Towards user-centric brain-computer interface design: Unsupervised learning and Markov chainbased methods to understand user capabilities

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Introduction

- Brain-computer interface (BCI) use is limited by "BCI Inefficiency," where users struggle to produce brain signals that can be reliably recognized
- Potential solutions: improve user performance via training and/or optimize classifiers to better leverage user abilities
- Both approaches require **descriptive measures of user performance**
- Current classifier-based performance measures are limited
- With aim of describing user abilities, we designed two user-performance metrics formulated using pattern clustering and Markov chain models

Methods



A. Apply clustering methods to define state space of distinct pattern states that users can produce, independent of task labels B. Segment trials into shorter temporal windows C. Observe the pattern state for each temporal window

- D. Represent trials as a stochastic sequence of pattern states
- E. Model transitions between pattern states as a Markov chain

Performance metrics

$$taskDistinct = \sum_{i=1}^{N_t - 1} \sum_{j=i+1}^{N_t} D_H(\pi^{(i)}, \pi^{(j)})$$

 $= \frac{\frac{1}{N_c} \sum_{i=1}^{N_c} 1 + H_i}{1 + H_{rest}}$ relativeTaskInconsistency =

Measures ability to produce distinct patterns for different tasks

Measures (in)ability to maintain consistent pattern sequences

Relations

- Positive corre taskDistinct a
- Negative corr scores and pa relativeTaskIr
- Metric values positive relation classifier perf relativeTaskIr

• Further insight provided by participant profiles

- State distributions (left) show for multiple tasks
- Transition probabilities (right) indicate temporal dynamics of pattern evolution and ability to maintain task specific patterns

Conclusions and Future Directions • User assessment approach and metrics yield insights into user performance not afforded by classifier-based metrics • Next steps: Develop training & feedback centred on model & metrics

Acknowledgements

This work has been generously supported by a National Sciences and Engineering Research Council of Canada (NSERC) Canada Graduate Scholarship-Doctoral, a Kimel Family Graduate Student Scholarship in Pediatric Rehabilitation and an Ontario Graduate Scholarship

New models provide descriptive information about our ability to control brain signals and pave the way for user-centric brain-computer interface design



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Results		
hip to classifier performance	0.8	
elation (N=14) between and classifier performance relation observed between F1 articipants (N=11) with	e 0.6 E 0.4 0.2	P1 P9
nconsistency < 1	0.0⊥ 0	.2 0.4
s for P6, P8, & P9 indicated possible	0.8	P1 P2 P12 P11
formance when nconsistency > 1	e 0.6 1 score 1 0.4	P3 È r = -0.860, p

extent to which pattern states are task specific or produced

Participant profiles





High performer (P14)

Re	est T	ransit	ion M	atrix			Task 2 Transition Matrix							
0.51	14	0.148	0.162	0.175			0.4	14	0.204	0.153	0.229)		
0.14	42	0.474	0.187	0.197			0.1	00	0.588	0.083	0.229)		
0.13	34	0.138	0.483	0.245			0.2	03	0.257	0.284	0.256	5		
0.07	79	0.092	0.164	0.666			0.0	73	0.197	0.074	0.655	5		
H = 1.650 $H = 1.602$										0.000				
$H_{rest} = 1.650$ $H_2 = 1.602$														
							_		_					
Task 1 Transition Matrix								Task 3 Transition Matrix						
0.63	33	0.206	0.086	0.075			0.6	59	0.150	0.144	0.047	,		
0.11	11	0.771	0.053	0.065			0.1	74	0.560	0.185	0.081			
0.21	16	0.285	0.281	0.218			0.1	87	0.216	0.527	0.069)		
0.20	07	0.247	0.176	0.370			0.2	15	0.238	0.256	0.291			
$H_1 = 1.404$ $H_3 = 1.606$														
		-							U					
		nr l												
	IE	: (LU)									
	Rest	t Trans	ition N	/latrix			Т	ask 2	2 Trans	sition N	Vlatrix	F	2	
528	0.08	5 0.069	0.057	0.159	0.103		0.473	0.08	8 0.114	0.076	0.126	0.123		
092	0.46	8 0.124	0.129	0.143	0.044		0.091	0.47	0 0.096	0.125	0.155	0.063		
115	0.13	0.403	0.009	0.089	0.122		0.103	0.14	5 0.403	0.463	0.098	0.105		
206	0.12	6 0.060	0.072	0.488	0.048		0.214	0.12	7 0.063	0.091	0.440	0.065		
166	0.07	1 0.127	0.103	0.084	0.449		0.100	0.10	0 0.108	0.130	0.059	0.502		
$H_{rest} = 2.172$									$H_2 = 2$	2.206				
Task 1 Transition Matrix Task 2 Transition Matrix														
							1					0.470		
439	0.07	6 0.112 7 0.122	0.070	0.166	0.138		0.197	0.160	0.159	0.157	0.151	0.178		
080	0.47	7 0.133 2 0.479	0.160	0.099	0.052		0.036	0.453	0.205	0.121	0.072	0.092		
097	0.14	6 0.064	0.084	0.080	0.136		0.028	0.174	5 0.018	0.485	0.045	0.147		
198	0.15	1 0.097	0.123	0.344	0.088		0.143	0.166	5 0.160	0.159	0.201	0.171		
127	0.06	1 0.112	0.161	0.054	0.485		0.032	0.053	3 0.157	0.141	0.024	0.594		
$H_1 = 2.207$ $H_2 = 1.958$														
	1		1.207			1	-3 -							