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Supplemental information

Quantifying brain-functional dynamics using deep dynamical systems: Technical considerations

Jiarui Chen, Anastasia Benedyk, Alexander Moldavski, Heike Tost, Andreas Meyer-Lindenberg, Urs Braun, Daniel Durstewitz, Georgia Koppe, and Emanuel Schwarz

Table S1. Age and gender distribution with p-value from the statistical test, related to "Dataset for Pipeline Implementation and Evaluation" section in STAR Methods.

Group		HC		SCZ		MDD		P-value[2]
		N/Mean[1]	%/STD[1]	N/Mean	%/STD	N/Mean	%/STD	
Gender	M	22	52.381	28	60.8696	19	43.1819	0.2441
	F	20	47.619	18	39.1304	25	56.8182	
Age		36.4762	12.4572	38.1957	11.3463	35.4546	11.1782	0.5306

Abbr. HC–Healthy Controls, SCZ–Schizophrenia, MDD–Major Depressive Disorder, M– male, F–female, N–number, STD–standard deviation.

[1]For age, we calculate the mean and standard deviation, while for gender, we count the number and calculate the percentage.

[2]We perform ANOVA and the chi-square test for age and sex respectively.

Table S2. The names of the 19 regions of interest (ROIs), related to "Dataset for Pipeline Implementation and Evaluation" section in STAR Methods.

Index	Region Name	Index	Region Name
1	Precentral Gyrus	11	Supramarginal Gyrus - Posterior Division
2	Postcentral Gyrus	12	Cingulate Gyrus – Anterior Division
3	Juxtapositional Lobule Cortex	13	Superior Temporal Gyrus - Anterior Division
4	Left Thalamus	14	Left Putamen
5	Right Thalamus	15	Right Putamen
6	Frontal Medial Cortex	16	Left Caudate
7	Precuneus Cortex	17	Right Caudate
8	Superior Frontal Gyrus	18	Insular Cortex
9	Superior Parietal Lobule	19	Frontal Pole
10	Supramarginal Gyrus - Anterior Division	—	—

Table S3. Description of the 18 extracted dynamical features[1,2], related to "PLRNN Model for Dynamics Reconstruction and Feature Extraction" section in STAR Methods.

Index	Feature Description	Data Type
F01	Total number of fixed points in system	Integer
F02	The number of unstable fixed points in system	Integer
F03	The average of absolute imaginary eigenvalues of all fixed points	Continuous
F04	The average of maximum absolute eigenvalues of all fixed points	Continuous
F05/6/7	The variance of the parameters in both/regularized/non-regularized part of transition matrices (A and W)	Continuous
F08/9	The average of the parameters in regularized/non-regularized part of bias matrix (h)	Continuous
F10	The number of stable cycles	Integer
F11/12	The average of the parameters in regularized/non-regularized part of weight matrix (W)	Continuous
F13	The sum of absolute model weights averaged across latent states	Continuous
F14	The average Euclidean distance between the inferred latent states over time (speed)	Continuous
F15	The average variance of the latent states over time	Continuous
F16	The frequency of system switched between different orthants in state space	Continuous
F17/18	The average and variance over columns of regression coefficient matrix (B)	Continuous

Table S4. Average performance of different classifiers on the HC/SCZ classification task in 5-fold cross-validation using dynamical features extracted from the model trained on 19 ROIs. This table can be compared with Figure 2a in the main text and indicates that using region pairs can achieve better classification performance.

Model Type	Training		Test	
	AUC	Std.	AUC	Std.
RF	1.0000	0.0000	0.5414	0.1029
SVM	0.6643	0.0590	0.5781	0.1445
DT	Fail To Predict		Fail To Predict	
KNN	0.5354	0.0304	0.5718	0.1229

Table S5. In the 5-fold CV, the average AUC scores of different classifiers using features extracted from different region pairs, related to Figure 2a in the main text.

