The RSVP Keyboard™ within an AAC framework

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Topics to touch on

1. The RSVP Keyboard™ BCI
2. Clinical screening for BCI
3. Learning to use a BCI for spelling
   – Mastery task
   – Attention training
4. Patient centered outcomes
5. The role of the clinical researcher and communication specialist
Need for AAC

• Another option within a person’s augmentative communication system

• MUST consider
  – Language system
  – Access method
Augmentative Communication Approaches

**Unaided Approaches**

- Speech
- Vocalization
- Gestures
- Eye gaze
- Body language
- Sign language

**Aided Approaches**

- Paper and pencil
- Communication books
- Communication boards and cards
- Speaking computers and mobile technology
- Talking typewriters
- Speech generating devices
The AAC System for individuals with SSPI

- Spelling device with BCI
- SGD with eye tracking
- Eye gaze
- Eye blinks
- Vocalization
BCI for spelling: different paradigms

• Row-column presentation with oddball paradigm

Berlin BCI: Hex-o-spell with oddball paradigm
Translational R01 from NIDCD

Signal Processing Engineering

Neurophysiology

Computer Science
(language modeling)

Clinical team

Northeastern U group:
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Murat Sina

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Brian Roark, PhD
Andrew Fowler
Steven Bedrick, PhD
Kyle Gorman, PhD

Melanie Fried-Oken, PhD
Barry Oken, MD
Aimee Mooney, MS CCC/SP
Betts Peters, MS CCC/SP
GB, participant with LIS
JS, participant with ALS
RSVP Keyboard:
Spelling stimuli for a P300 signal

• RSVP:
  – Rapid
  – Serial
  – Visual
  – Presentation of letters

• 400ms per letter
E
Unique aspects of OHSU BCI research

1. RSVP: stimulus presentation
2. Language modeling & EEG fusion
3. End users with SSPI (not only LIS)
4. Participatory Action Research
5. Language mastery tasks
6. Clinical BCI perspective
   1. Screening
   2. Training
   3. User within the loop
LANGUAGE MODELING
Word completion from language corpora

Technology-assisted spelling after # letters (n-gram prediction)

1: Automatic completion  2: Self-select from a list
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
The RSVP Keyboard™
Training Mode

Gathering Data to Train Classifier
(about 15 minutes)

- Subject instructed to look for a specific letter
- 50 series containing 2 sequences that present 30 characters (26 letters and 4 symbols)

Machine Learning
(about 15 minutes)

Learning Algorithm + EEG

Creation of the EEG/P3 Classifier

Writing Mode

Copy Task or Sentence Formulation

Subject presented with sequences of possible letters and attempts to write whatever they wish.

Hybrid Classifier

EEG/P3 Classifier

Language Model

Prediction and typing of intended letter
Measuring Speed and Accuracy

– Highest level completed on a copy-spelling task

– Selection accuracy score
  • Correct characters/minute
  • Total error rate
Measuring AUC for system accuracy

Calibration

• Every time the user puts on the cap, the system must determine what a ‘keystroke’ selection is.
• The computer learns the difference between a ‘target’ and a ‘non-target’.
  – A variable is created that predicts classifier accuracy by estimating the area under the curve (AUC) of true positive vs. false positive rate for target vs. non-target classification.
The Mastery Task for Copy-Spelling

- Word copying task to optimize user performance.
- Words embedded in phrases presented one at a time on laptop screen, above RSVP Keyboard™.
- Target words contain 4 letters and vary in LM predictability.
- Mastery task has 5 levels of difficulty, determined by degree of support from LM. At higher levels, target letters have lower probabilities, so LM provides less support and stronger EEG responses are required for correct selections.
- Each level includes 3 sets of 3 phrases.
- Words in different positions in sentences.
- Goal: successfully copy 2/3 words at each level.
- Mastery task continues until participant either completes all 5 levels or fails to pass a lower level.
Measuring spelling accuracy and speed

## Improvement measures

<table>
<thead>
<tr>
<th>Set 4</th>
<th>400/28</th>
<th>400/10</th>
<th>200/28</th>
<th>200/10</th>
<th>SSS during task: ___</th>
</tr>
</thead>
</table>

