

# MECO: A Multimodal Dataset for Emotion and Cognitive Understanding in Older Adults

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## 1 Appendices

### A Mini-Mental State Examination

To ensure the rigorous categorization of the experimental subjects into HC and MCI groups, a comprehensive cognitive assessment was conducted prior to multimodal data acquisition. The cognitive status of each participant was evaluated using the Chinese version of the Mini-Mental State Examination (MMSE) scale.

The assessment covers multiple cognitive domains, including orientation, registration, attention and calculation, recall, language, and visuospatial skills. Table A1 details the specific test items, the corresponding cognitive domains, and the scoring system used in the protocol. To account for demographic variations, the diagnostic cut-off scores were strictly adjusted based on the educational background of the participants to prevent false positive classifications of cognitive decline.

### B Details of the Model Architecture

The baseline model employs a straightforward early-fusion recurrent neural network. At each time step  $t$ , the extracted feature vectors from  $M$  individual modalities are temporally aligned and concatenated to form a unified multimodal representation  $\mathbf{x}_t^u \in \mathbb{R}^{d_u}$ , where  $d_u$  denotes the combined feature dimension. To capture the underlying temporal dynamics, the resulting fused sequence of length  $T$ , denoted as  $X_u$ , is processed by a single-layer, unidirectional Gated Recurrent Unit (GRU). The GRU yields a summarized temporal embedding  $\mathbf{h} = \text{GRU}(X_u) \in \mathbb{R}^{d_h}$  for the entire sequence. Subsequently, this sequence-level representation is passed through a unified prediction head, which consists of an initial linear projection, 1D Batch Normalization, a GELU activation, Dropout, and a final linear layer. The network produces the final predictions  $\hat{\mathbf{y}} \in \mathbb{R}^C$ , representing either class logits for classification tasks or continuous targets for regression tasks.

## C Further Analysis of Results

### C.1 Subgroup Analysis Based on Cognitive Status

Tables C1 and C2 detail the subgroup analysis of the HC and MCI groups under the SD protocol. By evaluating tasks from objective stimulus prediction (T1) to multi-grained subjective emotion assessment (T2–T5), we examine how cognitive decline alters the mapping between external stimuli, subjective experiences, and multimodal expressions. In stimulus-induced emotion recognition (T1), the HC group significantly outperforms the MCI group, achieving a peak UAR of 64.56% with the VC modality compared to 58.80% with VE. This performance drop suggests that individuals with MCI exhibit blunted or heterogeneous physiological and behavioral responses to standardized external stimuli. Such cognitive impairment likely disrupts natural empathetic responses, complicating the model’s ability to infer predefined video emotions solely from patient reactions.

This performance gap narrows during the 3-class sentiment analysis task (T2), where both groups peak using the VC modality (72.89% for HC versus 69.72% for MCI). This indicates that despite their atypical reactions to objective stimuli, patients with MCI largely retain the capacity to experience and physically express coarse-grained subjective emotional states. However, a clear modality shift emerges in the 5-class emotion recognition task (T3). The HC group achieves optimal performance using the VC modality (66.90%), whereas the MCI group relies on the VE combination (64.03%). This shift points to a potential decoupling between facial behaviors and peripheral autonomic nervous system responses in patients with MCI during complex emotional experiences, necessitating the use of central cortical activity (EEG) to compensate for the representational deficit of peripheral signals.

For dimensional emotion assessment, the HC group demonstrates a clear advantage in valence regression (T4), reaching a peak CCC of 0.6273 compared to 0.5675 for the MCI group. Since the continuous physiological mapping of valence requires higher-order cognitive involvement, cognitive degradation appears to impair

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**Table A1: MMSE protocol and scoring items.**

