Supplementary Material

A Hybrid Knowledge- and Data-driven Model for Automatic Assessment of Chemically Induced Spiking Patterns in C-fiber Microneurography

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Supplementary Tables

Table S1. **Performance metrics for spike detection**. This table summarizes the detection results for the spike detection algorithm, including the number of true positives (TP), false negatives (FN), and false positives (FP), along with computed evaluation metrics: precision, recall, and F1-score.

Dataset	Detected spike count	TP	FN	FP	F1-Score	Precision	Recall
A1	598	64	1	534	0.19	0.11	0.98
A2	357	80	0	277	0.37	0.22	1.0
A3	92	30	1	62	0.49	0.33	0.97
A4	4643	192	22	4451	0.08	0.04	0.9
A5	1802	109	6	1693	0.11	0.06	0.95
A6	497	48	4	449	0.17	0.1	0.92

Table S2. Summary of spike sorting performance across models and feature sets. This table presents the detailed results of spike sorting for various classification models and feature sets. Metrics include TP, FP, FN, and TN as well as the resulting precision, recall, and F1-score.

Dataset	Model	Feature Set	TP	FP	TN	FN	F1-Score	Precision	Recall
A1	svm	spdf	64.0	4.0	520.0	0.0	0.97	0.94	1.0
A2	svm	spdf	76.0	32.0	236.0	4.0	0.81	0.7	0.95
A3	svm	spdf	28.0	24.0	38.0	2.0	0.68	0.54	0.93
A4	svm	spdf	190.0	4355.0	5.0	0.0	0.08	0.04	1.0
A5	svm	spdf	85.0	576.0	1063.0	23.0	0.22	0.13	0.79
A6	svm	spdf	44.0	86.0	356.0	4.0	0.49	0.34	0.92
A1	svm	spdf_fv3	63.0	5.0	519.0	1.0	0.95	0.93	0.98
A2	svm	spdf_fv3	76.0	44.0	224.0	4.0	0.76	0.63	0.95
A3	svm	spdf_fv3	27.0	24.0	38.0	3.0	0.67	0.53	0.9
A4	svm	spdf_fv3	190.0	4360.0	0.0	0.0	0.08	0.04	1.0
A5	svm	spdf_fv3	0.0	0.0	1639.0	108.0	0.0	0.0	0.0
A6	svm	spdf_fv3	44.0	46.0	396.0	4.0	0.64	0.49	0.92
A1	svm	w_raw	56.0	3.0	531.0	8.0	0.91	0.95	0.88
A2	svm	w_raw	77.0	47.0	230.0	3.0	0.75	0.62	0.96
A3	svm	w_raw	29.0	12.0	50.0	1.0	0.82	0.71	0.97
A4	svm	w_raw	148.0	1237.0	3214.0	44.0	0.19	0.11	0.77
A5	svm	w_raw	88.0	126.0	1567.0	21.0	0.54	0.41	0.81
A6	svm	w_raw	43.0	73.0	376.0	5.0	0.52	0.37	0.9
A1	one_class_svm	spdf	57.0	4.0	520.0	7.0	0.91	0.93	0.89
A2	one_class_svm	spdf	58.0	52.0	216.0	22.0	0.61	0.53	0.72
A3	one_class_svm	spdf	25.0	27.0	35.0	5.0	0.61	0.48	0.83
A4	one_class_svm	spdf	84.0	180.0	4180.0	106.0	0.37	0.32	0.44
A5	one_class_svm	spdf	88.0	791.0	848.0	20.0	0.18	0.1	0.81
A6	one_class_svm	spdf	29.0	9.0	433.0	19.0	0.67	0.76	0.6
A1	one_class_svm	spdf_fv3	63.0	4.0	520.0	1.0	0.96	0.94	0.98
A2	one_class_svm	spdf_fv3	77.0	55.0	213.0	3.0	0.73	0.58	0.96
A3	one_class_svm	spdf_fv3	25.0	24.0	38.0	5.0	0.63	0.51	0.83

