**RESEARCH QUESTIONS**

- Can people with locked-in syndrome (LIS) use the RSVP Keyboard™ brain-computer interface (BCI) to type words?
- Does increased support from a language model (LM) lead to greater success in spelling with the RSVP Keyboard™?

**RSVP KEYBOARD™**

- Non-invasive, P300-based BCI system designed as a typing & communication tool for people with locked-in syndrome
- Rapid serial visual presentation (RSVP) of stimuli [Orhan et al., 2012]
- Selects letters based on combination of EEG data and input from integrated LM using probabilistic Bayesian fusion [Orhan et al., 2011]
- Signal acquisition with:
  - 16-channel g.USBamp (g.tec, Graz, Austria)
  - Active electrodes in a cap at approximate 10-20 locations, reference at TP10, ground at FpZ

**STIMULI and TASK**

**RSVP PARADIGM:**
- 28 characters (English alphabet, < for backspace and _ for space).
- Displayed on 18" laptop screen about 75cm from participant.
- White, blue, or yellow characters on a black background with a visual angle of 3.8°.
- Stimuli presented sequentially at 2.5 Hz.
- Calibration includes 75 sequences of 10 characters, each preceded by a target.
- Participant identifies target letters in sequences.
- Classifier accuracy is estimated from area under the curve (AUC) of true positive vs. false positive rate for target vs. non-target classification.

**MASTERY TASK:**
- Word copying task designed to optimize user performance.
- Stimuli embedded in phrases presented one at a time on laptop screen, above RSVP Keyboard™.
- 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.
- Goal is to successfully copy 2/3 words in a set at each level.
- Stopping criteria: program moves to next target phrase when:
  - Target word is copied correctly.
  - Participant spends 10 minutes on one word, or
  - # of presented sequences exceeds 32.
- Mastery task continues until participant either completes all 5 levels or fails to pass a lower level.

**LANGUAGE MODEL**

- Determines letters most likely to be selected next, based on previous 5 letters in word/sentence
- Trained on large sample of New York Times text from English Gigaword corpus [Roark et al., 2012]
- Symbol with highest a posteriori probability is selected once probability exceeds a set threshold, or once a set maximum number or sequences have been displayed

**PARTICIPANTS**

- 6 adults with LIS (1 classical, 5 incomplete*).
- Diagnoses of ALS, brainstem stroke, arterial venous malformation, and CP.
- 9 adults without disabilities

*Participants with incomplete LIS are successful less than 25% of time with oral speech or writing due to severe speech and physical impairments

**RESULTS**

**Copy mastery task results**

<table>
<thead>
<tr>
<th>Mastery task level</th>
<th>People with LIS (n = 6)</th>
<th>Controls (n = 9)</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>Participants who completed level</td>
<td>AUC</td>
</tr>
<tr>
<td>1</td>
<td>6</td>
<td>.73 (.116), .56 -.93</td>
</tr>
<tr>
<td>2</td>
<td>4</td>
<td>.76 (.124), .56 -.93</td>
</tr>
<tr>
<td>3</td>
<td>2</td>
<td>.83 (.105), .71 -.93</td>
</tr>
<tr>
<td>4</td>
<td>1</td>
<td>.92 (.014), .91 -.93</td>
</tr>
<tr>
<td>5</td>
<td>1</td>
<td>.92 (.014), .91 -.93</td>
</tr>
</tbody>
</table>

Note: values are presented as mean, (SD), range.

Maximum AUC score, highest level completed, and # of sessions

<table>
<thead>
<tr>
<th></th>
<th>People with LIS</th>
<th>Controls</th>
<th>p</th>
</tr>
</thead>
<tbody>
<tr>
<td>Maximum AUC score</td>
<td>.71 (.113), .62 -.93</td>
<td>.83 (.068), .70 -.92</td>
<td>0.045*</td>
</tr>
<tr>
<td>Highest level completed</td>
<td>2.3 (1.51), 1.5</td>
<td>4.0 (1.58), 1.5</td>
<td>0.089*</td>
</tr>
<tr>
<td>Number of sessions</td>
<td>1.7 (0.82), 1.3</td>
<td>1.3 (0.50), 1.2</td>
<td>0.414*</td>
</tr>
</tbody>
</table>

Notes: values are presented as mean, (SD), range.

*Mann-Whitney test, Asymp. Sig. (2-tailed); *statistically significant.

**IMPLICATIONS**

- The integrated language model (LM) is a unique and valuable feature of the RSVP Keyboard™ BCI system, and allows participants with low AUC scores to successfully type words at advancing difficulty levels.
- The LM is particularly helpful for high probability words, as shown by participants’ better performance on the lower levels of the mastery task.
- Participants without disabilities performed slightly better than those with LIS, achieving higher AUC scores and completing higher levels of the mastery task.
- Small sample size cannot determine why people with LIS had more difficulty with the task. Poor EEG signals or low AUC scores may result from problems with sustained attention, spasticity, facial and respiratory muscle interference, uncontrolled movements, medications, or interference from nearby electronic equipment.

This work is supported by NIH/NIDCD #1R01DC009834-01 and by NSF IIS-0914808. Correspondence: friedm@ohsu.edu

RESNA 2013, Bellevue, WA