Active Perceptual Inference: A Corticothalamic-Inspired Dynamic Nested Recurrent Network for Multimodal Sentiment Analysis with Incomplete Data

Supplementary Material

A. Additional Experiments and Analysis

A.1. Loss Weight Sensitivity Analysis

To assess the robustness of our proposed method, we conducted a hyperparameter sensitivity analysis on different datasets. During this process, all other training configurations remained unchanged. Detailed performance comparisons of different weight combinations on the MOSI, MOSEI, and SIMS datasets are presented in Table 4, Table 5, and Table 6, respectively. Empirical evidence indicates that the model exhibits good robustness and relative stability. Additionally, it is demonstrated that the precise calibration of loss weights is crucial for coordinating different learning objectives and maximizing model efficacy. We observed that due to inherent differences in data distributions and sample sizes, the optimal parameter values vary across datasets. Specifically, the model achieves peak performance with weight pairs (α, β) set to (0.5, 0.1) for MOSI, (0.9, 10) for MOSEI, and (0.9, 0.1) for SIMS.

Table 4. Effect of loss weighting on model performance on the MOSI dataset. Note: The lower MAE corresponds to superior results.

MOSI						
α, β	Acc-7	Acc-5	Acc-2	F1	MAE	Corr
0.1, 0.5	34.84	39.02	73.68 / 72.41	74.15 / 72.47	1.054	0.524
0.1, 0.9	34.80	**39.13**	73.26 / 71.95	73.77 / 71.76	1.064	0.521
0.9, 0.1	34.96	38.94	74.12 / 72.92	**74.28** / 73.20	1.043	0.529
0.9, 0.5	34.92	39.05	73.70 / 72.46	74.10 / 72.49	1.052	0.526
0.5, 0.1	**35.36**	39.11	**74.22 / 73.19**	74.24 / **73.28**	**1.036**	**0.538**

Table 5. Effect of loss weighting on model performance on the MOSEI dataset. Note: The lower MAE corresponds to superior results.

MOSEI						
α, β	Acc-7	Acc-5	Acc-2	F1	MAE	Corr
0.5, 0.1	**46.98**	47.70	77.96 / 78.25	78.65 / 79.97	0.670	0.586
0.1, 10	46.92	47.74	78.19 / 78.21	78.73 / 79.91	0.665	0.587
0.9, 5	46.96	**47.90**	77.89 / 78.20	78.49 / 79.99	0.670	0.590
0.1, 0.5	46.83	47.83	77.75 / 78.15	78.55 / 80.00	0.674	0.584
0.9, 10	46.89	47.84	**78.28 / 78.89**	**78.74 / 80.18**	**0.655**	**0.590**

Table 6. Effect of loss weighting on model performance on the SIMS dataset. Note: The lower MAE corresponds to superior results.

SIMS						
α, β	Acc-5	Acc-3	Acc-2	F1	MAE	Corr
0.1, 0.5	35.70	58.54	73.94	**78.55**	0.510	0.385
0.1, 0.9	**35.96**	59.41	**74.62**	76.74	0.508	0.390
0.5, 0.1	35.70	58.54	73.96	78.54	0.510	0.385
0.9, 0.5	35.95	59.34	73.57	76.74	0.508	0.390
0.9, 0.1	35.71	**59.54**	73.82	77.50	**0.498**	**0.416**

A.2. Detailed Performance under Different Missing Rates

Tables 7, 8, and 9 present a detailed comparison of DNRNet and baseline models under varying missing rates across the three benchmark datasets. According to the experimental findings, DNRNet achieves the best performance on the MOSI and MOSEI datasets in almost all missing rate settings, and also demonstrates highly competitive results on the SIMS dataset. Notably, models such as CENET and TETFN also exhibit relatively strong performance across specific metrics. A ubiquitous observation is that as the missing rate r increases, the performance of all evaluated models unfailingly declines, thus confirming the significant challenge posed by modality data incompleteness in multimodal sentiment analysis. This trend highlights the critical need for advanced mechanisms capable of mapping fragmented input representations back to a coherent semantic space. It also demonstrates the effectiveness of the brain-dynamic active perception and reasoning inspired recurrent nested network integrated within our model for handling severely incomplete data.

A.3. Classification Performance Visualization

We present the confusion matrices of a representative baseline model and DNRNet on the SIMS dataset under missing rates of 0.0, 0.1, 0.5, and 0.9. Detailed confusion matrices for each missing rate are shown in Figure 6. As the modality missing rate increases, the baseline model exhibits a significant class prediction bias, showing a pronounced tendency to collapse toward the weakly negative class. This suggests an excessive dependence on the single, dominant class under conditions of severe modality sparsity. In sharp contrast, DNRNet successfully maintains its predictions distributed across multiple sentiment categories even at the highest missing rates ($r = 0.9$), thereby demonstrating superior discriminative capacity. These observations are consistent with the performance trends observed on the MOSI

Table 7. Robustness comparison of the overall performance on MOSI datasets. Note: The lower MAE corresponds to superior results.