Cognitive Domain	Assessment Content	Max Score
Orientation (Time)	What is the year, season, month, date, and day of the week? (1 point each)	5
Orientation (Place)	What is the country, city, district/province, hospital, and floor/bed? (1 point each)	5
Registration	Repeat three words: "Tree", "Clock", "Car". (1 point for each correct word)	3
Attention & Calculation	Serial 7s starting from 100 (100-7, 93-7, 86-7, 79-7, 72-7). (1 point for each correct subtraction)	5
Recall	Recall the three words from the registration phase. (1 point for each correct word)	3
Language (Naming)	Name two objects presented: a watch and a pencil. (1 point each)	2
Language (Repetition)	Repeat the phrase: "If, and, but". (1 point)	1
Language (Comprehension)	Follow a 3-stage command: "Take this paper with your hand (unaffected side), fold it in half, and put it on your left leg." (1 point for each correct action)	3
Language (Reading)	Read and execute the written instruction: "Close your eyes". (1 point)	1
Language (Writing)	Write a complete, meaningful sentence. (1 point)	1
Visuospatial	Copy the drawing of two intersecting pentagons. (1 point)	1
<b>Total Score</b>		<b>30</b>

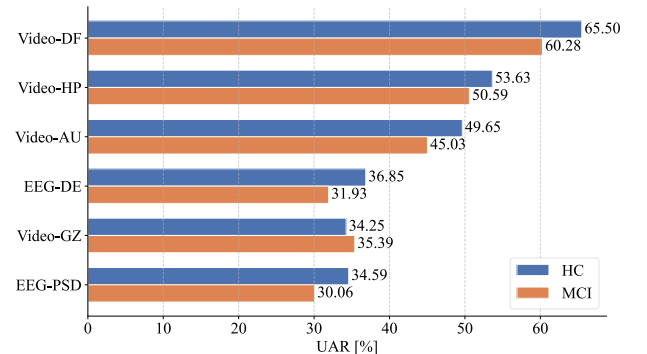
**Table C1: Results for five emotion prediction tasks (T1–T5) on MECO dataset under the SD protocol for HC. Best and second-best results are highlighted in bold and underlined, respectively. "M" denotes the modality: Video (V), EEG (E), and ECG (C).**