Region Piars	SVM		RF		KNN	
	AUC	Std.	AUC	Std.	AUC	Std.
6_7	0.6552	0.1629	0.6649	0.1005	0.6156	0.0650
6_10	0.5850	0.1068	0.7193	0.0958	0.5534	0.1285
6_11	0.6048	0.1171	0.5336	0.1092	0.6241	0.1481
7_10	0.5418	0.1362	0.4370	0.2201	0.5824	0.1128
7_11	0.5605	0.0448	0.5802	0.1076	0.5370	0.0913
10_11	0.5634	0.1253	0.5957	0.0973	0.5048	0.1115
14_15	0.6625	0.0972	0.5194	0.2072	0.5986	0.1251
14_16	0.5435	0.0700	0.5482	0.1290	0.5063	0.0815
14_17	0.6375	0.0706	0.6750	0.1019	0.7194	0.0733
14_18	0.6000	0.1393	0.4611	0.0593	0.6153	0.0874
15_16	0.6095	0.1515	0.5802	0.1218	0.6417	0.0849
15_17	0.5210	0.1370	0.4654	0.0564	0.5485	0.1154
15_18	0.6444	0.1219	0.5611	0.0836	0.6389	0.1632
16_17	0.5251	0.0922	0.5352	0.1147	0.4494	0.1122
16_18	0.5202	0.1163	0.4861	0.1335	0.4850	0.1591
17_18	0.6022	0.1575	0.6737	0.1171	0.5665	0.2447

Table S6. The Spearman's correlation coefficient matrix, each cell reflects the overall correlation between all dynamical features extracted in the corresponding repeat. This table, along with Tables S7 and S8 and Figure 2b in the main text, demonstrates the weak robustness and poor reproducibility of the individual-level dynamical features.

Repeat Index	**REP1**	**REP2**	**REP3**	**REP4**	**REP5**	**REP6**	**AVG REP 1/2/3**	**AVG REP 4/5/6**
REP1	1.0000	--	--	--	--	--	--	--
REP2	0.0958	1.0000	--	--	--	--	--	--
REP3	0.0996	0.0954	1.0000	--	--	--	--	--
REP4	0.0990	0.1026	0.1087	1.0000	--	--	--	--
REP5	0.0981	0.1152	0.0924	0.1071	1.0000	--	--	--
REP6	0.1050	0.1060	0.0968	0.1183	0.1140	1.0000	--	--
AVG REP 1/2/3	--	--	--	0.1085	0.1202	0.1095	1.0000	--
AVG REP 4/5/6	0.1052	0.1146	0.1082	--	--	--	0.1174	1.0000

Table S7. Average AUC scores of classifiers for the HC/SCZ classification task in 5-fold CV using features extracted from repetitions 1 to 6, as well as averaged features across different repetitions (Region pairs from DMN). This table, along with Tables S6 and S8 and Figure 2b in the main text, demonstrates the weak robustness and poor reproducibility of the individual-level dynamical features.

