OREGON HEALTH & SCIENCE UNIVERSITY

The RSVP Keyboard™: A Brain Computer Interface for Users who have Locked-in Syndrome

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Translational R01 from NIDCD

Signal Processing Engineering
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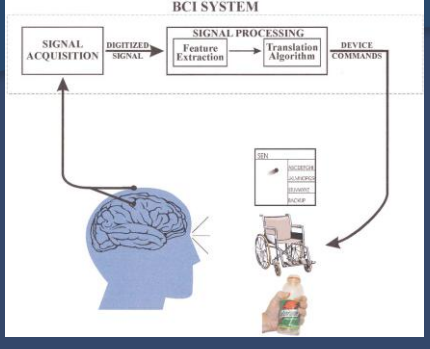
Northeastern U group: Deniz Erdogmus, PhD; Umut Orhan; Shalini Pulwar

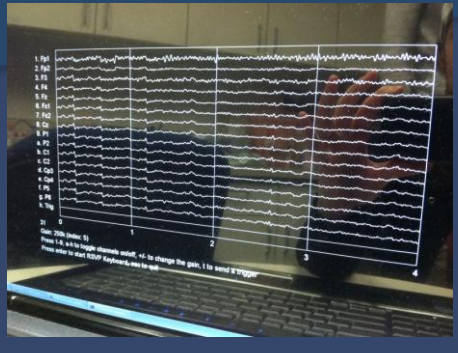
Introduction to BCI

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.



Wolpaw, et al (2002). Brain-computer interfaces for communication and control. *Clinical Neurophysiology, 113.* 767-791



Locked in Syndrome

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: Recovery of some voluntary movements in addition to eye movements (Bauer et al, 1979)

Common Diagnoses Leading to LIS

- End stage ALS
- Brainstem CVA
- High level spinal cord injury
- Traumatic Brain injury

Functional LIS diagnoses

- All of Common

+

- Cerebral palsy
- Muscular dystrophies
- Multiple sclerosis
- Parkinson's disease (plus)
- Tumors

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 electrical stimulation of paralyzed muscles through EMG activity in muscles above lesion level.
- Provide the brain with a new, non-muscular communication and control channel: BCI.

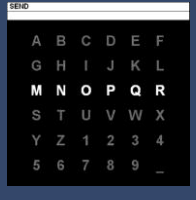
Current BCI Research

Current human BCI research for communication & control

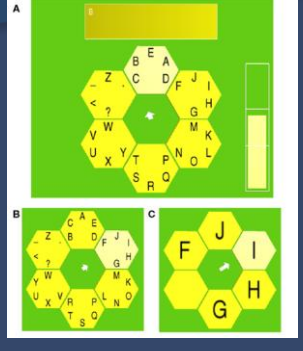
- Non-invasive BCI:
- Invasive BCI: Braingate

BCI 2000 with P300 speller

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



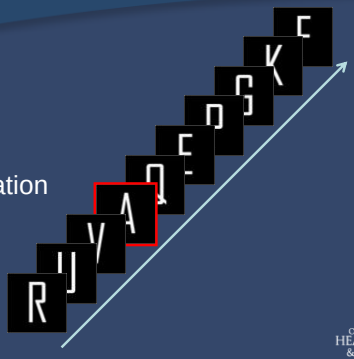
Berlin BCI: Hex-o-spell



RSVP Keyboard™ BCI Project

RSVP Keyboard™

- Rapid
- Serial
- Visual
- Presentation



Brain-Computer Interface with RSVP Keyboard™

Allows user to communicate independent of neuromuscular output by tracking selections via changes in EEG activity.

RSVP Keyboard™ BCI Overall Goal

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

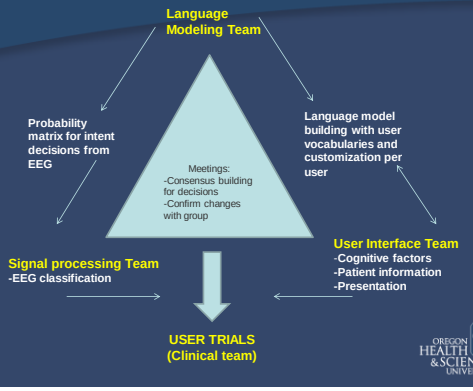
OHSU RSVP Keyboard™ BCI Project

Unique Aspects of OHSU BCI Research

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

"Through this research project, I have had the opportunity to assist the team in understanding things from a user's standpoint. It has shaped my concept of what I think would be most helpful, not only for me, but for others who are locked-in. This has been, and continues to be, a wonderful experience for me." *GB*

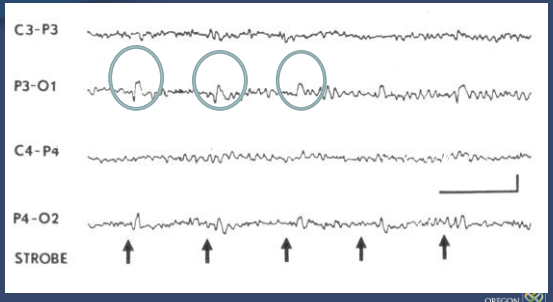
BCI Triangulated Collaboration



Signal Processing and Interface Design

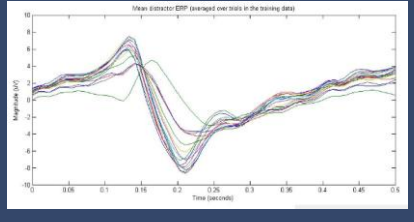
Non-invasive, wet electrode BCI

Photic stimulation at 1 Hz during routine EEG



P300 Response

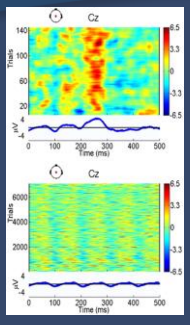
- Involuntary spike in EEG activity over the parietal cortex
- Indicates a salient, infrequent event following frequent/routine stimuli



P300 is a variable waveform

- Sensitive to alertness and attention
- Amplitude increased by stimulus infrequency and stimulus salience
- Latency affected by target detection difficulty and age

RSVP™ and P300



Target

Non-target (distracter)

Deniz Erdogmus, Cognitive Systems Laboratory, Northeastern University

Language Modeling

What is a language model?