A4	one_class_svm	spdf_fv3	178.0	3223.0	1137.0	12.0	0.1	0.05	0.94
A5	one_class_svm	spdf_fv3	95.0	1134.0	505.0	13.0	0.14	0.08	0.88
A6	one_class_svm	spdf_fv3	44.0	54.0	388.0	4.0	0.6	0.45	0.92
A1	one_class_svm	w_raw	55.0	7.0	527.0	9.0	0.87	0.89	0.86
A2	one_class_svm	w_raw	74.0	19.0	258.0	6.0	0.86	0.8	0.92
A3	one_class_svm	w_raw	27.0	11.0	51.0	3.0	0.79	0.71	0.9
A4	one_class_svm	w_raw	175.0	2198.0	2253.0	17.0	0.14	0.07	0.91
A5	one_class_svm	w_raw	47.0	0.0	1693.0	62.0	0.6	1.0	0.43
A6	one_class_svm	w_raw	46.0	104.0	345.0	2.0	0.46	0.31	0.96
A1	xgboost	spdf	62.0	2.0	522.0	2.0	0.97	0.97	0.97
A2	xgboost	spdf	76.0	29.0	239.0	4.0	0.82	0.72	0.95
A3	xgboost	spdf	27.0	34.0	28.0	3.0	0.59	0.44	0.9
A4	xgboost	spdf	141.0	1292.0	3068.0	49.0	0.17	0.1	0.74
A5	xgboost	spdf	78.0	236.0	1403.0	30.0	0.37	0.25	0.72
A6	xgboost	spdf	44.0	21.0	421.0	4.0	0.78	0.68	0.92
A1	xgboost	spdf_fv3	62.0	3.0	521.0	2.0	0.96	0.95	0.97
A2	xgboost	spdf_fv3	76.0	49.0	219.0	4.0	0.74	0.61	0.95
A3	xgboost	spdf_fv3	26.0	21.0	41.0	4.0	0.68	0.55	0.87
A4	xgboost	spdf_fv3	122.0	1291.0	3069.0	68.0	0.15	0.09	0.64
A5	xgboost	spdf_fv3	66.0	335.0	1304.0	42.0	0.26	0.16	0.61
A6	xgboost	spdf_fv3	44.0	41.0	401.0	4.0	0.66	0.52	0.92
A1	xgboost	w_raw	52.0	9.0	525.0	12.0	0.83	0.85	0.81
A2	xgboost	w_raw	76.0	21.0	256.0	4.0	0.86	0.78	0.95
A3	xgboost	w_raw	29.0	10.0	52.0	1.0	0.84	0.74	0.97
A4	xgboost	w_raw	148.0	1284.0	3167.0	44.0	0.18	0.1	0.77
A5	xgboost	w_raw	90.0	146.0	1547.0	19.0	0.52	0.38	0.83
A6	xgboost	w_raw	40.0	27.0	422.0	8.0	0.7	0.6	0.83

Table S3. Detection and sorting performance using Spike2. This table presents spike detection and sorting performance using Spike2 on the full ground truth data sets, including the number of false positives, true positives, and false negatives, as well as the calculated F1-score, precision, and recall.

Dataset	FP	TP	FN	F1-Score	Precision	Recall
A1	20.0	140.0	8.0	0.91	0.88	0.95
A2	782.0	271.0	28.0	0.4	0.26	0.91
A3	654.0	164.0	9.0	0.33	0.2	0.95
A4	20761.0	472.0	153.0	0.04	0.02	0.76
A5	24494.0	398.0	38.0	0.03	0.02	0.91
A6	1447.0	262.0	26.0	0.26	0.15	0.91

Table S4. Detection and sorting performance using Spike2 within the constrained post-hoc search space. This table presents spike detection and sorting results using Spike2, evaluated only on intervals included in the constrained post-hoc search space for comparison with our pipeline result. Metrics include the number of false positives, true positives, and false negatives, along with the corresponding F1-score, precision, and recall.