Method	Acc-7	Acc-5	Acc-2	F1	MAE	Corr
Random Missing Rate $r = 0$						
MISA	43.05	48.30	82.78 / 81.24	82.83 / 81.23	0.771	0.777
Self-MM	42.81	52.38	85.22 / 83.24	85.19 / 83.26	0.720	0.790
MMIM	45.92	49.85	83.43 / 81.97	83.43 / 81.94	0.744	0.778
CENET	43.20	50.39	83.08 / 81.49	83.06 / 81.48	0.748	0.785
TETFN	44.07	51.31	82.62 / 81.10	82.67 / 81.09	**0.719**	**0.794**
TFR-Net	40.82	47.91	83.64 / 81.68	83.57 / 81.61	0.805	0.760
ALMT	42.37	48.49	84.91 / 82.75	85.01 / 82.94	0.752	0.768
LNLN	44.56	49.76	84.25 / 81.24	84.61 / 81.79	0.751	0.778
P-RMF	44.31	48.83	84.15 / 82.65	84.37 / 82.69	0.726	0.782
DNRNet	**46.06**	**52.77**	**86.13 / 84.69**	**86.18 / 84.77**	0.726	0.788
Random Missing Rate $r = 0.1$						
MISA	40.28	46.21	80.18 / 79.01	80.21 / 78.97	0.847	0.721
Self-MM	40.33	**49.03**	81.40 / 80.03	81.19 / 80.03	0.812	0.728
MMIM	42.61	46.65	79.98 / 78.13	79.83 / 77.99	0.825	0.718
CENET	40.13	46.60	80.08 / 78.38	79.91 / 78.20	0.837	0.719
TETFN	40.67	46.84	80.59 / 78.91	80.55 / 78.79	0.805	0.731
TFR-Net	38.63	45.82	79.27 / 77.99	78.70 / 77.61	0.872	0.705
ALMT	39.84	45.48	80.90 / 78.67	81.15 / 79.08	0.843	0.703
LNLN	42.37	47.91	81.20 / 78.43	81.62 / 79.04	0.820	0.724
P-RMF	42.13	47.52	82.62 / 81.34	82.89 / **81.35**	0.800	0.730
DNRNet	**43.15**	48.83	**84.45 / 83.38**	**84.45 / 83.42**	0.802	**0.736**
Random Missing Rate $r = 0.2$						
MISA	36.25	41.55	77.54 / 76.34	77.58 / 76.30	0.939	0.654
Self-MM	36.64	43.98	78.15 / 76.48	77.76 / 76.51	0.901	0.660
MMIM	39.07	42.66	76.42 / 74.54	76.12 / 74.22	0.918	0.651
CENET	38.00	42.32	77.49 / 74.64	77.35 / 74.28	0.916	0.654
TETFN	35.81	41.79	77.49 / 75.60	77.35 / 75.35	0.910	0.657
TFR-Net	34.70	40.13	74.70 / 73.52	73.57 / 72.70	0.987	0.622
ALMT	35.33	40.33	77.64 / 75.70	77.94 / 76.24	0.927	0.645
LNLN	39.74	45.14	79.22 / 76.87	79.53 / 77.34	0.891	0.668
P-RMF	40.38	44.75	79.57 / 78.13	80.97 / 78.11	**0.853**	0.668
DNRNet	**40.38**	**45.48**	**82.47 / 81.20**	**82.51 / 81.28**	0.885	**0.677**
Random Missing Rate $r = 0.3$						
MISA	34.60	38.97	75.76 / 74.54	75.82 / 74.51	0.989	0.618
Self-MM	34.89	40.67	76.37 / 74.98	75.68 / 74.94	0.967	0.614
MMIM	36.83	40.43	74.08 / 71.91	73.47 / 71.28	0.974	0.612
CENET	34.74	38.97	76.83 / 72.01	76.56 / 71.30	0.983	0.605
TETFN	33.24	38.58	75.25 / 73.42	74.77 / 72.78	0.982	0.607
TFR-Net	32.55	38.34	72.36 / 71.28	70.12 / 69.58	1.065	0.572
ALMT	33.04	37.17	75.15 / 72.94	75.51 / 73.66	0.992	0.596
LNLN	38.00	42.81	77.29 / 75.46	77.56 / 75.68	0.953	0.617
P-RMF	39.21	42.71	76.83 / 75.80	79.27 / 75.82	**0.922**	0.621
DNRNet	**39.50**	**44.46**	**79.42 / 78.28**	**79.56 / 78.26**	0.933	**0.630**
Random Missing Rate $r = 0.4$						
MISA	32.65	35.37	73.88 / 72.59	73.88 / 72.49	1.041	0.585
Self-MM	31.20	36.30	73.17 / 71.96	71.74 / 71.75	1.027	0.579
MMIM	33.38	35.76	70.84 / 68.90	69.69 / 67.80	1.034	0.576
CENET	32.26	36.15	73.38 / 71.53	72.75 / 70.26	1.031	0.574
TETFN	30.66	35.28	72.05 / 70.07	70.79 / 68.58	1.051	0.571
TFR-Net	30.17	35.76	68.75 / 67.74	64.71 / 64.41	1.142	0.537
ALMT	31.44	35.03	73.12 / 71.14	73.85 / 72.47	1.045	0.560
LNLN	36.49	41.11	76.01 / 74.25	76.31 / 74.67	0.987	0.594
P-RMF	35.59	40.67	75.46 / 73.76	77.71 / 74.09	1.001	0.584
DNRNet	**38.05**	**41.98**	**78.05 / 76.38**	**78.19 / 76.62**	**0.970**	**0.612**