M	Feature	T1: SR (%)		T2: SA (%)		T3: ER (%)		T4: VR		T5: AR	
		UAR $\pm$ std $\uparrow$	WAR $\pm$ std $\uparrow$	UAR $\pm$ std $\uparrow$	WAR $\pm$ std $\uparrow$	UAR $\pm$ std $\uparrow$	WAR $\pm$ std $\uparrow$	CCC $\pm$ std $\uparrow$	MAE $\pm$ std $\downarrow$	CCC $\pm$ std $\uparrow$	MAE $\pm$ std $\downarrow$
V	AU	44.31 $\pm$ 8.96	46.78 $\pm$ 8.60	58.77 $\pm$ 9.02	61.36 $\pm$ 9.51	49.65 $\pm$ 11.28	51.54 $\pm$ 10.99	0.4800 $\pm$ 0.1661	1.7980 $\pm$ 0.5092	0.4941 $\pm$ 0.1502	1.7368 $\pm$ 0.3866
	HP	44.57 $\pm$ 11.75	46.85 $\pm$ 11.29	64.73 $\pm$ 12.34	70.00 $\pm$ 9.71	53.63 $\pm$ 11.68	58.69 $\pm$ 9.81	0.4909 $\pm$ 0.1883	1.7328 $\pm$ 0.5392	0.5229 $\pm$ 0.1702	1.6329 $\pm$ 0.4923
	GZ	31.11 $\pm$ 6.72	33.09 $\pm$ 7.11	45.89 $\pm$ 9.17	54.37 $\pm$ 11.55	34.25 $\pm$ 8.01	40.72 $\pm$ 8.74	0.2274 $\pm$ 0.1824	2.1613 $\pm$ 0.6451	0.2053 $\pm$ 0.2117	2.8636 $\pm$ 1.6564
	DF	59.73 $\pm$ 11.99	60.96 $\pm$ 11.30	70.64 $\pm$ 10.56	73.17 $\pm$ 8.44	65.50 $\pm$ 9.81	66.79 $\pm$ 9.07	0.6150 $\pm$ 0.1418	1.3855 $\pm$ 0.3666	0.6450 $\pm$ 0.1339	1.3173 $\pm$ 0.3256
E	DE	30.60 $\pm$ 7.16	33.63 $\pm$ 7.79	46.03 $\pm$ 7.54	53.54 $\pm$ 6.68	36.85 $\pm$ 7.83	42.67 $\pm$ 8.37	0.2970 $\pm$ 0.1598	2.1095 $\pm$ 0.5329	0.3226 $\pm$ 0.1574	2.0381 $\pm$ 0.5432
	PSD	28.02 $\pm$ 5.56	31.19 $\pm$ 6.14	45.31 $\pm$ 7.15	51.44 $\pm$ 10.03	34.59 $\pm$ 8.00	39.51 $\pm$ 8.62	0.2717 $\pm$ 0.1289	2.1358 $\pm$ 0.4562	0.3029 $\pm$ 0.1595	2.0390 $\pm$ 0.5671
	HFD	24.12 $\pm$ 6.51	27.37 $\pm$ 8.14	41.72 $\pm$ 7.19	46.43 $\pm$ 11.41	29.16 $\pm$ 7.18	34.40 $\pm$ 7.59	0.1519 $\pm$ 0.1547	2.3992 $\pm$ 0.6057	0.1898 $\pm$ 0.1621	2.2438 $\pm$ 0.5804
C	SE	23.68 $\pm$ 4.93	25.96 $\pm$ 6.17	40.05 $\pm$ 6.88	46.94 $\pm$ 6.98	27.02 $\pm$ 5.87	31.06 $\pm$ 6.10	0.1454 $\pm$ 0.1472	2.3361 $\pm$ 0.5552	0.1957 $\pm$ 0.1684	2.2202 $\pm$ 0.5965
	TD	19.11 $\pm$ 3.28	22.38 $\pm$ 5.16	34.61 $\pm$ 3.38	42.69 $\pm$ 10.21	23.41 $\pm$ 4.89	27.73 $\pm$ 9.82	0.0628 $\pm$ 0.0834	2.8358 $\pm$ 1.3342	0.0969 $\pm$ 0.1026	2.2432 $\pm$ 0.7185
	HFD	24.15 $\pm$ 4.30	28.09 $\pm$ 4.96	40.49 $\pm$ 7.55	47.56 $\pm$ 10.36	28.11 $\pm$ 5.09	36.72 $\pm$ 8.31	0.1687 $\pm$ 0.1526	2.1468 $\pm$ 0.4849	0.2320 $\pm$ 0.1709	2.0587 $\pm$ 0.5798
VE	SE	25.41 $\pm$ 4.67	28.71 $\pm$ 5.66	39.56 $\pm$ 6.17	49.26 $\pm$ 7.47	29.97 $\pm$ 6.20	36.71 $\pm$ 8.76	0.1850 $\pm$ 0.1418	2.1507 $\pm$ 0.4889	0.2341 $\pm$ 0.1488	2.0108 $\pm$ 0.5111
	Top-1	63.94 $\pm$ 9.57	64.99 $\pm$ 8.75	71.71 $\pm$ 8.58	74.21 $\pm$ 7.39	66.83 $\pm$ 8.10	<b>68.92</b> $\pm$ 7.58	0.6273 $\pm$ 0.1494	1.3801 $\pm$ 0.4059	0.6572 $\pm$ 0.1228	1.3313 $\pm$ 0.3601
	Top-2	55.16 $\pm$ 11.37	56.95 $\pm$ 11.11	61.73 $\pm$ 11.59	67.76 $\pm$ 8.48	56.91 $\pm$ 10.63	61.21 $\pm$ 8.51	0.4969 $\pm$ 0.1677	1.8130 $\pm$ 0.5221	0.5414 $\pm$ 0.1474	1.6392 $\pm$ 0.4110
VC	Top-1	<b>64.56</b> $\pm$ 11.65	<b>65.65</b> $\pm$ 10.60	<b>72.89</b> $\pm$ 10.55	<b>74.40</b> $\pm$ 8.79	<b>66.90</b> $\pm$ 11.41	<b>68.92</b> $\pm$ 8.83	0.6244 $\pm$ 0.1447	1.3856 $\pm$ 0.3843	0.6424 $\pm$ 0.1474	1.3288 $\pm$ 0.3219
	Top-2	53.29 $\pm$ 10.56	55.28 $\pm$ 9.86	63.95 $\pm$ 11.38	68.21 $\pm$ 10.74	57.10 $\pm$ 12.71	61.17 $\pm$ 10.71	0.5072 $\pm$ 0.2002	1.6724 $\pm$ 0.5456	0.5208 $\pm$ 0.1997	1.7573 $\pm$ 0.8113
EC	Top-1	35.81 $\pm$ 7.85	38.60 $\pm$ 7.52	51.20 $\pm$ 7.62	57.80 $\pm$ 8.77	41.22 $\pm$ 10.71	47.10 $\pm$ 9.74	0.3284 $\pm$ 0.1450	2.0549 $\pm$ 0.4499	0.3000 $\pm$ 0.1996	2.0984 $\pm$ 0.5733
	Top-2	33.69 $\pm$ 7.40	36.65 $\pm$ 7.49	48.84 $\pm$ 9.07	55.46 $\pm$ 8.40	37.77 $\pm$ 9.00	44.33 $\pm$ 7.53	0.2897 $\pm$ 0.1550	2.1658 $\pm$ 0.5104	0.2952 $\pm$ 0.1946	2.0822 $\pm$ 0.5488
VEC	Top-1	64.53 $\pm$ 9.62	65.55 $\pm$ 8.78	72.57 $\pm$ 8.94	74.36 $\pm$ 7.35	66.15 $\pm$ 8.81	68.15 $\pm$ 7.93	0.6252 $\pm$ 0.1539	1.3947 $\pm$ 0.3996	0.6436 $\pm$ 0.1323	1.3867 $\pm$ 0.3606
	Top-2	64.50 $\pm$ 9.99	65.37 $\pm$ 9.12	67.55 $\pm$ 8.71	69.56 $\pm$ 7.77	57.23 $\pm$ 11.53	60.28 $\pm$ 11.58	0.5075 $\pm$ 0.1768	1.8187 $\pm$ 0.6168	0.5300 $\pm$ 0.1668	1.6648 $\pm$ 0.3957