Dataset	FP	TP	FN	F1-Score	Precision	Recall
A1	5.0	61.0	4.0	0.93	0.92	0.94
A2	78.0	76.0	4.0	0.65	0.49	0.95
A3	71.0	29.0	2.0	0.44	0.29	0.94
A4	1944.0	159.0	55.0	0.14	0.08	0.74
A5	2991.0	96.0	19.0	0.06	0.03	0.83
A6	186.0	48.0	4.0	0.34	0.21	0.92

Table S5. Mean F1-scores from 5-fold cross-validation for different model and feature set combinations on background spikes from dataset AC. Three models (One-Class-SVM, SVM, and XGBoost) were evaluated using three different feature sets (SPDF, $\mathrm{SPDF}_{\mathrm{FV3}}$, and $\mathrm{W}_{\mathrm{raw}}$). Performance is reported as the mean F1-score across all folds.

Model	Feature Set	F1-Score
one_class_svm	spdf	0.96
one_class_svm	spdf_fv3	0.95
one_class_svm	w_raw	0.97
svm	spdf	0.92
svm	spdf_fv3	0.75
svm	w_raw	0.85
xgboost	spdf	0.97
xgboost	spdf_fv3	0.95
xgboost	w_raw	0.97

Table S6. Spike characteristics for dataset AC detected and sorted using Spike2.
This table lists detailed spike information for dataset AC, following detection and sorting with Spike2. Columns include detected and sorted spike ID, spike timestamp, inter-spike interval (ISI), and instantaneous firing frequency (Hz).

Spike ID	Spike Timestamp	Inter-spike-interval (ISI)	Instantaneous Frequency (Hz)
0	130.54		
1	130.62	0.08	12.92
2	130.76	0.14	7.27
3	130.82	0.06	16.13
4	130.88	0.06	16.84
5	130.93	0.05	18.69
6	131.0	0.07	14.33
7	131.06	0.06	18.08
8	131.11	0.05	20.88
9	131.15	0.05	20.45
10	131.21	0.05	18.48
11	131.27	0.06	16.92
12	131.32	0.06	17.92
13	131.37	0.05	21.55
14	131.42	0.05	21.69
15	131.48	0.06	15.7
16	131.54	0.06	16.31
17	131.6	0.06	15.5
18	131.68	0.08	12.82
19	131.73	0.05	19.92
20	131.81	0.08	12.94
21	131.88	0.07	13.5
22	131.95	0.07	14.29
23	132.05	0.09	10.95
24	132.13	0.08	12.42
25	132.13	0.01	188.68
26	132.24	0.1	9.55
27	132.31	0.08	13.25
28	132.44	0.13	7.7
29	132.54	0.1	10.16
30	132.62	0.08	12.92
31	132.7	0.08	12.06
32	132.84	0.14	7.04
33	132.87	0.02	43.48
34	133.0	0.13	7.42
35	133.1	0.1	10.21
36	133.21	0.11	8.98
37	133.45	0.24	4.09
38	133.73	0.28	3.62
39	133.97	0.24	4.12
40	134.21	0.24	4.17
50	146.55	12.34	0.08
51	146.85	0.3	3.32
52	146.95	0.09	10.85
53	147.06	0.12	8.69
54	147.31	0.24	4.08
55	147.52	0.22	4.56
56	147.71	0.19	5.38
57	147.95	0.23	4.26
58	148.14	0.19	5.27
59	148.26	0.12	8.12