Method	Acc-7	Acc-5	Acc-2	F1	MAE	Corr
Random Missing Rate $r = 0.5$						
MISA	28.14	30.61	70.53 / 69.34	70.50 / 69.20	1.124	0.519
Self-MM	26.97	31.39	67.43 / 67.54	64.27 / 66.81	1.129	0.503
MMIM	28.33	29.89	68.09 / 66.52	66.15 / 64.59	1.128	0.501
CENET	28.33	30.90	72.46 / 66.08	71.10 / 63.50	1.130	0.496
TETFN	27.55	31.34	67.23 / 65.06	64.30 / 61.78	1.157	0.492
TFR-Net	25.85	30.71	64.83 / 63.02	58.04 / 56.64	1.270	0.443
ALMT	28.42	31.25	68.24 / 65.94	69.74 / 68.54	1.138	0.485
LNLN	**33.92**	**38.39**	**73.37** / 71.86	**73.70** / 72.30	**1.059**	0.536
P-RMF	33.67	37.90	73.02 / 71.28	73.33 / 71.66	1.077	0.523
DNRNet	33.53	37.46	73.32 / **72.59**	73.24 / **72.59**	1.060	**0.553**
Random Missing Rate $r = 0.6$						
MISA	24.68	27.12	66.97 / 65.84	66.94 / 65.69	1.200	0.441
Self-MM	24.34	27.31	63.47 / 63.36	58.94 / 62.07	1.209	0.425
MMIM	25.41	27.11	63.67 / 62.49	60.87 / 59.48	1.208	0.418
CENET	24.54	26.53	67.58 / 61.47	64.87 / 57.86	1.215	0.415
TETFN	25.12	27.99	64.42 / 61.23	58.68 / 56.08	1.238	0.417
TFR-Net	24.05	28.33	61.64 / 59.47	52.44 / 50.53	1.371	0.363
ALMT	25.41	27.36	64.53 / 62.15	66.81 / 65.87	1.214	0.407
LNLN	30.37	34.35	69.00 / 67.69	69.19 / 67.99	1.147	0.458
P-RMF	29.30	33.24	68.75 / 67.35	68.64 / 67.64	1.147	0.432
DNRNet	**32.80**	**35.57**	**69.82 / 69.53**	**69.67 / 69.49**	**1.133**	**0.470**
Random Missing Rate $r = 0.7$						
MISA	21.14	23.27	65.09 / 63.89	65.07 / 63.74	1.257	0.381
Self-MM	20.70	23.81	61.74 / 61.46	55.11 / 58.97	1.271	0.339
MMIM	22.35	24.00	61.23 / 59.18	57.15 / 54.36	1.267	0.342
CENET	22.35	59.86	63.82 / 59.43	53.79 / 54.22	1.269	0.335
TETFN	23.13	25.27	61.13 / 58.65	53.79 / 50.77	1.293	0.337
TFR-Net	23.71	26.92	59.91 / 57.34	48.41 / 45.48	1.454	0.276
ALMT	23.71	24.97	61.84 / 59.67	65.30 / 65.19	1.266	0.336
LNLN	27.79	31.19	65.95 / 65.01	**65.95** / 65.14	**1.219**	0.383
P-RMF	27.84	**32.94**	**66.16** / 65.16	64.69 / 65.33	1.229	**0.383**
DNRNet	**29.30**	30.61	66.01 / **65.60**	65.87 / **65.59**	1.225	0.379
Random Missing Rate $r = 0.8$						
MISA	19.92	20.99	**63.56 / 62.24**	63.16 / 61.67	1.311	0.321
Self-MM	19.29	22.11	59.55 / 58.26	49.98 / 53.56	1.313	0.282
MMIM	20.26	21.77	58.33 / 55.30	52.46 / 47.89	1.312	0.287
CENET	21.14	21.67	60.93 / 57.53	54.68 / 50.80	1.314	0.274
TETFN	22.01	23.76	59.40 / 56.85	48.73 / 45.59	1.337	0.274
TFR-Net	23.23	27.70	58.49 / 55.98	44.70 / 41.88	1.497	0.155
ALMT	23.13	23.66	60.37 / 58.31	**65.45 / 66.14**	1.310	0.273
LNLN	26.34	28.23	62.75 / 62.10	62.56 / 62.03	1.283	0.314
P-RMF	25.97	**29.74**	62.04 / 61.08	60.76 / 61.22	**1.275**	0.316
DNRNet	**26.38**	28.13	62.65 / 61.95	62.47 / 61.90	1.281	**0.323**
Random Missing Rate $r = 0.9$						
MISA	17.7	18.4	58.64 / 58.21	56.84 / 56.19	1.369	**0.226**
Self-MM	18.32	19.78	58.59 / 55.25	46.16 / 47.46	1.353	0.197
MMIM	18.95	19.53	55.29 / 51.65	47.33 / 40.89	1.357	0.186
CENET	19.15	19.10	58.99 / 54.76	50.01 / 46.58	1.357	0.181
TETFN	20.75	21.19	58.43 / 55.88	45.24 / 42.12	1.378	0.186
TFR-Net	21.67	25.12	57.93 / 55.44	43.01 / 40.18	1.534	0.155
ALMT	20.31	20.50	57.32 / 56.66	**64.92 / 67.82**	1.349	0.205
LNLN	22.98	23.86	56.50 / 56.51	56.32 / 56.47	1.349	0.202
P-RMF	23.49	**26.68**	59.45 / **58.75**	56.66 / 59.01	**1.346**	0.212
DNRNet	**24.49**	25.80	**59.91** / 58.31	60.28 / 58.90	1.349	0.215

dataset, which further validates the robustness and stability of DNRNet when faced with extreme data incompleteness.

Table 8. Robustness comparison of the overall performance on MOSEI datasets. Note: The lower MAE corresponds to superior results.