Model Type	Region Pairs (DMN)	Features Version															
		REP_1	Std.	REP_2	Std.	REP_3	Std.	REP_4	Std.	REP_5	Std.	REP_6	Std.	REP123_AVG	Std.	REP456_AVG	Std.
KNN	6-7	0.6156	0.0650	0.5203	0.0812	0.5199	0.1584	0.5105	0.1113	0.6454	0.0713	0.6380	0.0793	0.5908	0.1440	0.6586	0.1197
KNN	6-10	0.5534	0.1285	0.4127	0.0682	0.6176	0.0848	0.5080	0.1289	0.5009	0.1319	0.6142	0.0952	0.6264	0.1706	0.6283	0.1708
KNN	6-11	0.6241	0.1481	0.5732	0.1245	0.6819	0.1516	0.6566	0.0963	0.5870	0.1330	0.6222	0.1143	0.5522	0.1578	0.6389	0.1383
KNN	7-10	0.5824	0.1128	0.4983	0.1485	0.5613	0.0781	0.6569	0.0808	0.6480	0.0416	0.7074	0.0857	0.5215	0.1037	0.6847	0.0951
KNN	7-11	0.5370	0.0913	0.5598	0.1125	0.6819	0.1151	0.5727	0.1455	0.5818	0.1092	0.6981	0.1409	0.6651	0.1272	0.7072	0.1152
KNN	10-11	0.5048	0.1115	0.6686	0.0870	0.5667	0.0329	0.5920	0.1776	0.5889	0.1346	0.6576	0.0581	0.4745	0.1489	0.5396	0.1288
RF	6-7	0.6649	0.1005	0.4981	0.1043	0.5383	0.0597	0.4870	0.0664	0.6914	0.1816	0.6735	0.0746	0.4314	0.1606	0.5875	0.1577
RF	6-10	0.7193	0.0958	0.5778	0.1906	0.6120	0.0759	0.5942	0.0451	0.5332	0.1181	0.5699	0.2222	0.6131	0.0669	0.5335	0.1596
RF	6-11	0.5336	0.1092	0.5002	0.0961	0.4772	0.1260	0.6189	0.1352	0.4865	0.0927	0.6380	0.1545	0.6252	0.1370	0.6848	0.1053
RF	7-10	0.4370	0.2201	0.5601	0.1434	0.5792	0.0697	0.4854	0.1291	0.7005	0.0480	0.5682	0.1254	0.5672	0.1424	0.6383	0.0928
RF	7-11	0.5802	0.1076	0.6143	0.0628	0.5833	0.1596	0.5510	0.0720	0.6099	0.1257	0.7177	0.1089	0.5226	0.0494	0.4738	0.1889
RF	10-11	0.5957	0.0973	0.5422	0.0468	0.5304	0.1501	0.3998	0.1708	0.6361	0.0977	0.5830	0.0934	0.5282	0.1084	0.4986	0.1234
SVM	6-7	0.6552	0.1629	0.5806	0.1621	0.6235	0.0858	0.5299	0.1279	0.6062	0.1299	0.6523	0.0521	0.6029	0.0695	0.6969	0.1019
SVM	6-10	0.5850	0.1068	0.4392	0.0632	0.5994	0.0987	0.5180	0.0658	0.5335	0.0587	0.6254	0.0389	0.6552	0.1913	0.6321	0.1888
SVM	6-11	0.6048	0.1171	0.6119	0.0585	0.6511	0.1581	0.7086	0.1350	0.5590	0.1768	0.6259	0.0924	0.5336	0.0755	0.6446	0.0813
SVM	7-10	0.5418	0.1362	0.5530	0.1397	0.5427	0.0760	0.6972	0.0872	0.6809	0.0372	0.6449	0.0684	0.5004	0.0735	0.6815	0.1146
SVM	7-11	0.5605	0.0448	0.6141	0.1443	0.6250	0.1001	0.5703	0.0882	0.5382	0.1145	0.7704	0.1108	0.6413	0.1461	0.7207	0.1423
SVM	10-11	0.5634	0.1253	0.6468	0.1042	0.5543	0.1612	0.5337	0.1440	0.6333	0.0992	0.6915	0.0854	0.5589	0.0651	0.5648	0.0996

Table S8. Average AUC scores of classifiers for the HC/SCZ classification task in 5-fold CV using features extracted from repetitions 1 to 6, as well as averaged features across different repetitions (Region pairs from SN). This table, along with Tables S6 and S7 and Figure 2b in the main text, demonstrates the weak robustness and poor reproducibility of the individual-level dynamical features.