60	148.48	0.22	4.44
61	148.65	0.16	6.09
62	148.94	0.3	3.37
63	149.14	0.19	5.13
64	149.32	0.18	5.65
65	149.55	0.23	4.33
66	149.84	0.3	3.38
67	150.21	0.37	2.71
82	162.55	12.34	0.08
83	163.83	1.28	0.78
84	165.12	1.28	0.78
85	165.88	0.76	1.31
86	166.0	0.12	8.36
87	166.27	0.27	3.69
88	166.56	0.28	3.54
89	166.7	0.14	6.97
90	166.8	0.1	10.26
91	166.96	0.16	6.28
92	167.1	0.15	6.85
93	167.22	0.12	8.29
94	167.37	0.15	6.8
95	167.51	0.14	6.9
96	167.64	0.12	8.19
97	167.86	0.22	4.57
98	167.98	0.12	8.29
99	168.1	0.12	8.11
100	168.42	0.32	3.1
101	168.53	0.11	9.38
102	168.88	0.35	2.85
103	169.43	0.55	1.82
104	169.69	0.26	3.9
105	169.98	0.29	3.47
144	194.45	24.47	0.04
145	194.52	0.07	14.16
146	194.66	0.14	7.1
147	194.77	0.11	9.12
148	194.92	0.15	6.55
149	195.03	0.11	9.12
150	195.14	0.11	9.12
151	195.28	0.14	7.23
152	195.57	0.29	3.45
153	195.86	0.29	3.47
154	195.95	0.1	10.48
155	196.57	0.61	1.63
156	196.88	0.31	3.22
157	197.26	0.38	2.62
186	226.49	29.23	0.03
187	226.55	0.06	16.53
188	226.69	0.14	7.2
189	226.8	0.11	9.43
190	226.95	0.15	6.72
191	227.06	0.11	8.84
192	227.16	0.1	9.73
193	227.3	0.14	7.29
194	227.4	0.1	9.55
195	227.54	0.13	7.55
196	227.62	0.08	12.39
197	227.8	0.19	5.32

198	227.95	0.15	6.78
199	228.08	0.13	7.54
200	228.27	0.18	5.42
201	228.4	0.13	7.76
202	228.57	0.17	5.96
203	228.7	0.13	7.62
204	228.82	0.13	7.89
205	229.06	0.23	4.28
218	254.56	25.5	0.04
219	254.92	0.37	2.71
220	255.03	0.1	9.75
221	255.49	0.47	2.15
222	256.14	0.65	1.55
223	256.44	0.3	3.29
224	256.8	0.36	2.79
225	256.99	0.19	5.14
226	257.28	0.29	3.49
227	257.9	0.61	1.63
228	258.09	0.2	5.09
229	258.36	0.26	3.8
230	258.56	0.2	4.89
231	259.06	0.5	1.99
232	259.3	0.24	4.17
233	259.51	0.21	4.81
234	259.71	0.2	5.07
235	260.19	0.48	2.07
236	260.31	0.12	8.67
237	260.38	0.07	13.76
238	261.04	0.66	1.51
239	261.69	0.65	1.54
240	262.24	0.55	1.82
256	278.45	16.21	0.06
257	278.49	0.04	25.45
258	278.54	0.04	23.2
259	278.55	0.01	71.43
260	278.97	0.42	2.36
261	279.11	0.14	7.37
262	279.33	0.22	4.47
263	279.84	0.51	1.96
264	280.54	0.7	1.43
265	280.72	0.17	5.79
266	281.57	0.86	1.17
267	281.88	0.3	3.31
268	282.17	0.29	3.45
279	294.56	12.39	0.08
280	295.23	0.67	1.49
281	296.27	1.04	0.96
282	296.78	0.51	1.95
283	297.16	0.38	2.67
284	297.74	0.58	1.72
285	298.29	0.55	1.82
292	302.55	4.25	0.24
293	303.0	0.45	2.21
294	303.59	0.59	1.68
295	303.94	0.35	2.89
296	304.95	1.02	0.98
297	305.71	0.76	1.32
298	306.19	0.47	2.11

323	326.56	20.37	0.05
324	327.04	0.48	2.06
325	328.12	1.08	0.93
326	329.43	1.31	0.76
327	329.88	0.45	2.23
355	350.55	20.67	0.05
356	351.73	1.18	0.85
357	351.97	0.24	4.14
358	354.03	2.06	0.49
377	370.55	16.52	0.06
378	371.47	0.91	1.09
379	372.23	0.76	1.31
380	373.17	0.94	1.06
381	373.24	0.07	14.6
421	410.55	37.31	0.03
422	411.2	0.64	1.55
423	412.14	0.94	1.07
424	412.75	0.61	1.64
425	414.11	1.36	0.74
435	422.55	8.45	0.12
436	423.31	0.76	1.32
437	425.46	2.15	0.47
438	425.97	0.51	1.96

Table S7. Spike characteristics for dataset AC detected and sorted using our pipeline.
This table presents detailed spike information for dataset AC, after sorting with our pipeline. Columns include detected and sorted spike ID, spike timestamp, inter-spike interval (ISI), and instantaneous firing frequency (Hz).