Method	Acc-7	Acc-5	Acc-2	F1	MAE	Corr	Method	Acc-7	Acc-5	Acc-2	F1	MAE	Corr
Random Missing Rate $r = 0$							Random Missing Rate $r = 0.5$						
MISA	51.79	53.85	85.28 / 84.10	85.10 / 83.75	0.552	0.759	MISA	38.12	36.05	67.38 / 73.21	58.38 / 64.14	0.834	0.492
Self-MM	53.89	55.72	85.34 / **84.68**	85.11 / 84.66	0.531	0.764	Self-MM	42.70	43.14	71.97 / 75.81	67.40 / 70.38	0.733	0.477
MMIM	50.76	53.04	83.53 / 81.65	83.39 / 81.41	0.576	0.724	MMIM	38.68	39.21	71.75 / 74.45	67.70 / 67.96	0.775	0.470
CENET	**54.39**	**56.12**	85.49 / 82.30	85.41 / 82.60	**0.531**	0.770	CENET	45.12	45.52	73.33 / 77.16	69.80 / 74.14	0.720	0.515
TETFN	44.07	55.96	82.62 / 81.10	82.67 / 81.09	0.719	**0.794**	TETFN	27.55	45.63	67.23 / 65.06	64.30 / 61.78	1.157	0.492
TFR-Net	53.71	47.91	84.96 / 84.65	84.71 / 84.34	0.550	0.745	TFR-Net	45.00	30.71	71.53 / 75.69	66.88 / 70.07	0.730	0.471
ALMT	52.18	53.89	**85.62** / 83.99	**85.69** / 84.53	0.542	0.752	ALMT	37.82	38.34	77.40 / 77.48	77.73 / 77.80	0.683	0.461
LNLN	50.66	51.94	84.14 / 83.61	84.53 / 84.02	0.572	0.735	LNLN	44.90	45.59	76.44 / 78.10	77.23 / 79.30	0.710	0.529
P-RMF	49.77	52.09	85.20 / 83.62	85.48 / 83.68	0.539	0.767	P-RMF	43.94	44.90	78.62 / 78.64	**79.49** / 79.74	0.666	**0.601**
DNRNet	52.46	54.07	85.28 / 84.12	85.53 / **84.67**	0.534	0.787	**DNRNet**	**45.57**	**46.51**	**78.87 / 78.92**	79.25/ **79.99**	**0.661**	0.588
Random Missing Rate $r = 0.1$							Random Missing Rate $r = 0.6$						
MISA	50.13	51.34	82.21 / 82.28	81.28 / 80.79	0.598	0.722	MISA	36.16	33.30	65.55 / 72.30	54.64 / 62.12	0.875	0.415
Self-MM	51.80	53.18	83.03 / **83.79**	82.43 / 83.23	0.564	0.725	Self-MM	41.47	41.75	69.33 / 73.93	63.01 / 66.76	0.762	0.401
MMIM	49.09	51.19	82.00 / 81.09	81.57 / 80.15	0.602	0.696	MMIM	37.13	37.48	68.83 / 73.16	63.09 / 65.43	0.808	0.402
CENET	**52.83**	54.23	83.75 / 82.41	83.42 / 82.34	0.556	0.739	CENET	44.45	44.64	70.50 / 75.39	65.27 / 70.86	0.749	0.446
TETFN	40.67	**54.28**	80.59 / 78.91	80.55 / 78.79	0.805	0.731	TETFN	25.12	44.07	63.42 / 61.23	58.68 / 56.08	1.238	0.417
TFR-Net	52.29	45.82	82.92 / 83.31	82.25 / 82.40	0.573	0.715	TFR-Net	43.88	28.33	68.80 / 74.05	62.51 / 67.07	0.762	0.397
ALMT	49.98	51.38	84.14 / 82.84	84.23 / 83.04	0.583	0.718	ALMT	35.99	36.30	74.98 / 76.26	75.44 / 76.71	0.710	0.395
LNLN	49.96	51.25	83.32 / 82.73	83.66 / 82.91	0.591	0.712	LNLN	43.52	44.00	73.82 / 76.50	75.03 / 78.33	0.736	0.471
P-RMF	49.04	51.45	83.98 / 82.79	**84.37** / 82.94	0.556	**0.748**	P-RMF	42.26	43.12	76.11 / **77.44**	**77.58 / 78.97**	0.703	**0.545**
DNRNet	51.49	53.21	**84.26** / 83.67	84.28 / **84.18**	**0.543**	0.741	**DNRNet**	**44.88**	**45.52**	**76.31** / 76.88	76.60 / 78.30	**0.700**	0.536
Random Missing Rate $r = 0.2$							Random Missing Rate $r = 0.7$						
MISA	47.24	47.66	77.84 / 79.93	75.56 / 76.88	0.659	0.674	MISA	34.54	31.21	64.28 / 71.71	51.82 / 60.65	0.906	0.344
Self-MM	49.44	50.51	80.84 / 82.33	79.76 / 81.17	0.604	0.678	Self-MM	39.93	40.12	66.79 / 72.55	58.05 / 63.45	0.786	0.329
MMIM	46.27	47.99	79.93 / 79.66	79.08 / 77.68	0.642	0.653	MMIM	35.25	35.47	66.89 / 72.26	58.90 / 63.26	0.834	0.341
CENET	50.72	51.85	81.46 / 81.62	80.78 / 81.17	0.590	0.698	CENET	43.93	44.03	67.50 / 73.39	59.88 / 67.02	0.776	0.384
TETFN	35.81	**52.35**	77.49 / 75.60	77.35 / 75.35	0.910	0.657	TETFN	23.13	43.15	61.13 / 58.65	53.79 / 50.77	1.293	0.337