- RSVP Keyboard™ BCI presents single symbols
- Assigns each symbol a probability of being next
  - Suppose user has typed: *"the Pittsburgh Pi"*
  - Then probability of *r* should be high; *e* maybe not so high but not very low; *q* should be low but not zero
- Builds statistical models to predict symbols given previously typed symbols
  - Estimates probabilities from collected text
- Also needs to include probability for delete

Word models

- We build models that predict the current word
- Users still able to type words never seen before
  - Estimation methods give no zero probabilities
- Collect evidence for symbols from words
  - Suppose user has typed: *"the Pittsburgh Pi"*
  - Possible next words: Pirates, Pie, Pilots, Pickles
  - Thus possible (high probability) next letters: r, e, l, c
- Thus this is an "open-vocabulary" system
  - Can incorporate word-completion easily

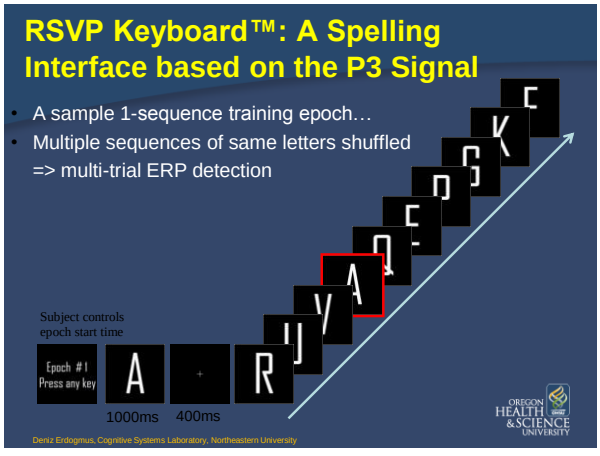
RSVP Keyboard™: Fusing Language Model & EEG Evidence

- RSVP Keyboard makes letter selections based on *joint evidence* from an n-gram language model and EEG signals.
- Language model is trained using large language databases:
  - *Wall Street Journal* and *New York Times* databases
  - Enron e-mails
  - User-provided previous conversations and vocabulary lists

Deniz Erdogmus www.ece.neu.edu/~erdogmus

Use of language model in BCI system

- LM probabilities can be used several ways
  - Fusion within ERP detection classifier (yes)
    - Aiding classification; contributing to stopping criteria
  - To select subset of symbols to display (not yet)
    - This is related to assigning the optimal code
  - To add strings (words) to display (not yet)
  - Soft keyboard: select sets of symbols (not yet)
  - Recover gracefully from spelling errors (not yet)


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
Subject controls epoch start time
Epoch # 1 Press any key
A
R
1000ms
400ms
Deniz Erdogmus, Cognitive Systems Laboratory, Northeastern University
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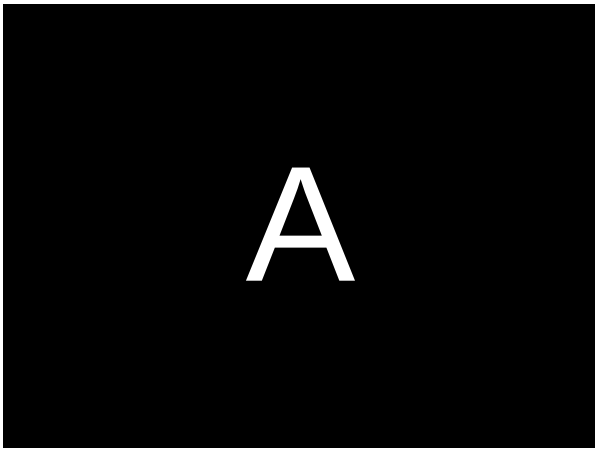
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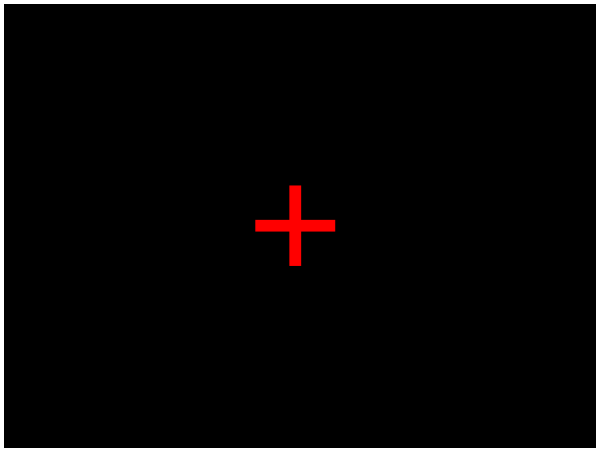
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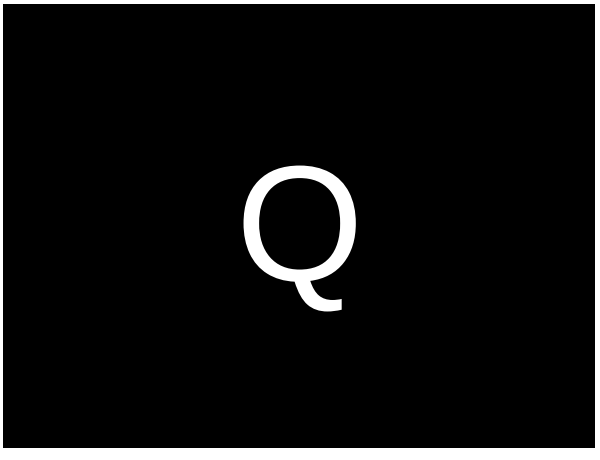
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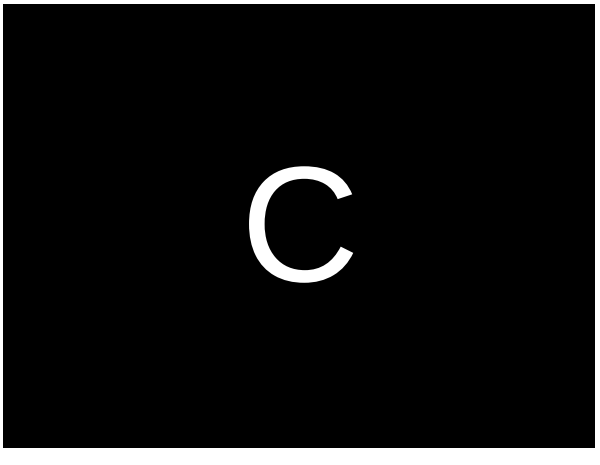
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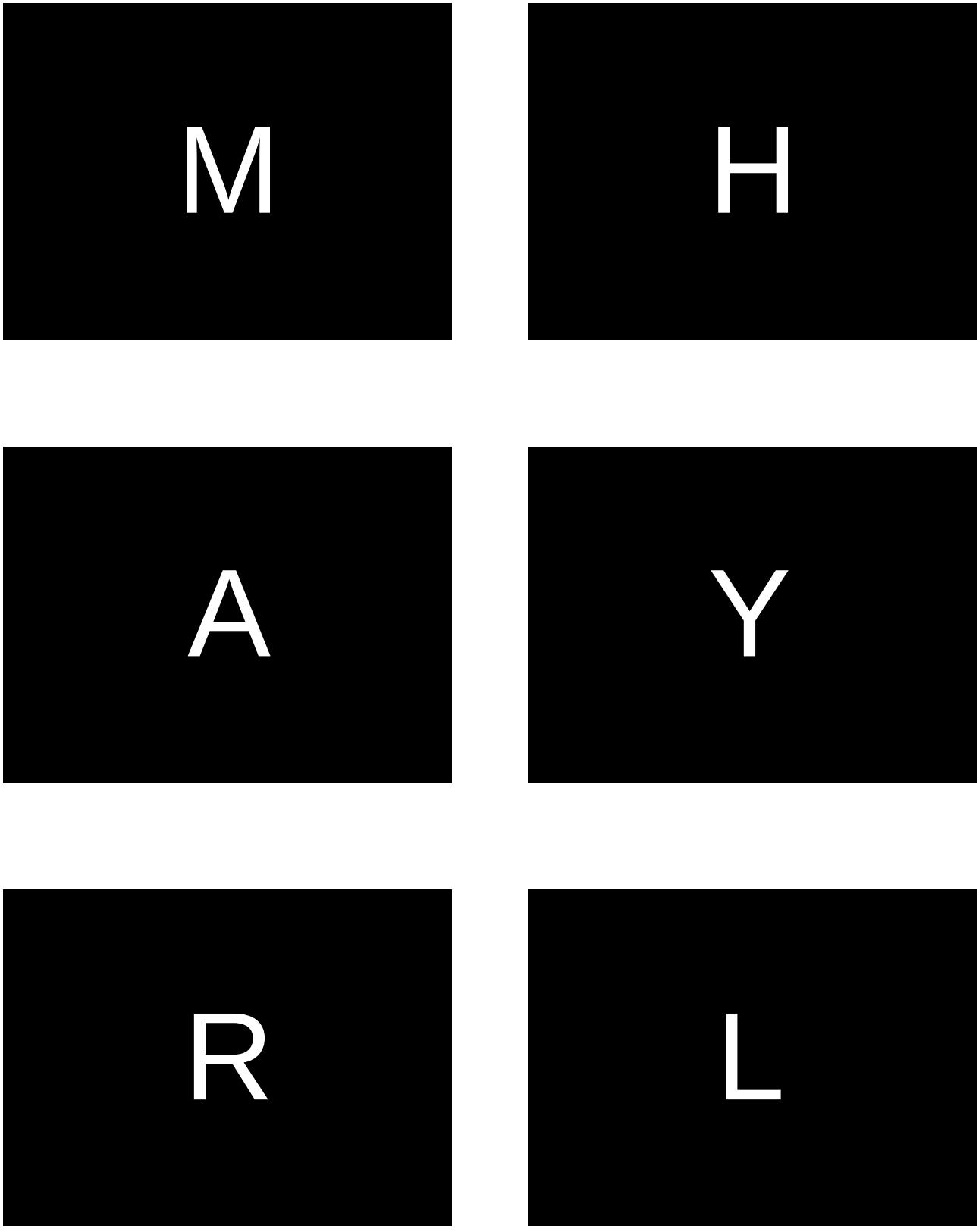
M
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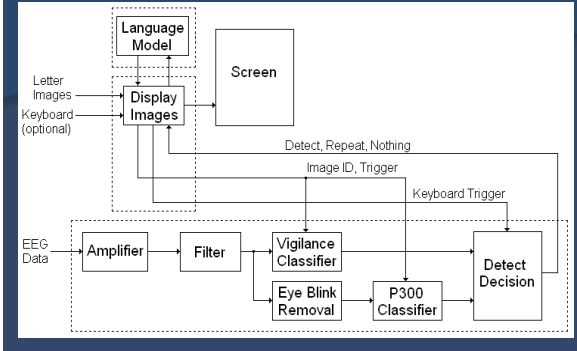
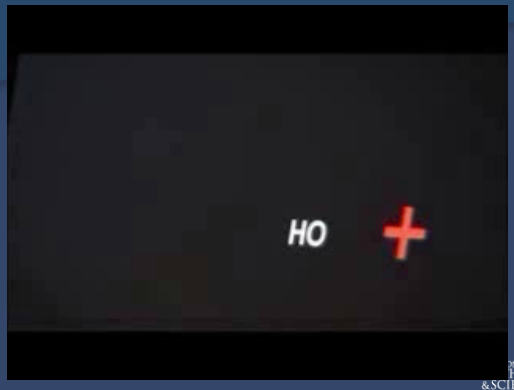
T

