EEG-Based Typing Interface with Language Model for Individuals Who are Functionally Locked-in

B. S. Oken, U. Orhan, B. Roark, D. Erdogmus, A. Fowler, B. Peters, M. Miller, M.B. Fried-Oken

Neurology, Biomedical Engineering, Center for Spoken language Understanding and Institute on Development and Disabilities Oregon Health & Science University, Portland, OR

Dept of Electrical and Computer Engineering, Northeastern University

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Brain-Computer Interface (BCI)

- Technology whereby a computer detects a ‘selection’ made by a person who does not rely on neuromuscular activity.
- The technology uses the person’s changes in brain activity as the intended execution.
- Technology substitutes for the loss of typical neuromuscular outputs so that people can interact with their environments through brain signals rather than through muscle movement.

Locked In Syndrome: American Congress of Rehab Med (1995)

- A syndrome characterized by preserved awareness, relatively intact cognitive functions, and ability to communicate while being paralyzed and voiceless. This syndrome is defined by five criteria:
  1. Sustained eye opening and preserved vertical eye movement
  2. Preserved higher cortical functions
  3. Aphonia or severe hypophonia
  4. Quadriplegia or quadriparesis
  5. Primary mode of communication involving vertical eye movements or blinking

Classifications of LIS

- Complete or Total LIS: Quadriplegia and anarthria. No eye movement
- Classic LIS: Preserved vertical eye movement and blinking
- Incomplete LIS: Some voluntary movements in addition to eye movements (Bauer et al, 1979)

Epidemiology of LIS

- Over 2 million people in the U.S. with some level of functional LIS
- Less than 1% of CVA
- More than 85% of individuals are still alive after 10 years
- Average age range: 17 – 52 years
- Younger patients have better potential of survival

Options for restoring functional motor function

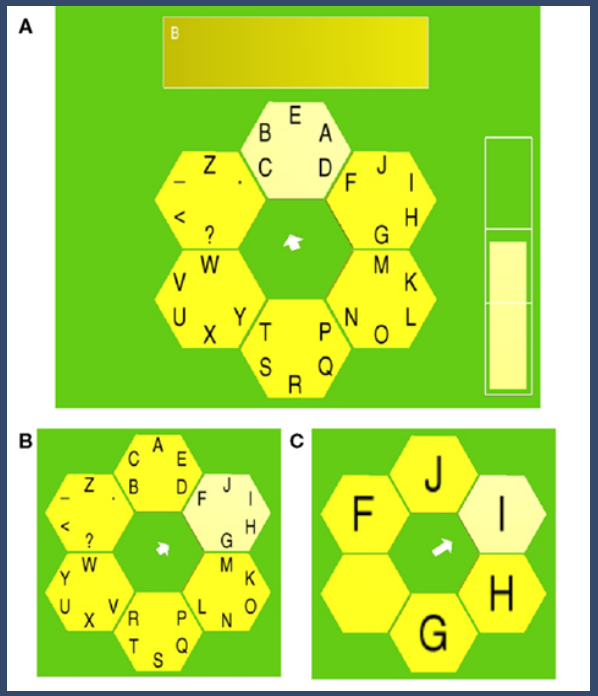
- Rely on capabilities of remaining pathways
  - Eye gaze communication system
  - Head mouse access to computer
- Detouring around neural pathway breaks
  - FES: Direct activation of paralyzed muscles through neural or EMG activity above lesion level.
- Provide the brain with a new, non-muscular communication and control channel: BCI.

  Either non-invasive scalp EEG or direct cortical EEG

BCI 2000 w/ P300 speller

- Most commonly used spelling interface
- Uses a grid with randomly flashing rows/columns
- 3 passes of same response = selection

Berlin BCI: Hex-o-spell



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RSVP Keyboard™: A Spelling Interface based on the P3 Signal

- A sample 1-sequence training epoch…
- Multiple sequences of same letters shuffled
  => multi-trial ERP detection
  - Rapid
  - Serial
  - Visual
  - Presentation

Cognitive Systems Laboratory,
Northeastern University

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OHSU

RSVP Keyboard™ BCI Overall Goal

To integrate new engineering developments in EEG analysis with language models for people who are locked-in to communicate and control their environments.

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Unique Aspects of OHSU BCI Research

1. RSVP: stimulus presentation
2. Language modeling
3. Single event ERP goal
4. Incomplete locked-in patients
5. Participatory Action Research
6. User-Centered Design
7. Community Based

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What is a language model?