the predictable expression of this specific dimension. Conversely, arousal regression (T5) yields comparable performance between the MCI (peak CCC of 0.6419) and HC (peak CCC of 0.6572) groups. This similarity suggests that arousal, functioning as a primitive physiological activation mechanism, maintains its mapping between subjective experience and objective bodily signals regardless of cognitive decline. Overall, while cognitive impairment compromises consistent reactions to external stimuli and the peripheral expression of complex subjective emotions, primal physiological arousal remains largely intact. Consequently, effectively modeling fine-grained subjective emotions in MCI populations requires integrating central nervous signals to overcome the decoupling of peripheral physiology from subjective cognitive appraisal.

## C.2 Feature-Level Importance Analysis

To further investigate the micro-level mechanisms driving multi-modal fusion, we conduct a feature-level importance analysis. As illustrated in Fig. C1, we select T3 as the representative task for

**Figure C1: Comparison of the feature-level importance ranking between the HC and MCI group.**

subjective emotion classification. We can find three observations.

**Table C2: Results for five emotion prediction tasks (T1–T5) on MECO dataset under the SD protocol for MCI. Best and second-best results are highlighted in bold and underlined, respectively.**

M	Feature	T1: SR (%)		T2: SA (%)		T3: ER (%)		T4: VR		T5: AR	
		UAR <sub>±std</sub> ↑	WAR <sub>±std</sub> ↑	UAR <sub>±std</sub> ↑	WAR <sub>±std</sub> ↑	UAR <sub>±std</sub> ↑	WAR <sub>±std</sub> ↑	CCC <sub>±std</sub> ↑	MAE <sub>±std</sub> ↓	CCC <sub>±std</sub> ↑	MAE <sub>±std</sub> ↓
V	AU	40.90 <sub>±13.13</sub>	43.48 <sub>±12.69</sub>	59.98 <sub>±10.94</sub>	63.91 <sub>±10.41</sub>	45.03 <sub>±9.80</sub>	52.92 <sub>±9.95</sub>	0.4480 <sub>±0.1943</sub>	1.7754 <sub>±0.5164</sub>	0.4872 <sub>±0.1494</sub>	1.6356 <sub>±0.4450</sub>
	HP	43.23 <sub>±11.46</sub>	44.30 <sub>±11.09</sub>	62.75 <sub>±9.74</sub>	67.58 <sub>±8.75</sub>	50.59 <sub>±10.94</sub>	57.15 <sub>±10.04</sub>	0.3925 <sub>±0.1891</sub>	1.8200 <sub>±0.4450</sub>	0.5280 <sub>±0.1489</sub>	1.6142 <sub>±0.5655</sub>
	GZ	30.05 <sub>±7.88</sub>	32.47 <sub>±7.67</sub>	45.60 <sub>±7.22</sub>	54.51 <sub>±7.95</sub>	35.39 <sub>±4.91</sub>	41.14 <sub>±8.09</sub>	0.1937 <sub>±0.1166</sub>	2.2291 <sub>±0.8048</sub>	0.2783 <sub>±0.1637</sub>	1.8866 <sub>±0.6579</sub>
	DF	55.13 <sub>±13.64</sub>	56.79 <sub>±13.41</sub>	68.42 <sub>±13.18</sub>	71.95 <sub>±8.95</sub>	60.28 <sub>±14.17</sub>	64.01 <sub>±12.11</sub>	0.5652 <sub>±0.1801</sub>	<b>1.4558</b> <sub>±0.4635</sub>	0.6162 <sub>±0.1411</sub>	<u>1.3443</u> <sub>±0.4597</sub>
E	DE	30.43 <sub>±8.71</sub>	32.94 <sub>±9.02</sub>	45.54 <sub>±6.45</sub>	53.28 <sub>±8.97</sub>	31.93 <sub>±3.79</sub>	39.16 <sub>±7.69</sub>	0.2957 <sub>±0.1611</sub>	1.8561 <sub>±0.4047</sub>	0.2492 <sub>±0.1970</sub>	2.0266 <sub>±0.6417</sub>
	PSD	29.23 <sub>±7.13</sub>	32.56 <sub>±7.37</sub>	43.14 <sub>±5.37</sub>	50.43 <sub>±10.14</sub>	30.06 <sub>±5.07</sub>	36.95 <sub>±7.49</sub>	0.2464 <sub>±0.1508</sub>	2.0473 <sub>±0.5118</sub>	0.1931 <sub>±0.1837</sub>	2.1057 <sub>±0.6079</sub>