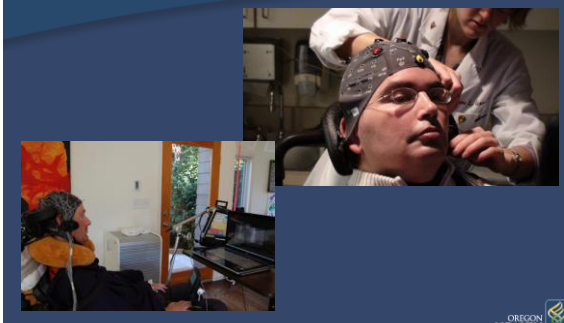
Bayesian Fusion for Calibration





User Centered Design
Participatory Action Research
Community Based

HB and GB as expert consultants



"Giving people with LIS the option to use a BCI in their daily life can provide so many benefits. It has the potential to give us a sense of control, the ability to communicate independently, and a sense of depth. The challenges of designing a BCI system for people who are social and intelligent are making it user friendly, reliable, just as easy and fast as our current communication method, and low-profile." - HB

"At the very least, I am hoping to get aid in communication from a BCI system. I want to be able to express myself without the help of others at all times. If the system were able to predict text based on how my sentences are formed, that would be helpful. I want to be able to write emails and use Facebook independently. For people like me who are completely locked-in, it would be nice to be able to control simple things like my wheelchair and the lift on my van. I would like to turn on lights, the thermostat, the radio, and my television. As I work more with the BCI system, I feel that it has the potential to do an unlimited amount of things in the future."-- GB

Participants

Inclusion Criteria

1) People with LIS or FLIS
   - Dx of acquired neuromuscular or neurodevelopmental disorder
   - 18 - 75 years of age
   - Capable of participating in 1-3 hour experimental interactions
   - Literate in English and capable of spelling words
   - WNL or corrected vision and hearing
   - Speech that is understood less than 25% of the time
     OR
   - Minimal reliable motor response

2) Controls

People with LIS/FLIS Summary

- **Gender:** 10 male, 2 female
- **Age:** *M* = 45.5 yrs
- **Diagnosis:** 5 ALS, 2 brainstem stroke, 2 cerebral palsy, 1 Traumatic Brain Injury, 1 Spinal Cerebellar Ataxia, 1 Duchenne Muscular Dystrophy
- **Status Post:** (7) 2-10 yrs, (2) >10 yrs, (3) lifetime
- **LIS Type:** 1 Total, 8 Incomplete, 3 Functional
- **Education:** *M* = 15.58 yrs
- **Residence:** 7 home, 5 adult foster home

People with LIS/FLIS (N=12)

Gender	Age	Dx	S/P	LIS Type	Edu.	Profession	Residence
Male*	42	ALS	2 yrs	Incomplete	19 yrs	Architect	Home with wife/child
Female	65	ALS	6 yrs	Functional	14 yrs	Homemaker/ Volunteer	Home with husband
Male	43	ALS	11	Incomplete	14 yrs	Business	Private
Male	40	ALS	5 yrs	Incomplete	23 yrs	Physician	Home with wife/children
Male	49	ALS	4	Incomplete	12	Sales	Private
Male	43	BS CVA	16 yrs	Incomplete	14 yrs	Landscaper	Home with parent
Male	41	BS CVA	2 yrs	Total	18 yrs	Engineer	AFH

*Deceased

People with LIS/FLIS (N=12)

Gender	Age	Dx	S/P	LIS Type	Edu.	Profession	Residence
Male	50	CP	N/A	Incomplete	12	SSDI	AFH
Female	55	CP	N/A	Functional	12 yrs	SSDI	AFH
Male	30	TBI	2 yrs	Incomplete	16 yrs	Musician	AFH
Male	62	Spinal Cerebellar Ataxia	8	Incomplete	21	Attorney	Private
Male	27	Duchene MD	N/A	Functional (+ speech)	12 yrs	SSDI	AFH

Control Summary

- 14 healthy controls
- 6 males, 8 females
- 17-66 years old (*M* = 42)
- Level of Education: 11-23 years
- Profession: Student, Computer programmer, Accountant, Physical Therapist, Academic Advisor, Graphic Designer, SLP (3), Researcher.