TFR-Net	**51.04**	40.13	80.47 / 81.61	79.29 / 79.99	0.604	0.672	TFR-Net	42.91	26.92	66.64 / 72.77	58.32 / 64.02	0.786	0.322
ALMT	46.61	47.82	82.71 / 81.65	82.82 / 81.83	0.607	0.669	ALMT	34.78	34.95	71.62 / 73.98	72.24 / 74.54	0.743	0.315
LNLN	48.75	49.95	81.70 / 81.68	81.95 / 81.89	0.616	0.677	LNLN	42.22	42.56	71.55 / 74.74	73.49 / 77.40	0.762	0.408
P-RMF	47.91	49.35	82.97 / 82.25	**83.37** / 82.58	0.576	**0.722**	P-RMF	41.73	42.41	**74.64 / 75.87**	**75.88 / 78.12**	**0.733**	**0.481**
DNRNet	50.29	51.62	**83.05 / 83.17**	83.08 / **83.79**	**0.572**	0.714	**DNRNet**	**43.40**	**44.02**	73.28 / 75.08	73.72 / 76.77	0.736	0.477
Random Missing Rate $r = 0.3$							Random Missing Rate $r = 0.8$						
MISA	43.99	43.40	73.32 / 77.28	68.91 / 72.25	0.724	0.615	MISA	33.29	29.51	63.43 / 71.30	49.95 / 59.69	0.927	0.267
Self-MM	47.23	48.07	77.63 / 79.99	75.69 / 77.74	0.653	0.610	Self-MM	38.69	38.78	65.07 / 71.83	54.44 / 61.49	0.805	0.259
MMIM	43.25	44.73	77.08 / 77.79	75.46 / 74.49	0.690	0.597	MMIM	33.64	33.71	64.97 / 71.57	54.76 / 61.45	0.858	0.269
CENET	48.49	49.37	78.65 / 80.02	77.34 / 78.94	0.636	0.640	CENET	42.71	42.74	65.88 / 72.16	56.80 / 64.67	0.798	0.316
TETFN	33.24	**50.23**	75.25 / 73.42	74.77 / 72.78	0.982	0.607	TETFN	22.01	42.11	59.40 / 56.85	48.73 / 45.59	1.337	0.274
TFR-Net	**48.75**	38.34	77.48 / 79.29	75.43 / 76.52	0.650	0.604	TFR-Net	42.23	27.70	65.05 / 71.95	54.91 / 61.82	0.807	0.241
ALMT	43.04	44.05	80.94 / 79.94	81.15 / 80.20	0.632	0.598	ALMT	34.01	34.09	68.15 / 71.48	69.12 / 72.28	0.774	0.231
LNLN	47.36	48.40	80.11 / 80.45	80.44 / 80.91	0.648	0.629	LNLN	40.76	40.97	68.62 / 72.86	71.83 / 76.80	0.791	0.325
P-RMF	45.95	47.78	81.26 / 80.88	**81.86** / 81.40	0.611	**0.683**	P-RMF	40.46	41.00	70.75 / **74.46**	**73.03 / 77.91**	0.764	0.401
DNRNet	48.44	50.07	**81.59 / 81.07**	81.83 / **81.41**	**0.601**	0.673	**DNRNet**	**42.86**	**42.88**	**71.24** / 73.58	72.01 / 76.03	**0.763**	**0.415**
Random Missing Rate $r = 0.4$							Random Missing Rate $r = 0.9$						
MISA	40.87	39.53	70.46 / 75.04	64.02 / 67.93	0.780	0.561	MISA	32.29	28.03	62.95 / 71.07	48.80 / 59.12	0.941	0.180
Self-MM	44.40	45.04	75.02 / 78.09	72.01 / 74.48	0.694	0.554	Self-MM	37.46	37.50	63.85 / 71.24	51.32 / 59.72	0.821	0.188
MMIM	40.84	41.86	74.56 / 76.15	71.98 / 71.40	0.732	0.542	MMIM	32.61	32.67	63.69 / 71.10	51.26 / 59.99	0.877	0.197
CENET	47.12	47.74	76.03 / 78.57	73.87 / 76.75	0.678	0.587	CENET	42.08	**42.08**	64.14 / 70.42	54.27 / 62.33	0.814	0.254
TETFN	30.66	47.62	72.05 / 70.07	70.79 / 68.58	1.051	0.571	TETFN	20.75	41.55	58.43 / 55.88	45.24 / 42.12	1.378	0.186
TFR-Net	46.70	35.76	74.74 / 77.65	71.67 / 73.71	0.688	0.548	TFR-Net	41.73	25.12	63.64 / 71.34	52.02 / 59.99	0.820	0.175
ALMT	40.40	41.21	79.40 / 79.16	79.68 / 79.50	0.651	0.536	ALMT	34.40	34.40	61.41 / 68.65	63.32 / 69.83	0.810	0.138
LNLN	45.99	46.88	78.49 / 79.70	78.98 / 80.46	0.673	0.592	LNLN	40.10	40.19	64.83 / 71.51	70.60 / 77.52	0.820	0.221
P-RMF	45.59	46.73	79.97 / 79.76	80.74 / 80.58	**0.631**	**0.653**	P-RMF	39.62	39.90	**67.86 / 72.59**	**71.51 / 77.95**	0.805	0.289
DNRNet	**47.50**	**48.36**	**81.26 / 80.30**	**81.41 / 80.64**	0.637	0.643	**DNRNet**	**42.15**	42.05	67.64 / 72.10	69.66 / 75.99	**0.801**	**0.322**