**Target:** WITH  
Output: SAR

**Target:** CITY  
Output: CITY

**Target:** HILL  
Output: HILL

**Time:** 4:10  
**Characters in output:** 11  
**Incorrect selections:** 6  
**Total selections:** 17

**Typing rate** = \( \frac{output \text{ characters}}{seconds} \times 60 = \frac{11}{250} \times 60 = 2.64 \text{ words per minute} \)

**Error rate** = \( \frac{incorrect}{total} = \frac{6}{17} = 35.3\% \)
Free spelling task

- Participant describes a line drawing
- Task ends when participant indicates phrase is complete or after 10 minutes
- Message is confirmed. Participant is asked, “Is that what you meant to type?”

Line drawings from Northwestern Anagram Test (Weintraub, Mesulam, Thompson)
CLINICAL ASSESSMENT OF FUNCTIONALLY LOCKED-IN SUBJECTS FOR RSVP BCI

Screening tool criteria*

1. Assess *requisite skills* for RSVP Keyboard
   1) Vision
   2) Hearing
   3) Language (Auditory & Reading Comprehension; Spelling)
   4) Sustained Visual Attention

2. Easy to administer

3. Less than 45 minutes total time

4. Completed at participant’s residence, at bedside or wheelchair

*Cannot use for *Complete LIS* participants
Sources for Assessment 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

Ergonomic information regarding computer monitor distance and angle taken from: The United States Department of Labor; Occupational Safety & Health Administration OSHA.
Confirm consistent and reliable YES/NO

- Binary code:
  - Eyes (up/down; left/right)
  - Eye blink
  - Thumb up/down
  - Smile/pucker
Vision

A. Questions to care providers
   1. Does patient wear glasses? Recent prescription?
   2. Do they see well enough to read?
   3. Any other visual problems (cataracts, macular degeneration, field cut)?

B. Diplopia: present?

C. Visual Perception: Computer-based task for central accuracy and peripheral accuracy
1. Questions about hearing function to participant (y/n response)
2. Questions to care provider about participant’s hearing function
3. Tuning fork test
A. Object Related Eye Movement Commands
Look at the (object) X4

B. Non-Object Related Eye Movement Commands
Look away from me
Look up/down (at ceiling/floor)

C. Visually based Situational Orientation (yes/no response)
Am I touching my ear/nose right now?  X4

D. Personal Orientation
Name, age, history

E. Yes/No to Complex Sentences
“Does a stone sink in water?”
Language
Reading Comprehension and Spelling

1. Object-picture matching X4
2. Picture-word matching from field of 4
3. Letter identification X4
4. Eye pointing to first letter of a word X4
   Bed  J M B A
5. Spelling words with eye gaze boards (want, ball, stop)
• E-TRAN board for yes/no responses
Cognition: Sustained Visual Attention

- RSVP Task created on EPRIME software
- Yes/no response to identify when a certain letter is present on the screen.
- Correct target and 3 foils/trial
- Must respond accurately in 9/10 trials
<table>
<thead>
<tr>
<th></th>
<th>LIS</th>
<th>CONTROLS</th>
<th>p value</th>
</tr>
</thead>
<tbody>
<tr>
<td>Age, mean (range)</td>
<td>45.8 (27-65)</td>
<td>45.2 (17-66)</td>
<td>0.965&lt;sup&gt;a&lt;/sup&gt;</td>
</tr>
<tr>
<td>Gender (M/F)</td>
<td>7/2</td>
<td>4/5</td>
<td>0.147&lt;sup&gt;b&lt;/sup&gt;</td>
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<tr>
<td>Ethnicity (%Caucasian)</td>
<td>77.8</td>
<td>100</td>
<td>0.134&lt;sup&gt;b&lt;/sup&gt;</td>
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<tr>
<td>Years of education (range)</td>
<td>14.6 (12-23)</td>
<td>18.2 (11-22)</td>
<td>0.067&lt;sup&gt;a&lt;/sup&gt;</td>
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<tr>
<td>First language English (n)</td>
<td>8</td>
<td>9</td>
<td>0.303&lt;sup&gt;b&lt;/sup&gt;</td>
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<tr>
<td>Level of familiarity with</td>
<td>4/5</td>
<td>2/7</td>
<td>0.317&lt;sup&gt;b&lt;/sup&gt;</td>
</tr>
<tr>
<td>computer(some/expert)</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Type of LIS (n)</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Incomplete</td>
<td>6</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Classical</td>
<td>2</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Total</td>
<td>1</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Years since LIS onset</td>
<td>14.8 (1-55)&lt;sup&gt;c&lt;/sup&gt;</td>
<td></td>
<td></td>
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</tbody>
</table>