Screening tool criteria

1. Assess *requisite skills* for RSVP Keyboard™
2. Easy to administer; uses laptop computer & eye-gaze board
3. Approximately 1 hour to administer
4. Completed at participant's residence, at bedside or wheelchair
5. Need to confirm consistent & reliable YES/NO; establish binary code (eye blink, eye up/down or left/right, pucker/smile)

Screening cannot be used for *Complete or Total LIS* participants

Sources for screening tool design

- Boston Naming Test, Kaplan, Goodglass, and Weintraub, 1983
- Functional Linguistic Communication Inventory, Bayles and Tomoeda, 1994
- Boston Assessment of Severe Aphasia, Helm-Estabrooks, Ramsberger, Morgan, Nicholas, 1989
- Coma Recovery Scale-Revised, Giacino, Kalmar, 2004
- Western Aphasia Battery-Revised, Kertesz, 2006
- PROMIS-Pain Interference Bank v1.0, National Institutes of Health Patient-Reported Outcome Measurement Information System (PROMIS®), www.nihpromis.org, 2010.

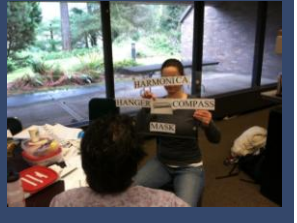
Ergonomic information regarding computer monitor distance and angle taken from: *The United States Department of Labor; Occupational Safety & Health Administration OSHA.*

BCI screening tool: *requisite skills* for RSVP™ Keyboard

- **A. Current yes/no signals**
- **B. Hearing:** Questions to participants & care providers
- **C. Pain:** Questions to participants & care providers
- **D. Vision:**
  1. Questions to participants & care providers
  2. Visual Perception: Computer-based task for central accuracy and peripheral accuracy
- **E. Communication:**
  1. Auditory Comprehension
  2. Reading Comprehension and Literacy
  3. Spelling
- **F. Cognition:**
  1. Questions to participants & care providers
  2. Sustained Visual Attention: Computer-based with adaptability for speed of information processing and working memory capacity (slower rate/fewer symbols)
- **G. Motor:** Physical Therapy input on optimal BCI positioning and description of current motor skills

Screening: Summary to Date

- Screening has been used with 10/12 participants and controls
- Can be completed with individuals with a variety of diagnoses
- Can be completed in one session for most participants



Screening: Summary to Date

Yes/No	- verbal - eye gaze - thumbs up/down -foot up/down
Hearing	0% report hearing loss
Pain	4/10 assessed report pain; none report pain interference with memory or attention
Vision	8/10 wear RX glasses 10/10 report seeing well enough to read 9/10 achieved 100% on Visual Perception
Communication	Auditory Comp: 9/10 achieved 100% on all tasks 1/10 achieved 83-90% on all tasks Reading Comp: 10/10 achieved 100% on all tasks Spelling: 10/10 achieved 100% on all tasks
Cognition	8/10 achieved 100% on Visual Attention 5/10 completed screening in "noisy environment"(divided attention)
Motor	10/10 seated in wheelchair, mostly power w/c 8/10 minimal to no movement while using BCI 2/10 frequent uncontrolled facial and respiratory muscle movement

RSVP™ Task Sequence

1) **Calibration** - System instructs participant to look for a specific letter to train the classifier

2) **Letter Generation Tasks**
   i. **Mastery –** A series of exercises to improve ability to use BCI RSVP Keyboard™ (levels 1-5)
   ii. **Copy** – A word-copy task

3) **Free Writing** - Participants use the system to write whatever they wish

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

↓

Creation of the EEG/P3 Classifier

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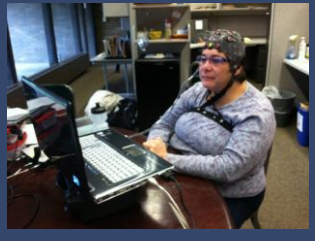
Hybrid Classifier

EEG/P3 Classifier ⇄ **Language Model**

Calibration

- Success using the RSVP Keyboard™ depends on the extent which the system is calibrated to recognize an individual's P300 response



Methods

- Document conditions which may affect p300*:
  - Pain
  - Medication changes
  - Recent illness and/or hospitalization
  - Scalp conditions
- Instruction period with demonstration
- Initial Stanford Sleepiness Scale (SSS) rating
- Series of calibration trials with SSS rating taken after each trial
- Opportunity for mastery with best calibration

* Oken, B.S, and Phillips, T.S., (2009). Evoked Potentials: Clinical *Encyclopedia of Neuroscience (2009), vol. 4, pp.19-28*

Stanford Sleepiness Scale

Degree of Sleepiness	Scale Rating
Feeling active, vital, alert, or wide awake	1
Functioning at high levels, but not at peak; able to concentrate	2
Awake, but relaxed; responsive but not fully alert	3
Somewhat foggy, let down	4
Foggy; losing interest in remaining awake; slowed down	5
Sleepy, woozy, fighting sleep; prefer to lie down	6
No longer fighting sleep, sleep onset soon; having dream-like thoughts	7
Asleep	X

http://www.stanford.edu/~dement/sss.html

Pain interference questions*

- How difficult was it for you to take in new information because of pain today?
- How much does pain interfere with your ability to concentrate today?
- How often is your pain so severe you could think of nothing else today?
- How often does pain make you feel discouraged today?
- How much does pain interfere with your ability to remember things today?

* Adapted from PROMIS Item Bank v1.0 – Pain Interference, https://www.assessmentcenter.net/ac1/files/pdf/8l0480790a2246da9711076c59.pdf

Selection Strategies

- **Motor:** Think about your hand clicking a mouse or reaching out to grab the target letter
- **Speech:** Scream the letter in your mind or think YES! or BAM! for the target letter
- **Visual:** Imagine a net "catching" the target letter, or Mario running along and jumping up to hit the target letter
- **Symbol:** Visualize a happy face for the target letter
- **Sensory:** Think about cold and then about warmth for the target letter
- **Auditory:** Think about a certain sound or song for the target letter

CALIBRATION RESULTS (N = 26)

Selection Strategies Reported (N = 26)

People with LIS/FLIS

Sensory:
- Imagining pinching self for target letter

Speech:
- "BAM" for target (multiple)
- Shout target letter in mind (multiple)
- "K" for target; "hmmm" for non-target
- "There she is!"
- "Yes!"
- "There!"
- "Chop!"