A.4. Sensitivity Analysis of Cycle Number

To further investigate the effectiveness of the iterative completion mechanism, we analyzed the impact of the number of iterations (n) on the model's regression performance. Specifically, we conducted experiments on the

Table 9. Robustness comparison of the overall performance on SIMS datasets. Note: The lower MAE corresponds to superior results.

Method	Acc-5	Acc-3	Acc-2	F1	MAE	Corr	Method	Acc-5	Acc-3	Acc-2	F1	MAE	Corr
Random Missing Rate $r = 0$							Random Missing Rate $r = 0.5$						
MISA	40.55	63.38	78.19	77.22	0.449	0.576	MISA	30.56	54.78	71.26	64.16	0.552	0.367
Self-MM	40.77	64.92	78.26	78.00	**0.421**	0.584	Self-MM	32.02	53.90	71.41	67.11	0.517	0.390
MMIM	37.42	60.69	75.42	73.10	0.475	0.528	MMIM	33.41	52.37	68.49	64.81	0.553	0.336
CENET	23.85	54.05	68.71	57.82	0.578	0.137	CENET	23.12	54.05	68.71	57.92	0.588	0.107
TETFN	41.94	65.86	**80.23**	79.25	0.424	0.589	TETFN	33.48	56.24	72.43	67.30	0.512	0.394
TFR-Net	33.85	54.12	69.15	58.44	0.562	0.254	TFR-Net	24.65	52.37	67.47	58.66	0.685	0.171
ALMT	23.41	54.78	75.64	76.27	0.527	0.536	ALMT	18.38	47.12	68.27	71.22	0.563	0.395
LNLN	38.66	63.97	75.93	**79.89**	0.458	0.570	LNLN	**36.40**	57.70	72.72	**78.77**	0.513	0.412
P-RMF	38.95	60.61	78.34	79.69	0.441	0.550	P-RMF	34.79	54.83	**73.61**	74.83	**0.495**	0.404
DNRNet	**42.23**	**66.28**	79.21	79.04	0.432	**0.581**	**DNRNet**	35.89	**58.74**	72.73	73.39	0.504	**0.439**
Random Missing Rate $r = 0.1$							Random Missing Rate $r = 0.6$						
MISA	38.88	63.02	77.39	75.82	0.461	0.561	MISA	27.72	53.97	70.46	61.81	0.578	0.286
Self-MM	40.26	63.53	77.32	76.76	0.433	0.563	Self-MM	29.10	51.86	70.02	64.21	0.548	0.313
MMIM	37.27	60.90	74.25	72.08	0.473	0.529	MMIM	29.18	49.31	67.91	63.86	0.578	0.270
CENET	22.83	53.98	68.57	57.36	0.580	0.136	CENET	22.46	53.69	69.00	58.64	0.592	0.102
TETFN	41.36	64.62	78.92	77.70	**0.432**	**0.578**	TETFN	29.90	53.54	70.97	64.19	0.545	0.309
TFR-Net	30.12	53.25	68.85	59.38	0.596	0.203	TFR-Net	24.80	52.59	67.03	58.30	0.696	0.157
ALMT	22.10	55.14	74.40	75.19	0.530	0.537	ALMT	18.67	43.69	66.81	70.69	0.574	0.322
LNLN	38.51	62.73	76.29	**80.07**	0.458	0.562	LNLN	33.70	54.63	71.55	**79.56**	0.535	0.352
P-RMF	37.72	59.52	77.24	78.88	0.454	0.530	P-RMF	**33.92**	53.03	**72.12**	73.32	0.515	0.383
DNRNet	**41.79**	**65.43**	**78.77**	79.18	0.434	0.566	**DNRNet**	32.83	**56.89**	71.77	72.04	**0.508**	**0.394**
Random Missing Rate $r = 0.2$							Random Missing Rate $r = 0.7$						
MISA	38.15	59.23	74.33	71.70	0.489	0.490	MISA	24.87	52.52	69.95	59.54	0.601	0.167
Self-MM	38.37	61.71	74.98	73.71	0.464	0.500	Self-MM	25.53	50.62	69.58	62.28	0.571	0.198
MMIM	37.27	57.33	72.36	69.80	0.504	0.460	MMIM	28.59	46.53	66.89	62.23	0.595	0.190
CENET	22.25	54.20	68.57	57.64	0.583	0.132	CENET	21.81	53.32	67.69	57.87	0.599	0.070
TETFN	39.46	61.56	75.49	73.59	**0.457**	**0.527**	TETFN	27.86	51.06	69.29	61.09	0.572	0.190
TFR-Net	29.03	53.61	68.64	59.74	0.619	0.191	TFR-Net	23.78	52.30	67.18	58.15	0.707	0.163
ALMT	21.08	53.17	72.65	73.90	0.541	0.485	ALMT	18.02	38.66	65.57	70.27	0.586	0.218
LNLN	38.88	61.78	74.76	**78.53**	0.474	0.513	LNLN	30.27	51.64	69.73	**79.37**	0.558	0.261
P-RMF	37.05	59.30	**76.23**	77.46	0.460	0.512	P-RMF	**32.23**	52.52	**71.58**	72.22	**0.531**	**0.369**
DNRNet	**41.79**	**62.06**	75.49	76.41	0.463	0.520	**DNRNet**	30.42	**54.39**	70.24	77.93	0.547	0.269
Random Missing Rate $r = 0.3$							Random Missing Rate $r = 0.8$						
MISA	36.40	59.3	74.11	70.40	0.505	0.464	MISA	22.69	52.22	69.37	57.82	0.610	0.092
Self-MM	37.93	59.81	74.76	72.85	0.474	0.487	Self-MM	22.03	50.77	69.51	60.68	0.585	0.138
MMIM	37.71	58.06	72.36	69.52	0.512	0.436	MMIM	22.32	44.35	65.28	60.53	0.607	0.145
CENET	21.44	54.05	68.42	57.41	0.578	0.175	CENET	21.73	52.15	67.47	58.44	0.599	0.074
TETFN	38.80	61.92	**75.86**	73.28	**0.463**	**0.521**	TETFN	23.48	49.60	**69.88**	60.92	0.584	0.154
TFR-Net	27.64	52.30	68.42	59.88	0.640	0.182	TFR-Net	22.97	52.74	67.54	57.55	0.721	0.100
ALMT	20.35	50.62	72.06	73.64	0.546	0.469	ALMT	18.60	34.06	64.19	69.64	0.597	0.133
LNLN	38.37	60.98	74.25	**78.60**	0.478	0.509	LNLN	27.94	50.47	69.58	80.23	0.580	0.183
P-RMF	36.89	56.89	75.66	75.89	0.475	0.483	P-RMF	**31.07**	49.89	69.51	70.34	**0.568**	**0.269**
DNRNet	**40.04**	**62.03**	75.27	76.47	0.471	0.512	**DNRNet**	25.16	**54.27**	69.37	**81.91**	0.574	0.192
Random Missing Rate $r = 0.4$							Random Missing Rate $r = 0.9$						
MISA	34.86	57.33	72.87	67.52	0.523	0.436	MISA	20.64	52.95	69.22	57.01	0.617	0.041
Self-MM	34.57	58.28	73.30	70.36	0.482	0.479	Self-MM	22.17	52.15	68.92	58.32	0.586	0.111
MMIM	34.57	55.36	69.95	66.49	0.533	0.399	MMIM	20.35	42.67	65.72	59.64	0.610	0.096
CENET	22.54	54.12	68.49	57.68	0.583	0.141	CENET	20.86	48.07	65.72	58.18	0.609	-0.002
TETFN	35.81	58.93	73.81	70.66	0.473	**0.504**	TETFN	22.10	45.73	68.92	58.75	0.590	0.108
TFR-Net	25.31	51.86	67.91	59.16	0.664	0.176	TFR-Net	23.05	53.76	69.08	57.71	0.721	0.088
ALMT	19.91	49.45	70.75	72.97	0.549	0.470	ALMT	19.47	26.91	66.23	73.76	0.596	0.076
LNLN	37.49	60.03	73.81	**78.82**	0.491	0.481	LNLN	26.19	47.48	68.64	80.42	0.591	0.127
P-RMF	36.54	55.80	75.32	76.30	0.482	0.472	P-RMF	**29.10**	45.08	66.77	67.54	0.581	0.168
DNRNet	**39.61**	**61.04**	**75.93**	76.68	**0.473**	0.495	**DNRNet**	27.35	**54.27**	**69.37**	**81.91**	**0.574**	**0.188**

