes the full list of performance results for random forest models with inputs of openSMILE functionals (Funct) and demographics (age, sex, education), openSMILE functionals and age, openSMILE functionals only, demographics only, and age only.

Metric	Funct + Demo	Funct + Age	Funct	Demo	Age
Accuracy	0.789 ± 0.015	**0.795 ± 0.021**	0.790 ± 0.022	0.752 ± 0.014	0.767 ± 0.019
Balanced Accuracy	0.586 ± 0.018	**0.589 ± 0.028**	0.583 ± 0.020	0.546 ± 0.016	0.517 ± 0.008
Sensitivity	**0.210 ± 0.044**	0.207 ± 0.059	0.197 ± 0.036	0.162 ± 0.030	0.053 ± 0.024
Specificity	0.963 ± 0.010	0.972 ± 0.006	0.968 ± 0.007	0.930 ± 0.014	**0.980 ± 0.015**
Precision	0.631 ± 0.047	**0.681 ± 0.046**	0.647 ± 0.078	0.410 ± 0.067	0.488 ± 0.189
F1 Score	0.311 ± 0.047	**0.313 ± 0.072**	0.301 ± 0.048	0.230 ± 0.037	0.093 ± 0.038
Weighted F1 Score	0.745 ± 0.027	**0.748 ± 0.034**	0.744 ± 0.030	0.709 ± 0.021	0.689 ± 0.017
MCC	0.272 ± 0.029	**0.292 ± 0.058**	0.272 ± 0.057	0.134 ± 0.044	0.091 ± 0.049
Precision-recall AUC	0.489 ± 0.044	**0.531 ± 0.044**	0.525 ± 0.038	0.334 ± 0.044	0.371 ± 0.023
ROC AUC	0.764 ± 0.019	**0.782 ± 0.016**	0.776 ± 0.015	0.645 ± 0.025	0.687 ± 0.017

Supplementary Table 8. Top 10 Random Forest Features, openSMILE functionals. The top 10 most important features to the Random Forest models that used only openSMILE functionals as input data.

NC versus DE	**MCI versus DE**	**NDE versus DE**
audSpec_Rfilt_sma[2]_percentile1.0	pcm_fftMag_spectralEntropy_sma_linregerrQ	audSpec_Rfilt_sma_de[25]_leftctime
mfcc_sma[12]_lpc4	audSpec_Rfilt_sma[1]_percentile99.0	mfcc_sma[9]_iqr1-3
audSpec_Rfilt_sma[2]_pctlrange0-1	audSpec_Rfilt_sma[2]_iqr1-2	audSpec_Rfilt_sma[2]_flatness
audSpec_Rfilt_sma_de[1]_percentile1.0	mfcc_sma[3]_segLenStddev	mfcc_sma_de[14]_skewness
mfcc_sma_de[9]_pctlrange0-1	audspec_lengthL1norm_sma_lpc0	audSpec_Rfilt_sma_de[1]_maxPos
voicingFinalUnclipped_sma_iqr1-3	pcm_fftMag_fband250-650_sma_de_leftctime	mfcc_sma[7]_iqr1-3
mfcc_sma[13]_iqr1-2	mfcc_sma[5]_linregc1	mfcc_sma[11]_lpc4
pcm_zcr_sma_risetime	pcm_fftMag_spectralRollOff25.0_sma_de_peakMeanAbs	pcm_fftMag_fband1000-4000_sma_lpc0
pcm_fftMag_spectralSkewness_sma_peakMeanRel	audSpec_Rfilt_sma[9]_upleveltime75	pcm_fftMag_spectralSkewness_sma_de_lpc4
mfcc_sma[10]_quartile2	audSpec_Rfilt_sma_de[1]_flatness	audSpec_Rfilt_sma[1]_kurtosis

Supplementary Table 9. Top 10 Random Forest Features, openSMILE functionals and age. The top 10 most important features to the Random Forest models that used openSMILE functionals and age as input data.

NC versus DE	MCI versus DE	NDE versus DE
mfcc_sma_de[9]_percentile1.0	pcm_fftMag_spectralEntropy_sma_linregerrQ	pcm_fftMag_spectralSkewness_sma_de_flatness
voicingFinalUnclipped_sma_iqr1-3	pcm_fftMag_fband1000-4000_sma_de_lpc0	audSpec_Rfilt_sma_de[1]_percentile1.0
age	audSpec_Rfilt_sma[1]_percentile99.0	audSpec_Rfilt_sma[9]_linregc2
mfcc_sma[12]_iqr2-3	audSpec_Rfilt_sma[1]_percentile1.0	audSpec_Rfilt_sma_de[25]_leftctime
mfcc_sma[8]_flatness	pcm_fftMag_spectralEntropy_sma_de_lpc4	pcm_fftMag_spectralEntropy_sma_linregerrQ
pcm_fftMag_spectralSkewness_sma_de_lpc1	mfcc_sma[1]_peakMeanMeanDist	pcm_zcr_sma_qregc3
audSpec_Rfilt_sma[3]_percentile1.0	audSpec_Rfilt_sma[2]_percentile1.0	pcm_fftMag_spectralRollOff75.0_sma_de_iqr2-3
pcm_fftMag_spectralSkewness_sma_de_lpc4	audSpec_Rfilt_sma_de[1]_flatness	audSpec_Rfilt_sma[2]_flatness
pcm_fftMag_psySharpness_sma_iqr1-3	mfcc_sma[7]_qregerrQ	audspec_lengthL1norm_sma_de_lpc0
audSpec_Rfilt_sma[13]_maxPos	audSpec_Rfilt_sma_de[0]_maxSegLen	pcm_fftMag_spectralRollOff25.0_sma_iqr1-2

Supplementary Table 10. Top 10 Random Forest Features, openSMILE functionals and demographics (age, sex, education). The top 10 most important features to the Random Forest models that used openSMILE functionals and demographics as input data.

NC versus DE	MCI versus DE	NDE versus DE
age	pcm_fftMag_fband1000-4000_sma_lpc0	mfcc_sma[5]_skewness
mfcc_sma[13]_peakMeanMeanDist	voicingFinalUnclipped_sma_iqr1-3	age
mfcc_sma[9]_iqr1-3	voicingFinalUnclipped_sma_iqr1-2	audSpec_Rfilt_sma_de[24]_leftctime
pcm_fftMag_spectralRollOff25.0_sma_iqr1-2	age	pcm_fftMag_spectralKurtosis_sma_de_flatness
pcm_fftMag_spectralSkewness_sma_de_flatness	audSpec_Rfilt_sma_de[3]_segLenStddev	pcm_fftMag_spectralEntropy_sma_de_lpc4
audSpec_Rfilt_sma[1]_percentile1.0	audSpec_Rfilt_sma[2]_percentile1.0	pcm_fftMag_spectralSkewness_sma_lpc0
voicingFinalUnclipped_sma_stddev	audSpec_Rfilt_sma_de[0]_skewness	audSpec_Rfilt_sma[1]_pctlrange0-1
pcm_fftMag_spectralRollOff25.0_sma_flatness	audSpec_Rfilt_sma[10]_qregc3	audSpec_Rfilt_sma[1]_qregerrQ
mfcc_sma[9]_rqmean	audSpec_Rfilt_sma_de[0]_minSegLen	audSpec_Rfilt_sma[1]_percentile1.0
pcm_fftMag_spectralRollOff90.0_sma_de_posamean	logHNR_sma_flatness	pcm_fftMag_spectralSkewness_sma_de_flatness