	HFD	23.10 <sub>±2.70</sub>	26.16 <sub>±6.73</sub>	39.52 <sub>±4.86</sub>	45.94 <sub>±8.90</sub>	28.24 <sub>±4.10</sub>	34.26 <sub>±6.42</sub>	0.1527 <sub>±0.1052</sub>	2.3679 <sub>±0.8882</sub>	0.1530 <sub>±0.1495</sub>	2.2629 <sub>±1.1134</sub>
	SE	22.15 <sub>±4.26</sub>	23.58 <sub>±6.23</sub>	37.10 <sub>±4.52</sub>	46.24 <sub>±8.17</sub>	25.48 <sub>±4.80</sub>	31.59 <sub>±5.71</sub>	0.1237 <sub>±0.1102</sub>	2.2430 <sub>±0.5204</sub>	0.1167 <sub>±0.1646</sub>	2.1927 <sub>±0.7317</sub>
C	TD	18.93 <sub>±2.91</sub>	21.90 <sub>±4.68</sub>	35.75 <sub>±4.06</sub>	44.57 <sub>±12.58</sub>	22.59 <sub>±3.27</sub>	29.40 <sub>±14.82</sub>	0.0359 <sub>±0.0810</sub>	2.5042 <sub>±1.1912</sub>	0.0763 <sub>±0.0849</sub>	2.5585 <sub>±1.4361</sub>
	HFD	22.02 <sub>±3.55</sub>	24.63 <sub>±3.61</sub>	42.18 <sub>±8.78</sub>	52.96 <sub>±8.94</sub>	28.60 <sub>±5.31</sub>	38.41 <sub>±8.78</sub>	0.1539 <sub>±0.1602</sub>	2.1050 <sub>±0.5552</sub>	0.2535 <sub>±0.1520</sub>	2.1081 <sub>±0.7105</sub>
	SE	25.14 <sub>±4.96</sub>	27.61 <sub>±6.18</sub>	41.07 <sub>±7.66</sub>	48.81 <sub>±9.47</sub>	25.50 <sub>±5.98</sub>	31.41 <sub>±9.74</sub>	0.1735 <sub>±0.1699</sub>	2.2315 <sub>±0.9766</sub>	0.2188 <sub>±0.1723</sub>	2.3622 <sub>±1.5326</sub>
VE	Top-1	<b>58.80</b> <sub>±13.04</sub>	<b>60.62</b> <sub>±12.89</sub>	68.27 <sub>±14.75</sub>	71.57 <sub>±9.85</sub>	<b>64.03</b> <sub>±13.22</sub>	<b>66.02</b> <sub>±11.50</sub>	0.5452 <sub>±0.1636</sub>	1.4916 <sub>±0.4609</sub>	0.6158 <sub>±0.1362</sub>	1.3648 <sub>±0.4694</sub>
	Top-2	46.15 <sub>±9.56</sub>	48.22 <sub>±9.16</sub>	60.05 <sub>±10.64</sub>	63.69 <sub>±9.62</sub>	50.40 <sub>±10.01</sub>	56.53 <sub>±9.66</sub>	0.3665 <sub>±0.1635</sub>	1.8734 <sub>±0.4257</sub>	0.4792 <sub>±0.1314</sub>	1.7242 <sub>±0.5605</sub>
VC	Top-1	<u>57.96</u> <sub>±13.37</sub>	59.26 <sub>±12.80</sub>	<b>69.72</b> <sub>±12.15</sub>	<b>72.80</b> <sub>±8.55</sub>	61.46 <sub>±14.18</sub>	64.86 <sub>±12.10</sub>	<b>0.5675</b> <sub>±0.1864</sub>	<u>1.4570</u> <sub>±0.5002</sub>	<b>0.6419</b> <sub>±0.1200</sub>	<b>1.3092</b> <sub>±0.4492</sub>
	Top-2	47.43 <sub>±12.16</sub>	48.62 <sub>±11.61</sub>	61.38 <sub>±9.85</sub>	67.16 <sub>±7.52</sub>	50.66 <sub>±12.32</sub>	57.46 <sub>±11.32</sub>	0.4221 <sub>±0.1958</sub>	1.8462 <sub>±0.4833</sub>	0.4962 <sub>±0.1521</sub>	1.6712 <sub>±0.5655</sub>
EC	Top-1	31.86 <sub>±8.80</sub>	34.47 <sub>±8.69</sub>	48.05 <sub>±5.93</sub>	55.33 <sub>±8.89</sub>	35.36 <sub>±6.13</sub>	42.84 <sub>±7.87</sub>	0.2500 <sub>±0.1468</sub>	2.3124 <sub>±0.9180</sub>	0.2427 <sub>±0.1914</sub>	2.4093 <sub>±1.1361</sub>
	Top-2	30.97 <sub>±7.40</sub>	33.93 <sub>±7.52</sub>	46.57 <sub>±8.69</sub>	51.71 <sub>±8.91</sub>	33.22 <sub>±5.05</sub>	38.17 <sub>±7.66</sub>	0.2270 <sub>±0.1347</sub>	2.3737 <sub>±0.9474</sub>	0.2259 <sub>±0.1715</sub>	2.4819 <sub>±1.1280</sub>
VEC	Top-1	57.80 <sub>±13.14</sub>	<u>59.54</u> <sub>±13.04</sub>	<u>68.77</u> <sub>±14.11</sub>	71.25 <sub>±9.67</sub>	<u>63.17</u> <sub>±13.13</sub>	<u>65.39</u> <sub>±11.41</sub>	0.5473 <sub>±0.1570</sub>	1.4785 <sub>±0.4197</sub>	0.6121 <sub>±0.1406</sub>	1.3936 <sub>±0.4998</sub>
	Top-2	56.04 <sub>±13.95</sub>	57.91 <sub>±13.80</sub>	63.09 <sub>±13.88</sub>	65.46 <sub>±12.44</sub>	50.61 <sub>±11.40</sub>	56.43 <sub>±11.35</sub>	0.4009 <sub>±0.1694</sub>	1.8558 <sub>±0.4443</sub>	0.4686 <sub>±0.1134</sub>	1.7784 <sub>±0.5718</sub>