MOSI dataset with a missing rate of 0.7, using the mean absolute error (MAE) metric for evaluation, where a lower value indicates better performance. As shown in Figure 7, the MAE gradually decreases as the number of iterations increases from 1 to 3, reaching its global minimum at $n = 3$. This suggests that the initial recursive iterations effectively refine the feature representations and reduce prediction errors. However, as n increases further, the error also in-

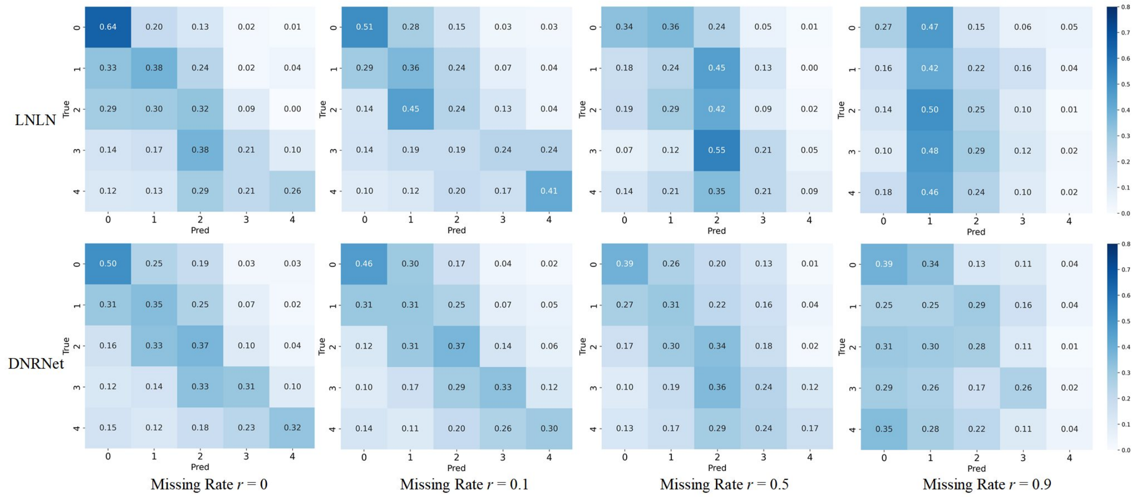

Figure 6. Confusion matrices of DNRNet and the baseline model LNLN on the SIMS dataset. Note: labels 0–4 denote negative, weakly negative, neutral, weakly positive, and positive, respectively.