Model Type	Region Pairs (SN)	Features Version															
		REP_1	Std.	REP_2	Std.	REP_3	Std.	REP_4	Std.	REP_5	Std.	REP_6	Std.	REP123_AVG	Std.	REP456_AVG	Std.
KNN	14_15	0.5986	0.1251	0.5056	0.0714	0.5642	0.0851	0.5539	0.0993	0.5574	0.0665	0.6083	0.1020	0.6189	0.1004	0.5672	0.1395
KNN	14_16	0.5063	0.0815	0.5764	0.0708	0.5250	0.1438	0.6770	0.1489	0.5532	0.0781	0.5964	0.0939	0.5115	0.1178	0.5674	0.0395
KNN	14_17	0.7194	0.0733	0.5819	0.0824	0.6064	0.1012	0.6159	0.1571	0.6058	0.1400	0.5800	0.0747	0.6286	0.0813	0.6489	0.0748
KNN	14_18	0.6153	0.0874	0.5694	0.0274	0.5417	0.1302	0.5956	0.1032	0.5000	0.1093	0.4801	0.0620	0.5157	0.1147	0.5404	0.0606
KNN	15_16	0.6417	0.0849	0.5514	0.0384	0.6096	0.1013	0.5097	0.0764	0.7148	0.1150	0.5957	0.1004	0.6338	0.0968	0.4733	0.1305
KNN	15_17	0.5485	0.1154	0.5750	0.0453	0.5981	0.1653	0.5375	0.1711	0.6039	0.1081	0.4889	0.0790	0.5722	0.0716	0.5917	0.0438
KNN	15_18	0.6389	0.1632	0.5993	0.0827	0.4878	0.0933	0.6501	0.1251	0.5361	0.1730	0.5646	0.1294	0.5927	0.1844	0.5344	0.0976
KNN	16_17	0.4494	0.1122	0.5351	0.1814	0.5417	0.1294	0.5627	0.0573	0.5455	0.1004	0.6820	0.1072	0.5885	0.0895	0.6486	0.1090
KNN	16_18	0.4850	0.1591	0.6775	0.1751	0.5351	0.1281	0.5057	0.1476	0.5107	0.1488	0.4458	0.1029	0.6310	0.1036	0.4991	0.0687
KNN	17_18	0.5665	0.2447	0.6125	0.0910	0.5164	0.1532	0.5897	0.1115	0.5602	0.1466	0.5127	0.0798	0.5866	0.1216	0.5500	0.1005
RF	14_15	0.5194	0.2072	0.6497	0.1411	0.6047	0.0846	0.7228	0.0893	0.5665	0.1550	0.6456	0.1017	0.5973	0.0336	0.6781	0.1245
RF	14_16	0.5482	0.1290	0.5861	0.0840	0.5306	0.0624	0.6667	0.1214	0.4191	0.0947	0.5193	0.1234	0.6113	0.0874	0.5764	0.0754
RF	14_17	0.6750	0.1019	0.5139	0.0886	0.6647	0.1240	0.7332	0.0889	0.5564	0.1894	0.6443	0.0953	0.5824	0.0541	0.6188	0.0593
RF	14_18	0.4611	0.0593	0.6886	0.1393	0.6269	0.1222	0.4578	0.1044	0.5682	0.1160	0.5534	0.1234	0.6150	0.0680	0.5533	0.1179
RF	15_16	0.5802	0.1218	0.6472	0.0988	0.6790	0.1153	0.6108	0.0898	0.5417	0.1205	0.4694	0.0934	0.5529	0.0965	0.5777	0.1492
RF	15_17	0.4654	0.0564	0.5926	0.1748	0.6310	0.0728	0.5198	0.1207	0.6549	0.0958	0.6181	0.0905	0.6168	0.0451	0.6107	0.1454
RF	15_18	0.5611	0.0836	0.5918	0.0630	0.4399	0.1110	0.6043	0.1127	0.6248	0.1543	0.6413	0.0632	0.5190	0.1153	0.6353	0.1550
RF	16_17	0.5352	0.1147	0.6056	0.1410	0.5167	0.0885	0.5719	0.1225	0.5273	0.1533	0.5583	0.0514	0.7388	0.1060	0.6883	0.0433
RF	16_18	0.4861	0.1335	0.6522	0.0778	0.7188	0.1002	0.6168	0.0671	0.5714	0.0804	0.4228	0.1620	0.6357	0.1434	0.5222	0.1027
RF	17_18	0.6737	0.1171	0.5986	0.0515	0.6986	0.0718	0.5719	0.1280	0.4723	0.1163	0.6289	0.1102	0.5902	0.0786	0.6023	0.1103
SVM	14_15	0.6625	0.0972	0.5361	0.0779	0.5698	0.0292	0.6551	0.0940	0.5881	0.0742	0.6992	0.0831	0.5098	0.1043	0.5916	0.0994
SVM	14_16	0.5435	0.0700	0.6528	0.0288	0.5514	0.0981	0.6526	0.1920	0.5472	0.1281	0.5924	0.0884	0.5236	0.1029	0.5861	0.0766
SVM	14_17	0.6375	0.0706	0.5583	0.0636	0.5961	0.0522	0.6179	0.1451	0.5561	0.1432	0.5835	0.1177	0.6449	0.0894	0.6412	0.1321
SVM	14_18	0.6000	0.1393	0.5583	0.1256	0.4657	0.0904	0.5974	0.1192	0.5139	0.0977	0.5843	0.1488	0.5368	0.1065	0.5190	0.0546
SVM	15_16	0.6095	0.1515	0.6167	0.1284	0.6008	0.0524	0.5129	0.0918	0.6850	0.0659	0.5748	0.1244	0.5371	0.0673	0.4956	0.1415
SVM	15_17	0.5210	0.1370	0.6422	0.0561	0.6153	0.0823	0.6770	0.1050	0.6123	0.0938	0.5012	0.0744	0.5570	0.0640	0.6146	0.1917
SVM	15_18	0.6444	0.1219	0.6462	0.1180	0.4831	0.1011	0.6581	0.1045	0.5127	0.1039	0.6106	0.0314	0.6286	0.1708	0.5114	0.1308
SVM	16_17	0.5251	0.0922	0.5526	0.1567	0.6000	0.1196	0.5554	0.0789	0.4986	0.0801	0.6577	0.0865	0.6523	0.1325	0.5664	0.1138
SVM	16_18	0.5202	0.1163	0.6772	0.1254	0.5769	0.1611	0.4989	0.0856	0.5421	0.1649	0.4860	0.0667	0.6372	0.0873	0.5415	0.1429
SVM	17_18	0.6022	0.1575	0.6847	0.0933	0.5694	0.0810	0.6347	0.1063	0.5614	0.0706	0.5137	0.0820	0.5726	0.1003	0.6143	0.0951