- Builds statistical models to predict symbols given previously typed symbols
  - Given *San Diego Pa*
  - The language system predicts *Padres*

RSVP Keyboard™ Fuses Language Model & EEG Evidence

RSVP Keyboard makes letter selections based on *joint evidence* from an n-gram language model and EEG signals.

Calibration Task

Gathering Data to Train Classifier
(about 12 minutes)

- Subject instructed to look for a specific letter
- 75 or 50 series containing 10 letters or symbols, including the target letter
- **Machine Learning:**
  Learning Algorithm + EEG

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Creation of the EEG/P3 Classifier

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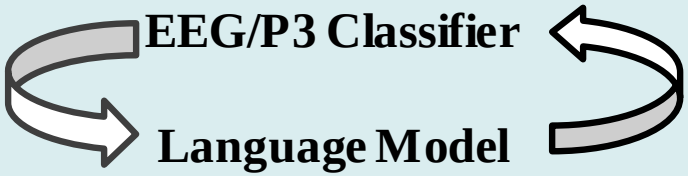
Hybrid Classifier



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Current use of the RSVP Keyboard ™ : The Mastery Copy Task

- To give practice opportunity to improve performance with the RSVP Keyboard™
- To allow participants to experience success before free spelling
- To incorporate the concept of errorless learning into the RSVP™ paradigm

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Mastery Copy Task: Design

- Participants are presented with a pre-selected set of phrases, one at a time
- Task is to copy a target word from each phrase
- 5 levels of difficulty
  - Earlier levels provide more support from the language model, so participant can spell successfully even if brain signals are not optimal
- Participant must complete 2 out of 3 phrases at each level
- 3 sets of 3 phrases at each level so participant can re-attempt levels if necessary

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Mastery Examples

Level 1	i do **not** agree
Level 2	i have said too **much**
Level 3	the third **seat** from the left
Level 4	a long time **span**
Level 5	the man with **wavy** eyebrows

The probability of letters in the *target word* range from 5 times more likely as the next most likely letter (level 1) to 0.3 times as likely as the most likely letter (level 5).

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Mastery Copy Task: Stopping Criteria

- RSVP Keyboard™ will move on to next phrase when one of the following criteria is met:
  - Target word is spelled correctly
  - Participant has spent 10 minutes attempting to type target word
  - Number of sequences exceeds 2LS, where L = # of letters in word and S = maximum # of sequences shown before a letter is chosen

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Instructions

- First there will be a fixation cross.
- Then a sentence will appear in the upper left .
- The word you are to try to spell is in green.
- If the computer chooses a wrong letter, please try to fix it using a backspace.

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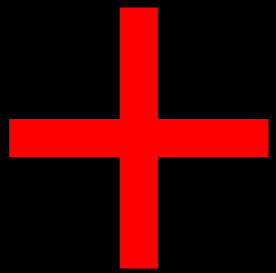

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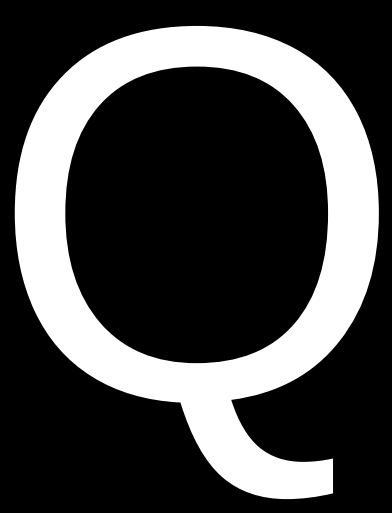

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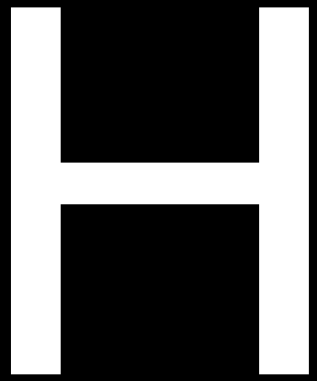

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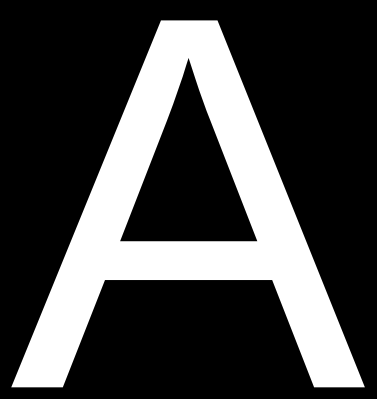

