

An artificial intelligence that increases simulated brain-computer interface performance

Supplementary Materials

Sebastian Olsen^{1,*}, Jianwei Zhang^{1,*}, Ken-Fu Liang¹, Michelle Lam¹, Usama Riaz², Jonathan C Kao^{1,3}

¹Dept of Electrical and Computer Engineering, University of California, Los Angeles, CA, 90024, United States

²Dept of Computer Science, University of California, Los Angeles, CA, 90024, United States

³Neurosciences Program, University of California, Los Angeles, CA, 90024

*These authors contributed equally to this work.

Supplementary Video 1

This video compares the performance of the T-BCI (left) and the AI-BCI (right) with no perturbations over the course of an experimental block. On the left, cpm denotes characters per minute, and the RNN top 3 accuracy denotes the percentage of typed characters that were in the top 3 predictions of the RNN. These probabilities are affected by selections made prior to the start of the video, and so may differ even when the sequence of characters selected in the video are the same.

Supplementary Video 2

This video compares T-BCI (left) and AI-BCI (right) performance under the maximum neuron drop condition. The neuron dropping induces a strong bias into the decoder, consistent with what has previously been reported in similar experiments.

Supplementary Video 3

This video compares T-BCI (left) and AI-BCI (right) performance under the 128.5 cm/s noise perturbation.

Supplementary Tables

		CPM		Dial-in Time (ms)		TFA (ms)		PE (%)	
		T-BCI	AI-BCI	T-BCI	AI-BCI	T-BCI	AI-BCI	T-BCI	AI-BCI
Noise Std (cm/s)	0	25.3	36.0	301.9	71.2	1004.8	585.7	52.2	69.5
	128.5	14.3	25.8	1196.0	326.3	1600.3	744.5	32.6	55.4
	257	5.0	16.7	3282.6	515.2	2007.0	929.6	15.0	42.8
	385.5	0.3	8.1	2932.0	1184.3	4881.0	1353.8	6.8	37.2
	514.1	2.2	2.6	12382.1	6756.5	3752.7	1146.6	2.3	5.8
# Neurons Dropped	3	23.7	34.9	750.5	188.2	934.0	652.1	44.4	62.3
	6	20.8	28.6	647.1	302.7	1102.2	819.5	38.7	52.5
	9	13.3	22.2	1491.1	447.1	1888.5	1114.1	18.6	48.9
	12	12.6	19.8	1617.8	404.5	1956.2	1136.6	24.1	53.6
	15	14.8	21.5	1561.2	456.2	1473.5	931.9	23.9	48.0

Table 1. Subject 1 results. CPM is characters per minute on the typing task.

		CPM		Dial-in time (ms)		TFA (ms)		PE (%)	
		T-BCI	AI-BCI	T-BCI	AI-BCI	T-BCI	AI-BCI	T-BCI	AI-BCI
Noise Std (cm/s)	0	18.2	16.9	867.8	863.5	1312.6	1096.5	39.9	54.3
	128.5	15.9	21.9	1322.0	423.5	1372.3	880.5	29.1	48.6
	257	10.1	12.3	3018.0	1103.0	1757.4	1118.8	20.0	32.6
	385.5	3.8	5.3	7155.3	2376.2	1902.0	1324.2	12.4	24.7
	514.1	2.9	1.0	16243.7	2136.0	1658.9	1022.7	8.2	29.7
# Neurons Dropped	3	16.5	21.8	784.1	407.0	1139.1	723.4	37.9	58.1
	6	12.6	18.7	1375.7	941.8	2216.3	1238.4	28.5	44.3
	9	6.5	11.0	3783.8	1494.4	2950.4	1587.4	18.2	34.7
	12	5.9	6.7	2204.4	656.6	1788.6	2532.7	17.1	36.2
	15	2.2	7.0	14698.0	1747.0	1445.3	2285.9	3.6	42.1

Table 2. Subject 2 results.