<sup>a</sup> Mann-Whitney test.  
<sup>b</sup> Chi-square test.  
<sup>c</sup> Years since LIS onset was calculated for all participants since diagnosis, either classical or incomplete LIS. The cause of LIS was ALS (4), brainstem stroke (2), cerebral palsy (1), brainstem AVM (1), and Duchenne muscular dystrophy (1)
BCI Screening

- Clinical screening for use of BCI as an AAC access method is feasible.
- An adapted screening tool has been developed and should be administered to gain important clinical information about potential users with SSPI.
Learning to Use a BCI
Preparing for independent BCI use at home: How can we help people learn to use BCI?
Learner in the Loop:
What skills does the learner bring to the BCI task?
What affects user performance?

Lack of reliable performance by BCI users is a common problem.

- Cognitive status
- Medications
- Pain
- Motivation
- Language and literacy

Polin and Kok, 1995
PROCESS-SPECIFIC ATTENTION TRAINING
Process-Specific Attention Training

- We adapted an evidence-based direct attention training program developed for people with TBI.

- Attentional abilities can be improved by providing structured opportunities for exercising particular domains of attention.

Sohlberg & Mateer, 1987; Sohlberg et al., 2000
Attention Training for the RSVP Keyboard™

- Independent home practice with a series of video simulations of RSVP Keyboard™ task
- 3 sessions each week
- Each 30-minute session includes 3 calibration simulations
- Videos contain random animal photo. Presented to assess wakefulness and vigilance. At the end of each simulation, the participant is asked whether s/he saw an animal.
Patient Centered Outcomes for BCI
John and Greg as expert consultants
BCI users in research

• Recent BCI studies have solicited feedback from people with disabilities using:
  – Questionnaires and rating scales
    • Zickler et al., 2011; Lorenz, Pascual, Blankertz, & Vidaurre, 2014
  – Anecdotal reports
    • Sellers, Vaughan, & Wolpaw, 2010; Townsend et al., 2010
  – Surveys
    • Huggins, Wren, & Gruis, 2011
  – Focus groups
    • Blain-Moraes, Schaff, Gruis, Huggins, & Wren, 2012
Patient Centered Outcomes study of BCI

- **Who:** Participants with SSPI recruited from the existing participant pool of the RSVP Keyboard™ BCI study, and their chosen paid or unpaid (family) caregivers.

- **What:** 1-2 interview sessions, each lasting 1-2 hours. Interviews consisted of core questions and follow-up probes.

- **Where:** Participants' homes.
PCOR: 8 participants with SSPI

• All had experience using the RSVP Keyboard™ BCI during research visits. Oken et al., 2014; Fried-Oken et al., 2012
• Gender: 6 men, 2 women; Ages: 28-66 years
• Diagnoses:
  – 4 ALS
  – 1 cerebral palsy
  – 1 spinocerebellar ataxia
  – 1 Duchenne MD
  – 1 brainstem stroke
• Primary communication methods:
  – 4 SGD with alternative access
  – 2 speech
  – 1 partner-assisted scanning
  – 1 letter board
7 caregivers

- 4 unpaid (family) caregivers:
- 3 parents
- 1 spouse
- 4 women, 3 men
- 3 paid caregivers;
- Length of relationship with PSSPI: 2-13 yrs.
- Ages: under 35 to over 65 years
14 interviews

- (2 parents interviewed together)
- most required one 1-2 hour session;
- Two participants with SSPI required one or two additional sessions due to fatigue or slow communication speed
- four people with SSPI prepared typed responses
- two people with SSPI had a family member and/or paid caregiver present to assist with communication
# Preliminary outcomes framework