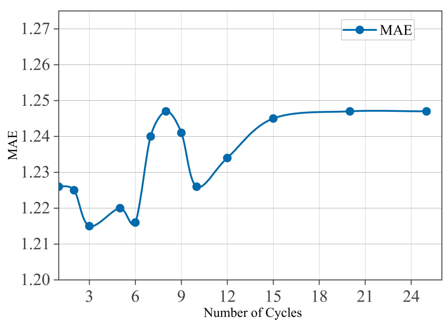

Figure 7. Sensitivity analysis of the cycle number n on the MOSI dataset under a missing rate of 0.7.

creases, demonstrating that an appropriate number of iterations can enhance feature completion, while excessive iterations may amplify the noise generated in the previous steps and introduce unnecessary interference.

A.5. Modality-Level Missingness Analysis

As shown in Table 10, DNRNet consistently outperforms all baselines across all six modality-level missing scenarios on the MOSI dataset. Notably, it achieves superior accuracy even in challenging non-verbal cases (V, A), demonstrating strong inference capabilities without the dominant language modality. These results empirically validate that our nested recurrent network effectively compensates for complete modality loss, ensuring stable semantic representation.

A.6. Validation of Dynamic Recurrent Inference

To further validate that our proposed DNRNet simulates the brain's dynamic recurrent inference, we quantitatively analyzed the evolution of internal states during the recurrent completion phase. Specifically, at a 70% missing rate, we evaluated the mean squared error between the reconstructed and ground-truth complete features across each recurrent loop. As shown in Figure 8, the overall reconstruction error demonstrates a consistent and significant monotonic de-

Table 10. Acc-2 under modality-level missing conditions on the MOSI dataset. Note: The modalities inside the { } are the present modalities.

Method	{V}	{A}	{L}	{V,A}	{V,L}	{A,L}
MMIM	48.20	48.64	81.29	49.61	81.15	81.83
CENET	51.85	51.80	81.54	51.80	81.54	81.49
TETFN	55.25	55.25	81.05	55.25	81.00	81.10
ALMT	54.96	55.10	79.83	55.05	79.98	79.98
LNLN	49.03	49.03	82.48	49.03	82.21	82.26
P-RMF	56.01	56.85	81.01	58.42	82.01	82.16
DNRNet	**56.79**	**57.41**	**84.11**	**58.86**	**83.82**	**84.26**

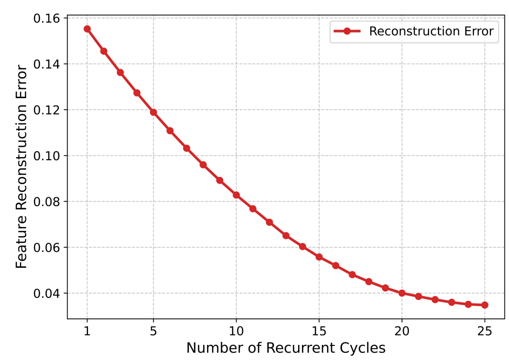

Figure 8. The trend of reconstruction error across recurrent cycles.

Table 11. Average performance comparison with the tensor completion baseline on the MOSI dataset. Lower MAE indicates better performance.

Method	Acc-7	Acc-5	Acc-2	F1	MAE	Corr
DNRNet (Tensor)	35.27	**39.43**	73.90 / 72.62	73.82 / 72.72	1.037	0.528
DNRNet	**35.36**	39.11	**74.22 / 73.19**	**74.24 / 73.28**	**1.036**	**0.538**

crease. The error converges rapidly in the initial cycles before gradually plateauing. This dynamic behavior confirms that our model effectively mimics the corticothalamic circuit, iteratively accumulating evidence to refine the missing features.

A.7. Comparison with Tensor Completion Paradigms

To conduct a comprehensive evaluation of our model, we designed a new baseline model that employs the representative mathematical algorithm of low-rank tensor completion to fill in the missing multimodal features. As shown in Table 11, DNRNet achieved superior results. This indicates that the tensor completion algorithm can only restore low-level smooth signals and cannot effectively complete the emotional semantic information. In contrast, by imitating the cortical-thalamic circuit, DNRNet performs dynamic semantic inference and effectively achieves highly accurate feature restoration.

A.8. Notation Table

For ease of reference, the primary mathematical notations used throughout this paper are summarized in Table 12.

Table 12. Key mathematical notations used in this paper.

Symbol	**Description**
$m \in \{v, a, l\}$	Index for modalities: vision (v), audio (a), and language (l).
$U_m \in \mathbb{R}^{T_m \times D_m}$	The intact modality sequence with full information.
$X_m \in \mathbb{R}^{T_m \times D_m}$	The incomplete modality sequence with frame-level missingness.
T_m, D_m	Sequence length and feature dimensionality for modality m.
x_m	Input feature sequence for modality m.
L_m	Local correction features generated by the Local Recurrent Loop.
G_m	Global correction features generated by the Global Recurrent Loop.
w_m	Confidence score estimating the reliability of modality m.
HLI($\cdot$)	High-Level Inference Module simulating higher-order cortex.
LP($\cdot$)	Local Perception Module simulating lower-order cortex.
CA($\cdot$)	Confidence-Aware Module simulating thalamic regulatory function.
GP($\cdot$)	Global Perception Module for cross-modal information integration.
$\mathcal{L}_{task}$	The sentiment prediction loss.
$\mathcal{L}_{ca}$	The confidence-aware loss.
$\mathcal{L}_{rec}$	The reconstruction loss.
α, β	Hyperparameters balancing the auxiliary losses.