		CPM		Dial-in Time (ms)		TFA (ms)		PE (%)	
		T-BCI	AI-BCI	T-BCI	AI-BCI	T-BCI	AI-BCI	T-BCI	AI-BCI
Noise Std (cm/s)	0	19.8	23.3	786.0	334.9	1246.1	1151.5	41.4	51.4
	128.5	9.2	12.7	1915.2	596.7	1797.1	1272.2	22.0	39.9
	257	7.8	11.3	4556.2	1200.1	1811.0	1800.5	18.1	23.0
	385.5	2.6	9.9	6625.2	1294.6	1933.2	1689.8	6.6	28.1
	514.1	0.6	1.0	27893.5	9504.7	2906.5	2955.3	2.6	6.7
# Neurons Dropped	3	19.8	25.1	747.0	291.5	1224.6	986.7	39.3	55.1
	6	17.2	14.5	869.8	679.1	1616.8	1378.0	28.6	43.0
	9	8.4	15.2	2943.8	640.0	1704.7	1597.0	23.7	40.7
	12	15.2	16.8	1510.4	865.7	1406.9	1028.6	30.3	44.0
	15	5.8	14.1	4039.7	1033.4	2110.2	1265.9	11.8	44.9

Table 3. Subject 3 results.

		CPM		Dial-in Time (ms)		TFA (ms)		PE (%)	
		T-BCI	AI-BCI	T-BCI	AI-BCI	T-BCI	AI-BCI	T-BCI	AI-BCI
Noise Std (cm/s)	0	23.4	24.7	601.2	283.0	1018.5	916.9	44.2	54.3
	128.5	13.6	23.3	2179.4	660.2	1298.0	979.8	22.1	44.7
	257	7.5	19.5	4377.3	1240.0	1174.6	796.6	12.7	36.8
	385.5	3.6	8.2	8451.9	3350.2	1905.4	1113.7	13.6	21.3
	514.1	1.9	9.3	15762.0	2746.0	1188.7	1271.2	3.5	21.2
# Neurons Dropped	3	18.0	25.4	1669.4	555.4	850.3	670.5	24.3	39.8
	6	14.3	20.8	1882.1	686.8	1196.3	1057.8	23.0	47.2
	9	12.6	18.7	2020.6	743.6	1342.7	1307.0	23.7	41.0
	12	8.4	14.4	3010.2	881.6	2511.1	1437.8	13.5	39.6
	15	9.1	14.5	3480.3	899.5	1491.9	1502.4	16.6	39.1

Table 4. Subject 4 results.

		CPM		Dial-in Time (ms)		TFA (ms)		PE (%)	
		T-BCI	AI-BCI	T-BCI	AI-BCI	T-BCI	AI-BCI	T-BCI	AI-BCI
Noise Std (cm/s)	0	27.2	30.4	425.4	131.4	922.6	685.7	51.9	61.9
	128.5	22.4	31.5	985.0	343.4	916.6	725.3	35.6	53.2
	257	8.1	13.0	2388.9	883.8	1284.7	1248.6	24.9	37.3
	385.5	2.2	5.8	9094.3	860.3	1519.9	891.4	6.4	32.2
	514.1	0.3	3.0	18206.0	2515.8	2189.0	1774.0	5.7	28.6
# Neurons Dropped	3	26.0	31.2	639.9	343.2	879.5	627.3	44.1	61.5
	6	18.9	28.2	653.9	298.0	1424.6	706.0	38.0	57.9
	9	14.6	22.6	1237.6	527.3	1439.0	770.7	32.5	55.1
	12	12.3	16.0	1900.0	528.4	1126.2	1315.2	37.4	50.9
	15	15.9	25.7	1117.4	498.3	1384.6	810.7	36.2	53.6

Table 5. Subject 5 results.

		CPM		Dial-in Time (ms)		TFA (ms)		PE (%)	
		T-BCI	AI-BCI	T-BCI	AI-BCI	T-BCI	AI-BCI	T-BCI	AI-BCI
Noise Std (cm/s)	0	23.7	28.7	611.3	221.1	1084.4	662.3	46.7	62.4
	128.5	13.0	23.6	1320.2	284.1	1092.0	864.4	34.7	51.0
	257	11.7	20.1	1845.5	479.3	1243.5	865.2	29.6	46.3
	385.5	3.7	10.6	4591.7	1062.3	1469.0	1275.5	11.9	30.1
	514.1	0.0	1.0	184999.0	2174.3	-	1973.7	0.0	11.2
# Neurons Dropped	3	24.0	23.6	541.2	373.1	929.5	848.4	49.2	58.3
	6	12.3	15.0	1180.2	555.1	2639.6	1290.4	36.2	45.6
	9	7.1	10.7	1797.6	934.1	2799.2	1949.5	30.0	40.6
	12	7.0	5.5	3258.4	2481.8	2936.3	1824.4	22.2	38.0
	15	1.9	9.7	9245.3	258.6	2310.0	2116.9	6.0	50.4

Table 6. Subject 6 results.