<table>
<thead>
<tr>
<th>Constructs</th>
<th>Domains</th>
<th>Component themes</th>
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</thead>
<tbody>
<tr>
<td>Quality of Life</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Social participation</td>
<td>Recreation, Spiritual, Community, Entertainment</td>
<td></td>
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<tr>
<td>Communication</td>
<td>Expressive, Self-expression, Independence, Social interaction, Interaction with healthcare providers</td>
<td></td>
</tr>
<tr>
<td>Roles</td>
<td>Professional/volunteer, Civic, Family/parenting, Caregiving, Home</td>
<td></td>
</tr>
<tr>
<td>Relationships</td>
<td>Family, Friends, Caregivers, Intimate</td>
<td></td>
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<tr>
<td>Emotions &amp; attitudes</td>
<td>Self-worth, Motivation, Attitudes (self), Attitudes (others), Affect symptoms</td>
<td></td>
</tr>
<tr>
<td>Environment</td>
<td>Safety, Privacy, Finances, Living situation, Caregivers &amp; support</td>
<td></td>
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<tr>
<td>Physical &amp; health</td>
<td>Pain, Variability, Personal care, Function, Transition</td>
<td></td>
</tr>
<tr>
<td>Assistive Technology</td>
<td>Reliability, Communication speed, Applications, Ease of use</td>
<td></td>
</tr>
<tr>
<td>Function</td>
<td>Portability, Appearance, Software (user interface, output, etc.), Invasive vs. noninvasive, Comfort, Hardware &amp; setup requirements</td>
<td></td>
</tr>
<tr>
<td>Design</td>
<td>Technical support, Training (user), Training (caregiver)</td>
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</tbody>
</table>
QoL: Social Participation

• “When other people think of coming over to visit him ...sometimes people feel clumsy and unable to know what to say ... You have to use a certain way of talking with him [PAS]. That process intimidates some people from visiting with him.” (paid caregiver)

• AAC “is unable to keep pace with the flow of ordinary conversation.”

• “When I'm being his translator, I can't connect with people socially the way that I would like to.” (spouse)
QoL: Communication

- "Obviously, [my SGD] helps a lot with my communication. But it takes time."
- "You need a certain amount of spontaneity to be able to express yourself. Spontaneity is limited by slow communication speeds."
- "Current system can't change pitch, do impressions, or show emotion."
- "There are no words to describe how important it is for me to communicate independently! Personally, I can't imagine life without a communication device. It is as important for me as breathing and nutrition."
AT: Function

• "A BCI communication system should be able to help me get online so that I can access the internet independently ... and do my e-mails on my own."

• "[BCI should be] dependable, [so I] could use [it] with confidence."

• "My concern about him using [BCI] as his primary means of communication is that it might be too slow for him."
  (spouse)

• "I would like it if [BCI] could read my thoughts so that I could keep up with group conversations."

• "Any system needs [the] ability to have replies stored for repetitive situations. Also daily needs."
AT: Design

• "Portability [is important]. I like to go out often."

• "I would think if he's wearing that weird cap ... that would be a bit of a thing to overcome for the grandkids. 'Why is Pop-pop wearing that weird hat?'" (spouse)

• "[BCI should] not require extensive hardware or multiple components. Do away with the 'hairnet' electrodes. Design electrodes which can plug into an outlet subcutaneously imbedded in some easily accessible spot on the body."

• "The perfect situation would probably have some kind of implant into your head."
AT: Support

• "I think there almost needs to be a class for caregivers to emphasize the importance of encouraging people like [my son] to become more independent [and show how to] set up their equipment for them." (parent)

• "People having the patience and the 'know-how' to set up the BCI communication system might be hard to come by."

• "I think therapists and other healthcare professionals ... should be aware of BCI. I also believe such individuals should be trained in the use of BCI for the benefit of those patients or clients and their caregivers."

• "Any technology breakdowns would be worrisome since I can't make any repairs by myself."
“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
“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.”
“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 also be nice to be able to control simple things in my environment 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.”
References


RSVP team references


The take home message

Regardless of your BCI system, R&D and implementation will not be effective or adopted without the participation of clinicians and persons who need to rely on this new AT, their families and care providers.
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