Table S9. The full performance scores of the RF models using the graph clustering method in SCZ/HC, MDD/HC and SCZ/(HC+MDD) classification tasks, related to Figure 3b in the main text.

Task	F_{cut}	Dataset Size	P-value	Sensitivity	Specificity	ACC	AUC
SCZ/HC	0.530	88	0.3512	0.5772	0.5405	0.5597	0.5613
	0.535	88	0.1494	0.6348	0.5429	0.5909	0.5896
	0.540	87	0.3195	0.6011	0.5171	0.5615	0.5595
	0.545	83	0.1822	0.5593	0.6125	0.5849	0.5861
	0.550	78	0.6908	0.5037	0.5487	0.5256	0.5263
	0.555	69	0.3776	0.5576	0.5681	0.5630	0.5628
	0.560	43	0.0010	0.7588	0.7904	0.7779	0.7687
	0.565	**28**	**0.0009**	**0.6923**	**0.9467**	**0.8286**	**0.8501**
	0.570	25	0.0713	0.6955	0.7464	0.7240	0.7219
MDD/HC	0.530	86	0.3889	0.5955	0.5238	0.5605	0.5600
	0.535	86	0.0567	0.4352	0.3476	0.3924	0.6093
	0.540	84	0.5919	0.4279	0.4915	0.4589	0.5405
	0.545	82	0.7665	0.4083	0.5375	0.4713	0.5275
	0.550	75	0.0118	0.6838	0.6250	0.6540	0.6549
	0.555	68	0.0042	0.7219	0.6472	0.6824	0.6845
	0.560	37	0.2389	0.6273	0.6385	0.6351	0.6136
	0.565	**22**	**0.0702**	**0.8286**	**0.6900**	**0.7341**	**0.7266**
	0.570	18	0.8904	0.5000	0.6321	0.6028	0.5498
SCZ/(HC+MDD)	0.530	132	0.5895	0.4457	0.4942	0.4773	0.4726
	0.535	132	0.2257	0.5587	0.5698	0.5659	0.5586
	0.540	130	0.5283	0.5609	0.5042	0.5242	0.5298
	0.545	125	0.3414	0.5442	0.5591	0.5540	0.5468
	0.550	115	0.7750	0.4475	0.5320	0.5026	0.4906
	0.555	101	0.7980	0.5303	0.4507	0.4767	0.4915
	0.560	54	1.80E-05	0.7882	0.8446	0.8269	0.7985
	0.565	**35**	3.80E-05	**0.8731**	**0.8841**	**0.8800**	**0.8704**
	0.570	29	0.0027	0.7682	0.8694	0.8310	0.8223
	0.575	26	0.0105	0.7722	0.8176	0.8019	0.7818
	0.580	10	0.9321	0.5750	0.4000	0.4700	0.5531

Table S10. The performance of RF classifiers using features filtered and integrated via hypothesis-driven pipeline on SCZ/HC, MDD/HC and SCZ/non-SCZ classification tasks. This table can be compared with Table S9 and Figure 3b in the main text and indicates that our proposed hypothesis-free pipeline does not improve classification performance compared to the hypothesis-driven pipeline.

Task	Dataset Size	P-value	Sensitivity	Specificity	ACC	AUC
SCZ/HC	88	0.0009	0.7370	0.6357	0.6886	0.6886
MDD/HC	86	0.3465	0.6182	0.5048	0.5628	0.5624
SCZ/(HC+MDD)	132	0.0480	0.6065	0.5890	0.5951	0.5890

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