Spike ID	Spike Timestamp	Inter-spike-interval (ISI)	Instantaneous Frequency (Hz)
1	130.55		
2	130.62	0.08	12.94
4	130.82	0.2	5.01
7	131.01	0.18	5.49
11	131.21	0.21	4.84
13	131.33	0.11	8.75
14	131.37	0.05	21.6
15	131.42	0.05	21.69
16	131.48	0.06	15.72
17	131.55	0.06	16.16
18	131.61	0.06	15.67
19	131.69	0.08	12.85
20	131.74	0.05	19.88
22	131.89	0.15	6.61
23	131.96	0.07	14.31
26	132.14	0.18	5.65
27	132.24	0.1	9.55
28	132.32	0.08	13.28
29	132.45	0.13	7.68
31	132.62	0.18	5.71
38	133.1	0.48	2.08
40	133.46	0.36	2.81
44	134.21	0.76	1.32
48	146.86	12.64	0.08
49	146.95	0.09	10.88
50	147.07	0.12	8.65

55	148.14	1.07	0.93
58	148.65	0.51	1.95
59	148.95	0.3	3.38
61	149.32	0.37	2.69
68	163.84	14.52	0.07
71	166.01	2.17	0.46
72	166.28	0.27	3.7
74	166.56	0.29	3.5
75	166.7	0.14	6.99
76	166.8	0.1	10.27
77	166.96	0.16	6.28
78	167.11	0.15	6.84
79	167.23	0.12	8.34
80	167.37	0.15	6.8
82	167.52	0.14	6.91
84	167.86	0.34	2.93
85	167.98	0.12	8.29
87	168.43	0.45	2.24
89	168.88	0.46	2.19
90	169.43	0.55	1.82
92	169.98	0.54	1.83
93	194.45	24.47	0.04
95	194.66	0.21	4.73
97	194.93	0.26	3.81
100	195.28	0.36	2.8
101	195.57	0.29	3.45
102	195.86	0.29	3.47
104	196.57	0.71	1.41
108	197.26	0.69	1.45
110	226.5	29.24	0.03
113	226.8	0.31	3.27
114	226.95	0.15	6.73
118	227.41	0.46	2.19
119	227.54	0.13	7.56
120	227.62	0.08	12.3
121	227.81	0.19	5.34
123	227.96	0.15	6.65
124	228.09	0.13	7.7
132	254.93	26.84	0.04
133	255.03	0.1	9.72
134	255.5	0.47	2.15
135	256.14	0.64	1.55
138	257.0	0.86	1.17
139	257.28	0.29	3.5
141	258.09	0.81	1.23
143	258.57	0.47	2.12
145	259.31	0.74	1.35
146	259.51	0.21	4.82
147	259.71	0.2	5.07
148	260.19	0.48	2.07
154	261.04	0.85	1.18
155	261.69	0.65	1.54
156	262.24	0.55	1.82
160	278.5	16.26	0.06
162	278.55	0.06	17.48
165	279.11	0.56	1.79
166	279.34	0.22	4.48
167	279.85	0.51	1.96

168	280.55	0.7	1.43
169	280.72	0.17	5.81
171	281.88	1.16	0.86
172	282.17	0.29	3.45
173	294.56	12.4	0.08
174	295.23	0.67	1.49
175	296.27	1.04	0.96
176	296.79	0.51	1.95
178	297.16	0.37	2.67
179	297.74	0.58	1.72
182	303.0	5.26	0.19
183	303.6	0.59	1.68
186	305.72	2.12	0.47
188	326.56	20.85	0.05
189	327.05	0.48	2.07
190	328.13	1.08	0.93
192	329.88	1.76	0.57
197	351.74	21.85	0.05
199	354.03	2.3	0.44
200	370.56	16.53	0.06
201	371.47	0.91	1.1
202	372.23	0.76	1.31
205	410.56	38.33	0.03
207	412.14	1.58	0.63
208	412.75	0.61	1.64
210	414.11	1.36	0.74
211	422.56	8.45	0.12
214	425.97	3.41	0.29