1) For single modalities, deep video features (V-DF) and head pose (V-HP) consistently provide the highest UAR for both groups. However, the performance of these behavioral markers experiences a global decline in the MCI groups. For instance, the UAR of V-DF drops from 65.50% to 60.28%. This uniform degradation across facial and postural features quantitatively supports the clinical hypothesis of facial apathy and reduced expressive behavior associated with MCI. 2) Within the physiological signals, differential entropy (E-DE) emerges as the most effective EEG feature for distinguishing emotions in both groups, outperforming power spectral density and non-linear dynamic features. Nevertheless, the informative value of E-DE decreases by nearly 5% in the MCI group. This decay suggests that the cortical responses to emotional stimuli in patients with MCI become more homogeneous, thereby reducing the specificity of the brain in representing fine-grained emotional states. 3) The most notable finding is the rank inversion between visual attention and deep cortical activity. In the HC group, the importance of E-DE surpasses that of gaze behavior (V-GZ). Conversely, in the MCI group, visual attention patterns overtake E-DE to become the fourth most important feature overall. This shift implies that because cognitive decline often accompanies attention deficits, the atypical gaze behavior of patients with MCI during emotional elicitation inherently serves as a strong biomarker for emotion classification. This behavioral shift compensates for the loss of discriminative power in degraded cortical signals.