Visual:
- "Think of seeing boobs when I see the target letter"

No strategy

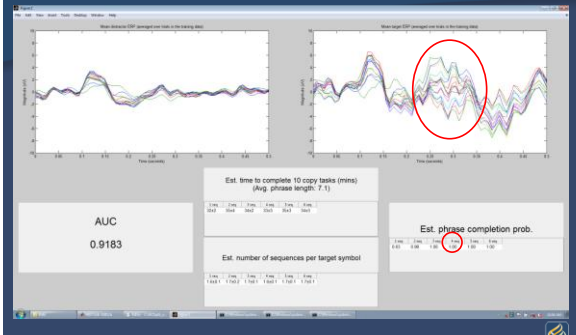
Controls

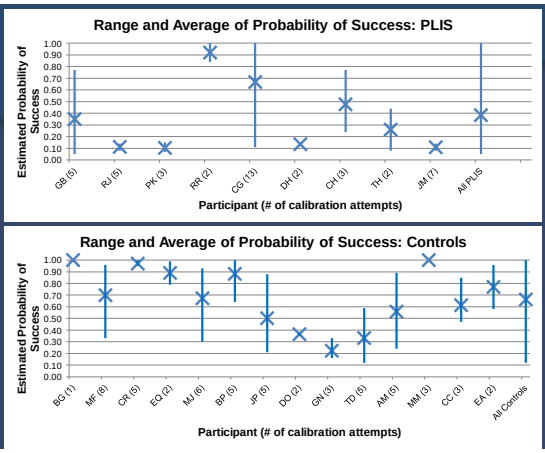
Motor:
- Swinging a golf club
- Sword slashing
- Punching the letter

Speech:
- "BAM" for target; (multiple)
- Shout target letter in mind (multiple)
- "no, no, no, YES!"
- "Whoo!" for target letter
- "Yeah!"

Visual:
- "Think of letter exploding"
- Imagine cutting letter in half
- Imagine a line slashing letter

Calibration Results





Mastery: LM assisted & structured copy task

Goals of the Mastery Task

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

Mastery 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 phrases at each level so participant can re-attempt levels if necessary

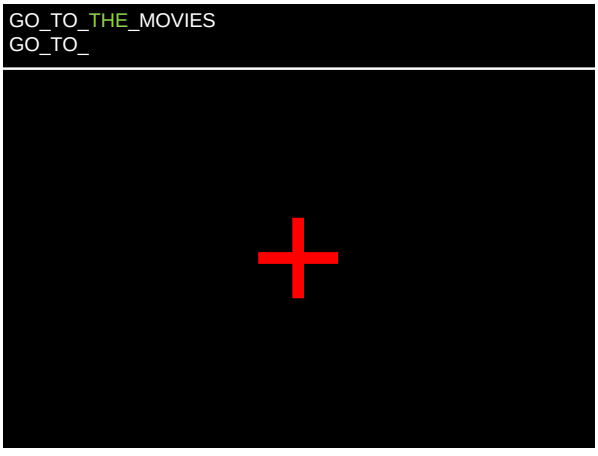
Mastery Task: Stimuli

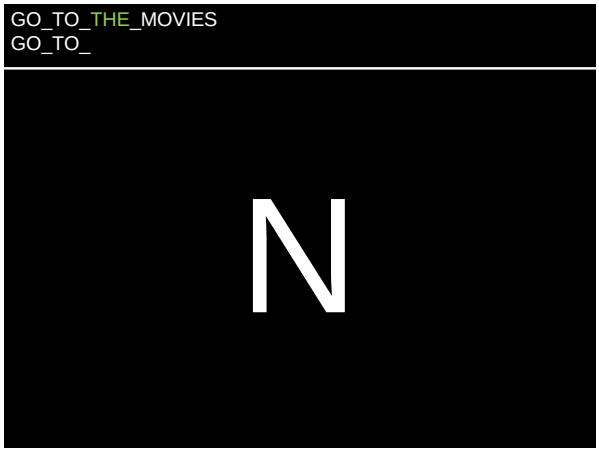
- Chosen by LM team from MacKenzie & Soukoreff (2003)'s set of 500 balanced phrases of text
- Phrases 3-6 words long
- Target words 3-4 letters long
- Target word always appears second or later in phrase so preceding word(s) provide information to language model

MacKenzie, I. S., & Soukoreff, R. W. (2003). Phrase sets for evaluating text entry techniques. *Extended Abstracts of the ACM Conference on Human Factors in Computing Systems - CHI 2003*, pp. 754-755. New York: ACM.

Mastery Task: Sample Phrases

- Level 1 (maximal support from LM)
  - I DO _NOT_ AGREE
  - GO TO _THE_ MOVIES
  - MUSIC _AND_ LAUGHTER
- Level 5 (minimal support from LM)
  - A CAN OF _FLEA_ POWDER
  - SHE NEVER _AIMS_ OFF THE MARK
  - SOMETHING THAT _BUYS_ US TIME