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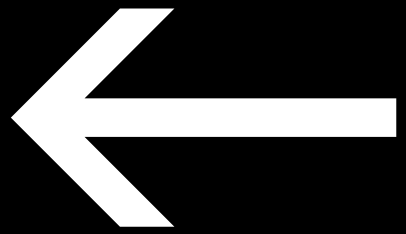

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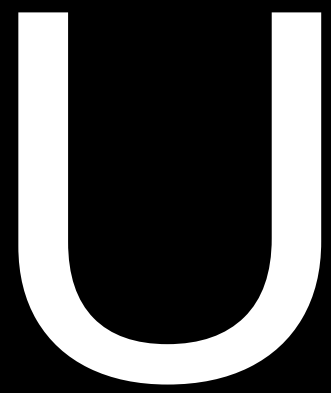

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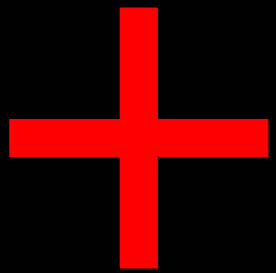

Participants

	LIS	CONTROLS	p value
Age, mean (range)	45.8 (27-65)	45.2 (17-66)	0.965[a]
Gender (M/F)	7/2	4/5	0.147[b]
Ethnicity (%Caucasian)	77.8	100	0.134[b]
Years of education (range)	14.6 (12-23)	18.2 (11-22)	0.067[a]
First language English (n)	8	9	0.303[b]
Level of familiarity with computer(some/expert)	4/5	2/7	0.317[b]
Type of LIS (n)			
Incomplete	6		
Classical	2		
Total	1		
Time since onset LIS	14.8 (1-55)		

Cause of LIS was ALS (4), brainstem stroke (2), cerebral palsy (1), brainstem AVM (1), and Duchenne muscular dystrophy (1)

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Mastery Task Results (N = 17)

	PLIS (n = 6)			Controls (n = 9)		
Level	**N**	**AUC**	**TER (%)**	**N**	**AUC**	**TER (%)**
1	6	.73 (.116), .56-.93	9.1 (18.61), 0-66.7	9	.81 (.071), .69-.92	5.9 (15.97), 0-71.4
2	4	.76 (.124), .56-.93	9.3 (21.04), 0-71.4	8	.81 (.074), .69-.92	10.2 (27.15), 0-100.0
3	2	.83 (.105), .71-.93	4.1 (10.21), 0-25	7	.83 (.067), .73-.92	6.7 (11.40), 0-33.3
4	1	.92 (.014), .91-.93*	0 (0), 0	6	.86 (.056), .79-.92	21.0 (21.83), 0-71.4
5	1	.92 (.014), .91-.93*	15.4 (24.88), 0-57.1	6	.86 (.056), .79-.92	11.3 (12.59), 0-33.3

- N = number of participants who successfully completed a given level (out of 6 for PLIS and 9 for controls)
- AUC = Area under the receiver operating characteristic curve calibration scores of participants who passed each level
- TER = total error rate for participants who passed each level

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Mastery Task Results (N = 15)

	PLIS	Controls	p
Maximum AUC score	.71 (.113), .62-.93	.83 (.068), .70-.92	0.045[a,b]
Highest level completed	2.3 (1.51), 1-5	4.0 (1.58), 1-5	0.069[a]
Number of sessions	1.7 (0.82), 1-3	1.3 (0.50), 1-2	0.414[a]

- All participants starting mastery task completed at least level 1
- At higher levels, fewer participants were successful and higher AUC scores were required to pass
- 1/6 PLIS and 6/9 controls passed all 5 levels
- Controls had significantly higher AUC scores than PLIS, and tended to reach higher levels
- Several PLIS consistently achieved low AUC scores
  - Spasticity, meds, external interference, attention, ???

Challenges

Participant issues

- Physical positioning
- Fatigue
- Decreased aroual/attention
- Medications
- Eye control

Equipment issues

- Interference from other medical equipment
- Lengthy set up time requiring skilled personnel
- Portability

Service Delivery

- Training
- Cost
- Caregiver responsibility
- Technology support needs

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Next steps

- Use LM to better select subset of symbols to display
- Use LM to add strings (words) to display
- Inclusion of personalized LM's
- Vigilance and attention measures
- Improved artifact reduction algorithms
- Patient-centered outcomes framework

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"BCI also can open new doors, which is hard to do when you're literally locked-in." GB

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