### C.3 Subject-Level Analysis

To provide a granular perspective on how cognitive decline impacts emotion recognition, we present a comprehensive subject-level analysis using T3. Table C3 details the performance for each subject across all unimodal, bimodal, and trimodal configurations, categorized by their cognitive status, highlighting the extent of inter-subject heterogeneity and the dynamics of multimodal fusion.

Additionally, there are two observations can be found. 1) The MCI group shows large individual variance, as indicated by a significantly higher standard deviation in video-only (V) performance compared to the HC group (0.1417 vs. 0.0981). While some MCI subjects retain high expressive capabilities (e.g., S36), others display severe emotional blunting (e.g., S1, S6). These individual outcomes explain the broader modality shift: HC subjects generally benefit from incorporating peripheral signals (V+C), whereas certain MCI subjects achieve their best performance through central cortical activity (V+E, e.g., S2, S22). This reliance on central signals appears to compensate for impaired or decoupled peripheral responses. 2) The full trimodal configuration frequently underperforms the best bimodal combinations across both groups. This suggests that forcing the fusion of potentially noisy or irregular signals, which are common in the MCI group, induces negative transfer. The varied degradation patterns observed in MCI subjects indicate that generic architectures are sub-optimal. Future work should therefore focus on personalized modeling paradigms and adaptive cross-modal routing strategies that account for the diverse neuro-physiological profiles of cognitively impaired populations.