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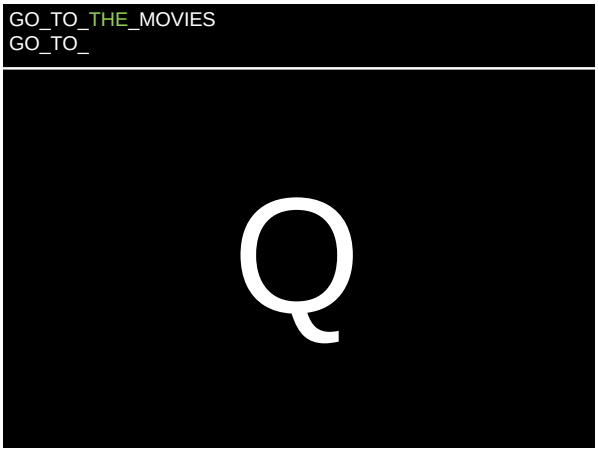
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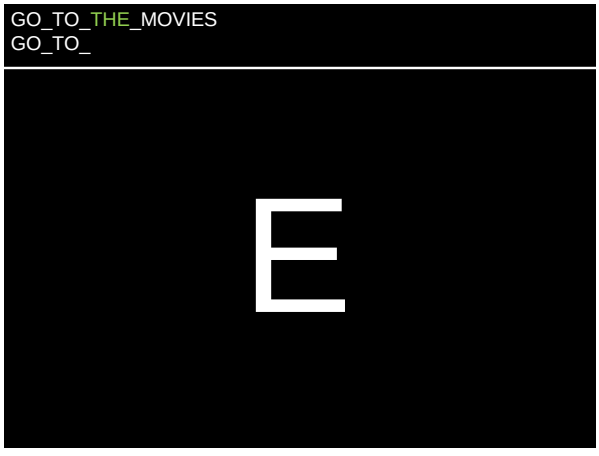
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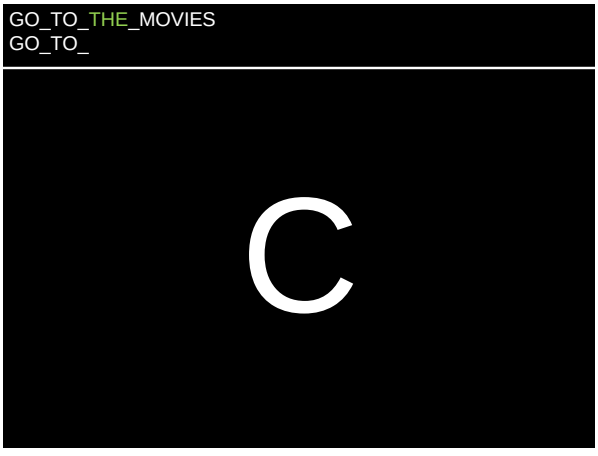
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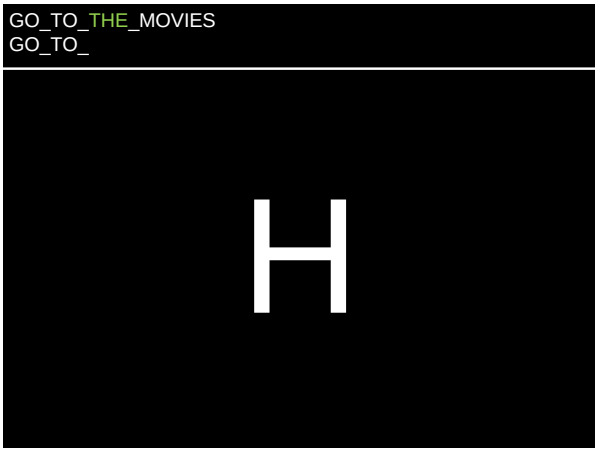
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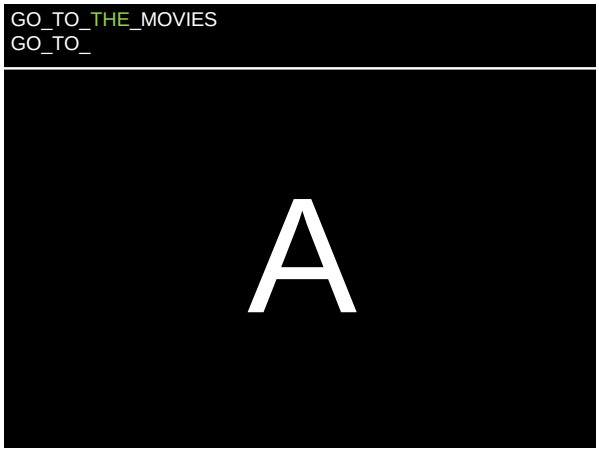
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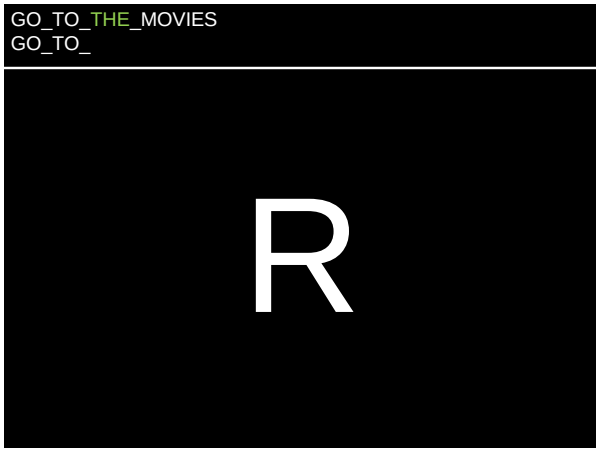
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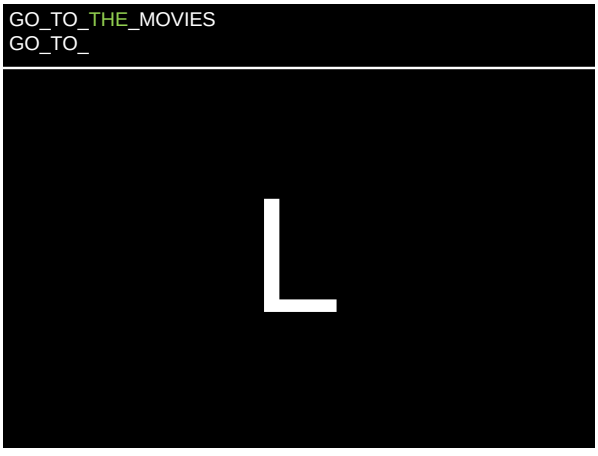
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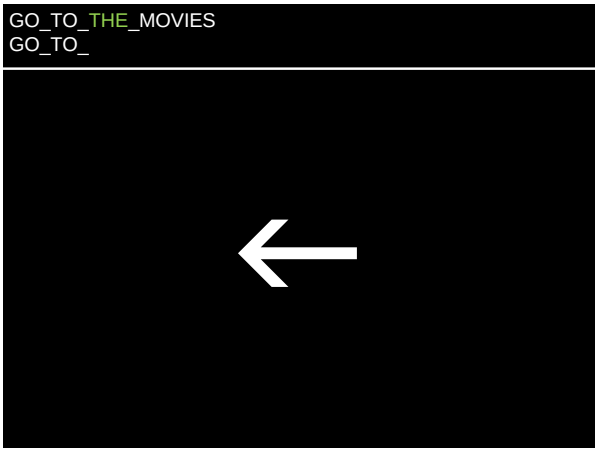
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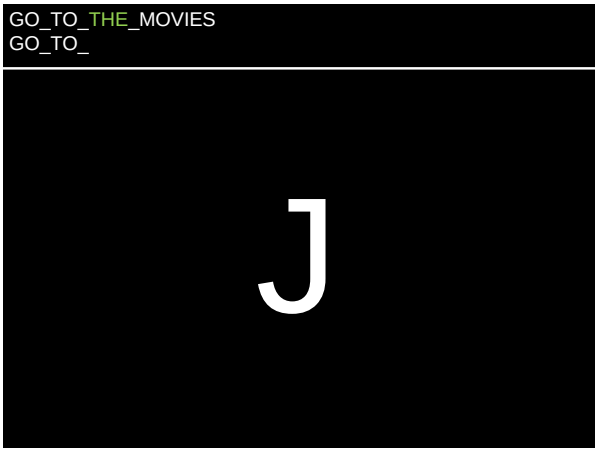
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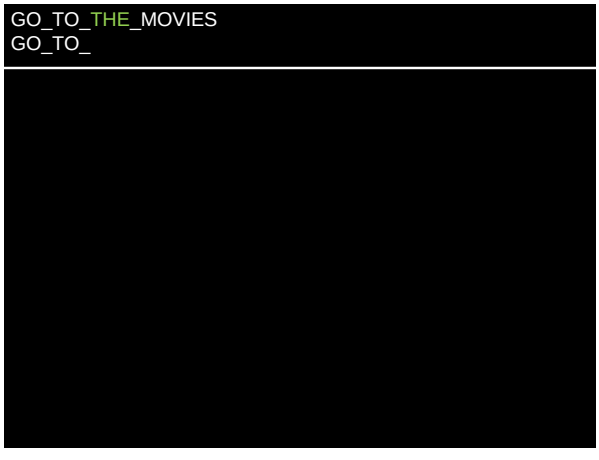
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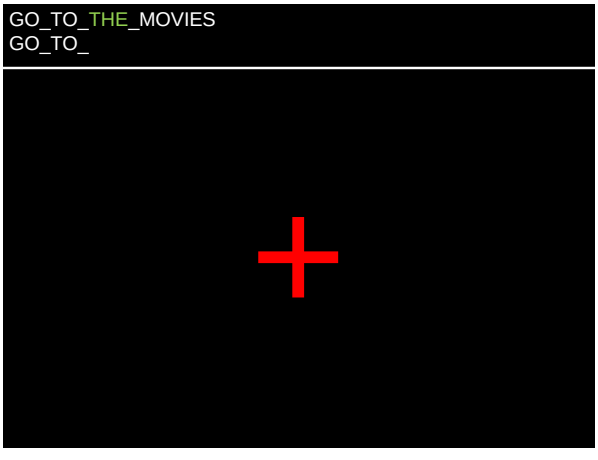
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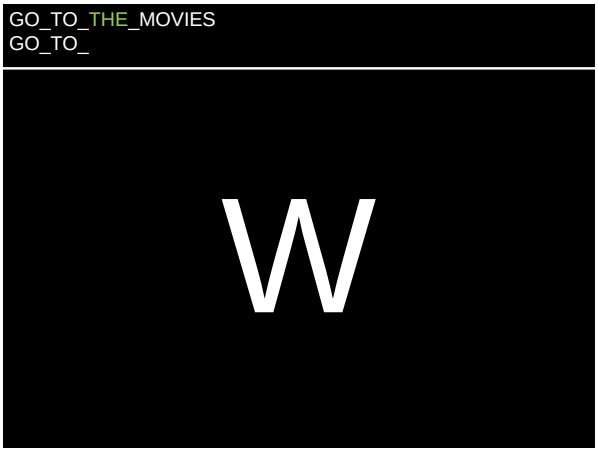
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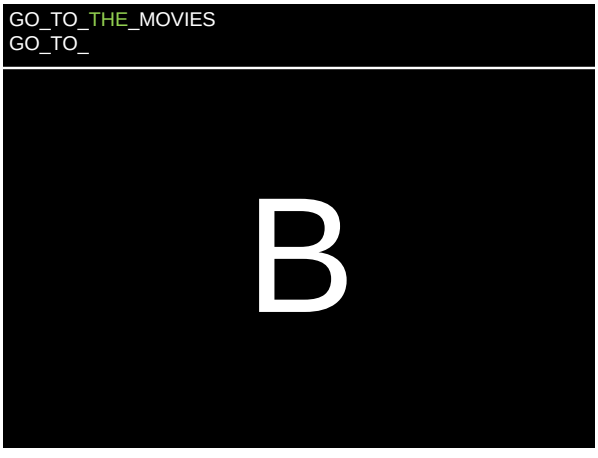
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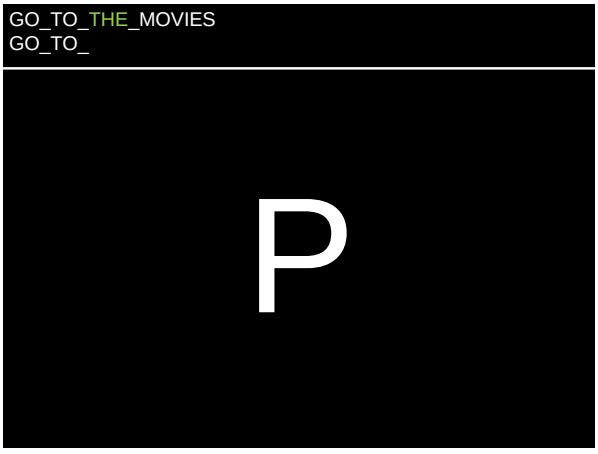
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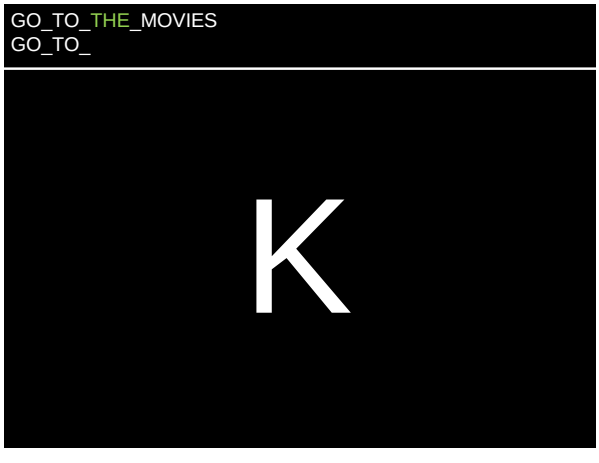
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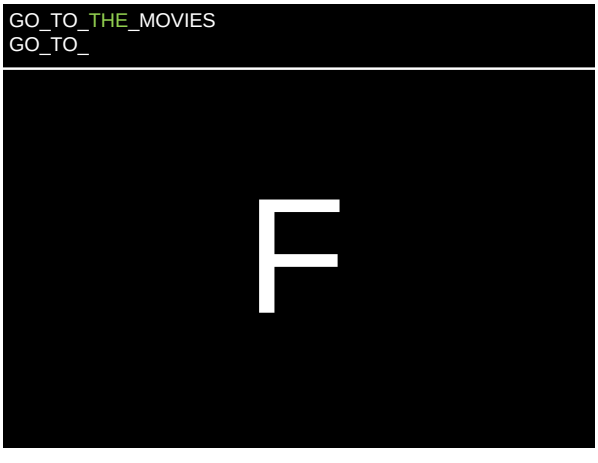
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Mastery Task: Stopping Criteria