		CPM		Dial-in Time (ms)		TFA (ms)		PE (%)	
		T-BCI	AI-BCI	T-BCI	AI-BCI	T-BCI	AI-BCI	T-BCI	AI-BCI
Noise Std (cm/s)	0	25.9	28.4	356.7	95.2	935.1	697.7	50.7	68.7
	128.5	13.9	29.5	1021.4	78.7	1360.6	799.7	36.6	61.1
	257	7.5	18.0	1305.6	577.6	1196.7	882.0	31.5	45.9
	385.5	2.6	11.0	4539.8	463.8	2003.8	1058.5	9.8	44.8
	514.1	0.3	6.5	42628.0	2845.8	712.0	1340.8	1.5	17.7
# Neurons Dropped	3	22.1	32.0	481.2	232.9	1062.8	692.8	49.9	66.6
	6	16.2	25.1	852.1	356.6	1237.1	779.3	42.8	61.3
	9	14.9	19.2	1334.9	537.3	1131.6	809.0	36.7	53.5
	12	13.9	18.7	1483.0	567.9	1233.0	1088.3	34.3	48.0
	15	9.3	8.6	1674.8	455.2	1256.4	933.8	35.4	47.5

Table 7. Subject 7 results.

		CPM		Dial-in Time (ms)		TFA (ms)		PE (%)	
		T-BCI	AI-BCI	T-BCI	AI-BCI	T-BCI	AI-BCI	T-BCI	AI-BCI
Noise Std (cm/s)	0	22.7	30.4	517.4	260.5	997.5	743.0	48.0	64.4
	128.5	18.9	25.8	809.0	326.2	1078.8	838.0	42.1	57.3
	257	5.7	8.9	3757.7	1477.9	1165.9	1099.5	17.7	29.3
	385.5	0.6	12.3	4573.5	1341.2	3463.5	1078.4	5.3	34.9
	514.1	0.3	6.3	37456.0	2237.7	1054.0	1779.7	1.5	23.1
# Neurons Dropped	3	15.2	23.3	1162.9	460.3	973.2	706.1	39.7	57.6
	6	18.2	20.8	1084.4	425.4	1293.6	1157.0	33.5	48.9
	9	11.7	15.9	1898.6	571.8	1791.8	1339.8	25.0	47.5
	12	8.5	18.0	2417.9	808.9	1672.8	1446.4	30.9	45.5
	15	5.5	7.5	4834.5	614.2	1786.2	1957.4	15.2	44.8

Table 8. Subject 8 results.

		CPM		Dial-in Time (ms)		TFA (ms)		PE (%)	
		T-BCI	AI-BCI	T-BCI	AI-BCI	T-BCI	AI-BCI	T-BCI	AI-BCI
Noise Std (cm/s)	0	17.8	21.2	715.6	130.2	1352.9	821.6	44.2	64.6
	128.5	12.6	18.9	922.3	249.8	1379.3	965.0	37.0	50.1
	257	8.8	13.7	2277.2	385.1	1823.1	1080.0	23.3	44.6
	385.5	2.5	13.4	7297.5	1174.4	1783.5	1180.1	14.6	31.6
	514.1	0.4	9.3	4443.0	2609.7	5331.0	1360.6	4.6	19.8
# Neurons Dropped	3	12.3	20.0	1048.6	322.8	2249.2	1011.7	30.1	56.2
	6	17.5	17.1	477.6	240.5	1663.2	1420.0	37.4	49.6
	9	9.4	7.5	1428.4	970.2	2032.6	1404.1	24.6	47.7
	12	12.3	15.2	1541.2	602.9	1820.9	1262.8	30.3	46.9
	15	4.2	9.6	4608.6	1107.9	1960.8	2423.0	20.8	30.6

Table 9. Subject 9 results.