**Table C3: Subject-level performance across modality configurations for the HC and MCI groups under T3.**

Subject ID	Group	Unimodal			Bimodal			Trimodal
		V	E	C	V+E	V+C	E+C	V+E+C
S3	HC	0.7818	0.3751	0.1985	0.7517	0.8481	0.4228	0.7832
S4	HC	0.6675	0.4510	0.3000	0.7662	0.6998	0.5277	0.7273
S8	HC	0.6686	0.3584	0.4472	0.6763	0.6514	0.3502	0.6123
S9	HC	0.6356	0.3376	0.2767	0.6489	0.6836	0.4316	0.6497
S10	HC	0.5085	0.4186	0.3396	0.5307	0.5496	0.5068	0.5084
S14	HC	0.7183	0.2763	0.2828	0.6907	0.6641	0.3470	0.6868
S16	HC	0.7163	0.4151	0.3940	0.8070	0.7796	0.4070	0.8347
S17	HC	0.6814	0.3895	0.2015	0.7085	0.7025	0.3428	0.6515
S19	HC	0.3478	0.4547	0.2737	0.5885	0.2622	0.4583	0.5164
S20	HC	0.7398	0.3840	0.3543	0.6738	0.6739	0.4329	0.6354
S21	HC	0.7558	0.3820	0.2390	0.7472	0.6958	0.4240	0.7489
S24	HC	0.7124	0.1532	0.2520	0.5586	0.7069	0.1349	0.5516
S25	HC	0.6557	0.4571	0.3011	0.6817	0.7235	0.4805	0.7206
S26	HC	0.6938	0.2820	0.2631	0.7418	0.7170	0.2420	0.6827
S27	HC	0.7319	0.3189	0.3144	0.7168	0.8263	0.3629	0.6107
S28	HC	0.6969	0.2630	0.3052	0.6116	0.6978	0.3333	0.6645
S29	HC	0.6111	0.4017	0.2043	0.5851	0.6113	0.4313	0.5731
S31	HC	0.6900	0.4568	0.2667	0.6754	0.6245	0.4366	0.6648
S32	HC	0.6646	0.4144	0.2657	0.7445	0.6538	0.4702	0.6811
S33	HC	0.6194	0.3480	0.3752	0.6458	0.7114	0.3608	0.6190
S34	HC	0.6447	0.4619	0.3280	0.6710	0.6436	0.6682	0.7588
S35	HC	0.5403	0.4489	0.3895	0.5767	0.5826	0.4867	0.5474
S37	HC	0.8417	0.4752	0.3434	0.8300	0.8490	0.6258	0.8310
S38	HC	0.5614	0.3278	0.3689	0.5833	0.6462	0.4133	0.6195
S39	HC	0.5815	0.2989	0.2718	0.5643	0.5008	0.3014	0.5609
S40	HC	0.5448	0.2798	0.2540	0.5663	0.6472	0.3502	0.7041
S41	HC	0.6740	0.3209	0.2822	0.7023	0.7112	0.3796	0.7151
<b>HC Mean ± STD</b>	<b>HC</b>	<b>0.6550±0.0981</b>	<b>0.3685±0.0783</b>	<b>0.2997±0.0620</b>	<b>0.6683±0.0810</b>	<b>0.6690±0.1141</b>	<b>0.4122±0.1071</b>	<b>0.6615±0.0881</b>
S1	MCI	0.4377	0.3253	0.2470	0.4441	0.4104	0.2948	0.3915
S2	MCI	0.3967	0.2825	0.3170	0.5042	0.4393	0.2833	0.5384
S5	MCI	0.7073	0.2869	0.3207	0.7721	0.7280	0.3009	0.7186
S6	MCI	0.4539	0.3275	0.2963	0.4052	0.4689	0.3321	0.4021
S7	MCI	0.6642	0.3398	0.3403	0.7477	0.6827	0.4239	0.7289
S11	MCI	0.4416	0.3776	0.2397	0.5711	0.5430	0.3675	0.5803
S12	MCI	0.6166	0.3437	0.2330	0.6173	0.5932	0.4265	0.6378
S13	MCI	0.5565	0.2458	0.4000	0.6303	0.6296	0.2557	0.5963
S15	MCI	0.6336	0.3476	0.2295	0.6302	0.5606	0.3451	0.6370
S18	MCI	0.6597	0.3335	0.3034	0.7308	0.6563	0.4399	0.7210
S22	MCI	0.8014	0.3056	0.2262	0.8434	0.7598	0.3111	0.7920
S23	MCI	0.7519	0.3526	0.2479	0.7226	0.7820	0.4507	0.7508
S30	MCI	0.6158	0.3421	0.2641	0.6624	0.6358	0.3875	0.6389
S36	MCI	0.8468	0.2496	0.3594	0.8037	0.8940	0.3229	0.8295
S42	MCI	0.4590	0.3294	0.2653	0.5200	0.4352	0.3626	0.5131
<b>MCI Mean ± STD</b>	<b>MCI</b>	<b>0.6028±0.1417</b>	<b>0.3193±0.0379</b>	<b>0.2860±0.0531</b>	<b>0.6403±0.1322</b>	<b>0.6146±0.1418</b>	<b>0.3536±0.0613</b>	<b>0.6317±0.1313</b>
<b>Global Mean ± STD</b>	<b>All</b>	<b>0.6364±0.1166</b>	<b>0.3510±0.0703</b>	<b>0.2948±0.0587</b>	<b>0.6583±0.1015</b>	<b>0.6496±0.1258</b>	<b>0.3913±0.0968</b>	<b>0.6508±0.1049</b>