- 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

Mastery Task Results (N = 17)

Mastery Task Level	N (PLIS/FLIS)	Avg. Prob of Success (PLIS)	N (Controls)	Avg. Prob of Success (Controls)
1	6	.25	11	.73
2	4	.53	10	.74
3	2	.89	7	.86
4	1	1.00	6	.92
5	1	1.00	6	.92

- N = number of participants who successfully completed a given level (out of 6 for PLIS and 11 for controls)
- Avg. Probability of Success determined by calibration results

User Feedback: Workload

Question	PLIS Avg Response	PLIS Range	Control Avg Response	Control Range
How much **physical effort** or activity was required to operate the system?	2.4	1-7	1.3	1-2
How much **mental effort** or activity was required to operate the system?	5.2	4-7	5.7	4-7
How much **time pressure** did you feel under?	2.5	1-6	4.0	1-6
What level of **frustration** did you experience?	3.5	1-7	2.5	1-5
Overall, how hard did you have to **work** during the task?	3.4	2-5	4.5	2-6

Response	Meaning
7	Extremely high
6	Considerably high
5	Somewhat high
4	Neither high nor low
3	Somewhat low
2	Considerably low
1	Extremely low

* User feedback questions selected or adapted from: Bates, R. (2005) *Enhancing the Performance of Eye and Head Mice: A Validated Assessment Methodology and Investigation into the Performance of Eye and Head Based Assistive Technology Pointing Devices* (doctoral dissertation, De Montfort University, 2005). Retrieved from http://www.cse.dmu.ac.uk/~rbates/Richard%20Thesis.pdf.

User Feedback: Comfort

Question	Participant Avg Response	Participant Range	Control Avg Response	Control Range
After using the system, do you have **headache** pain of any kind?	1.2	1-3	1.0	1-1
After using the system, do your **eyes** feel tired, strained or painful?	2.0	1-5	2.5	1-5
After using the system, do your **facial muscles** feel tired, strained or painful?	1.4	1-4	2.0	1-3
After using the system, does your **neck** feel tired, stiff or painful?	2.2	1-5	2.3	1-6
Overall, did using the system make you comfortable or uncomfortable?	3.2	2-5	3.2	1-5

Response	Meaning
7	Extremely painful
6	Really painful
5	Considerably painful
4	Moderately painful
3	A little painful
2	Scarcely painful
1	Not at all painful

Response	Meaning
7	Extremely uncomfortable
6	Considerably uncomfortable
5	Somewhat uncomfortable
4	Neither comfortable nor uncomfortable
3	Somewhat comfortable
2	Considerably comfortable
1	Extremely comfortable

User Feedback: Ease of Use and Overall Satisfaction

Question	Participant Avg Response	Participant Range	Control Avg Response	Control Range
Did you find that **letter selection** was accurate or inaccurate?	3.1	1-6	2.2	1-5
Did you find that the **speed of letter selection** was fast or slow?	3.6	1-5	4.0	2-5
How satisfied are you with the system overall?	2.6	1-5	2.7	1-4

Response	Meaning
7	Extremely inaccurate/slow
6	Considerably inaccurate/slow
5	Somewhat inaccurate/slow
4	Neither/nor
3	Somewhat accurate/fast
2	Considerably accurate/fast
1	Extremely accurate/fast

Response	Meaning
7	Extremely unsatisfied
6	Considerably unsatisfied
5	Somewhat unsatisfied
4	Neither satisfied nor unsatisfied
3	Somewhat satisfied
2	Considerably satisfied
1	Extremely satisfied

Participant Profiles

Participant Profile: CG

- 65 year old woman
- Diagnosed with ALS in 2006, on vent since 2011
- Functional LIS (reliable eye movement + some reliable body movement)
- Scored 90% or above on all screening tasks
- Communicates via mouthing words, yes/no signals, SGD with foot-controlled trackball, or tracing letters with toe
- Seated in power wheelchair with comfortable, stable positioning
- Cap secured with chin strap (outside cervical collar)

Participant Profile: CG

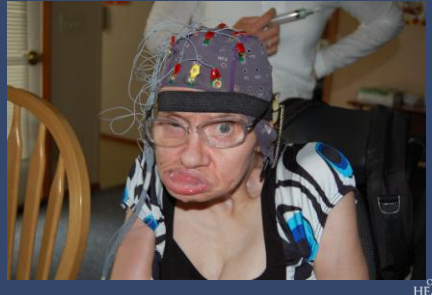
Participant Profile: RJ

- 40 year old man
- Diagnosed with ALS in 2007, on vent since 2009
- Incomplete LIS (reliable eye movement)
- Scored 100% on all screening tasks
- Communicates via yes/no signals, eye-controlled SGD, or partner-assisted scanning
- Seated in power wheelchair with comfortable, stable positioning
- Cap secured with typical cap straps connected to chest strap

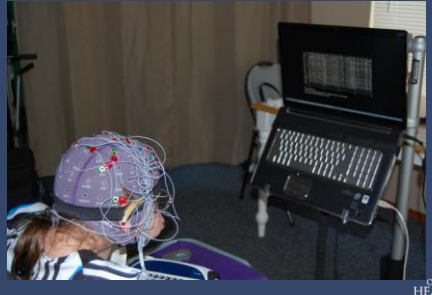
Participant Profile: PK

- 55 year old woman with spastic-athetoid CP
- Functional LIS (reliable eye movement + some body movement)
- Scored 100% on all screening tasks
- Communicates via keyboard-based SGD with stylus, yes/no signals, or partner-assisted scanning
- Frequent, uncontrolled movements when using RSVP Keyboard™
- Seated in manual wheelchair or lying in bed, all joints contracted
- Cap secured with sports headband over ears

Participant Profile: PK



Participant Profile: PK

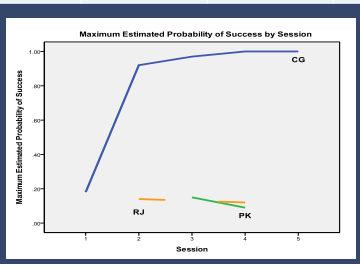


Participant Profile: PK (cap secured with headband; support for head, upper back to reduce muscular tension)

Participant Profile: PK

Participant Profiles: Comparison

PLIS	# Calibration Attempts	Max Est. Probability of Success	Mastery Levels Completed	Overall Satisfaction with RSVP™ at last visit
CG	13	1.00	5	1
RJ	7	.14	2	5
PK	5	.15	1	3



Discussion

"It was so awesome to really be able to direct my thoughts and spell a word." CG

Challenges

Participant issues

- Bald head
- Physical Positioning
- Athetosis
- Level of alertness/arousal
- Decreased eye control
- Recent hospitalization/illness
- Medications
- Emotional stressors
- Fatigue/decreased concentration

Equipment issues

- Use of non-invasive wet electrodes
- SGD near computer
- Interference from equipment to manage complex medical conditions
- Lengthy set up time

Challenges

Service Delivery

- Training
- Ease of use
- Cost
- Portability
- Reliability
- Caregiver responsibility
- Technology support needs

Next Steps

- Customization for individual users
- Vigilance and attention measures
- Inclusion of personalized language models
- Stored calibration data over time
- Artifact reduction algorithms
- Patient-centered outcomes framework

Dear BCI Team,

I am so sorry to tell you, H passed away on Tuesday at noon.

I can't tell you how much participating in this trial meant to him. It was probably more meaningful and life-preserving for him than his one ALS related drug said to extend his life maybe by 3 months. The BCI study gave him hope that there was a better world for locked-in patients to be in in the future. You guys are making the world a better place, you truly are.

My best,
Amie

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

This research was supported by NIH Grant #1R01DC009834-01.
Melanie Fried-Oken, PhD, P.I.
OHSU IRB # 4863