Learning to use a brain-computer interface: Attention training

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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 electricity 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.

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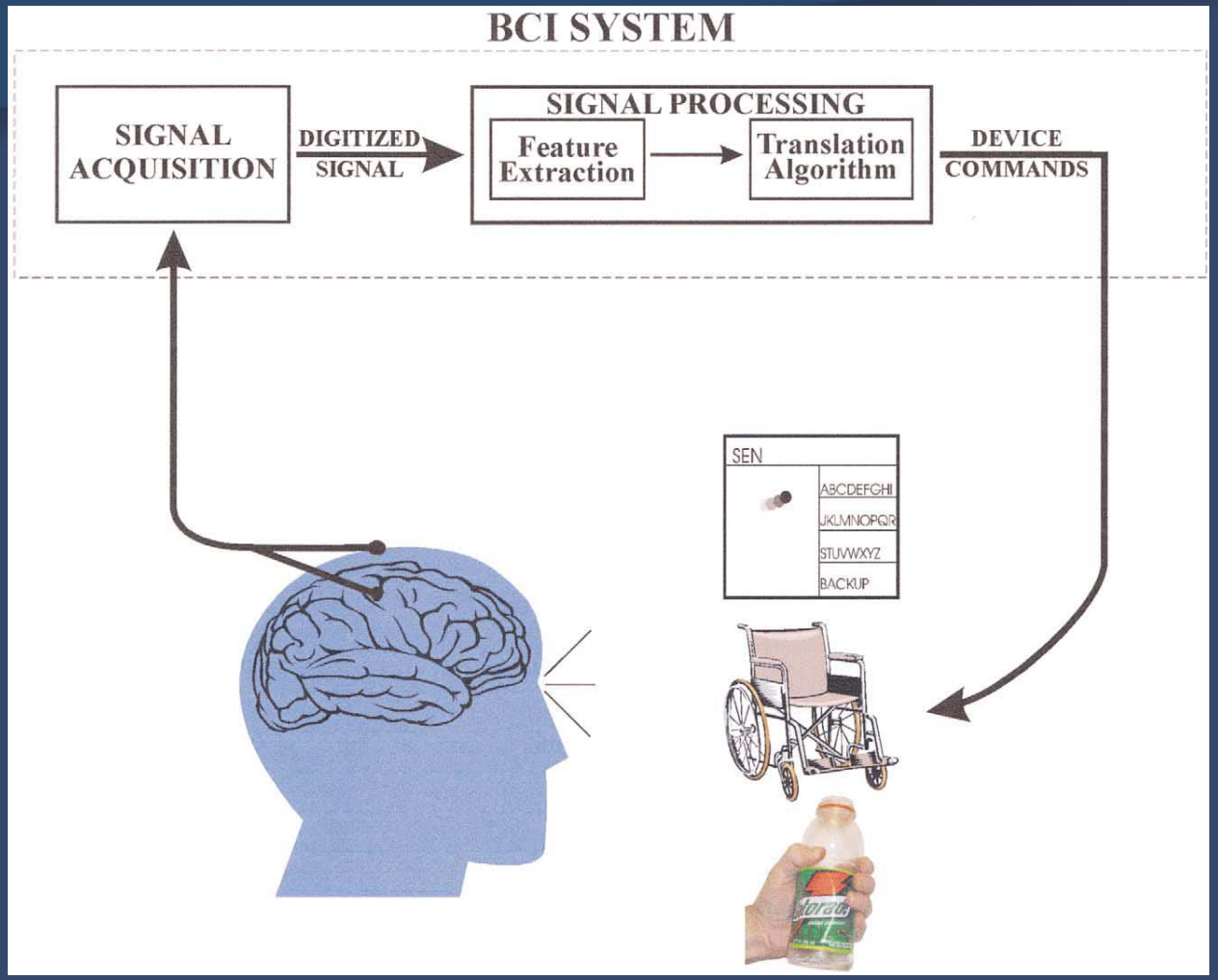

Wolpaw, et al (2002). Brain-computer interfaces for communication and control. *Clinical Neurophysiology, 113*. 767-791

BCIs vary

- Location of signal detection
  - Non-invasive
  - Invasive
- Signals detected
  - Sensory-motor rhythm (motor imagery)
  - P300 event related potentials (novel stimuli)
- Some Tasks
  - Communication (Typing)
  - Gaming
  - Painting
  - Robotic movement

http://www.newschannel5.com/story/20969876/unlocking-voices-of-the-locked-in

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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 eyes 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 that uses vertical eye movements or blinking

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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)

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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 px of survival.

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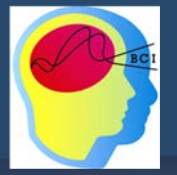
Common Diagnoses Leading to LIS



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

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Expanding LIS diagnoses by function: severe speech and physical impairment (SSPI)

- Cerebral palsy
- Muscular dystrophies
- Multiple sclerosis
- Parkinson's disease
- Parkinson's plus
  - Progressive Supranuclear Palsy (PSP)
  - Multiple System Atrophy (MSA)
- Tumors
- Progressive ataxias
  - Cerebellar ataxia

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.

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Need for AAC

- Another option within a person's augmentative communication system
- MUST consider
  - Language system
  - Access method

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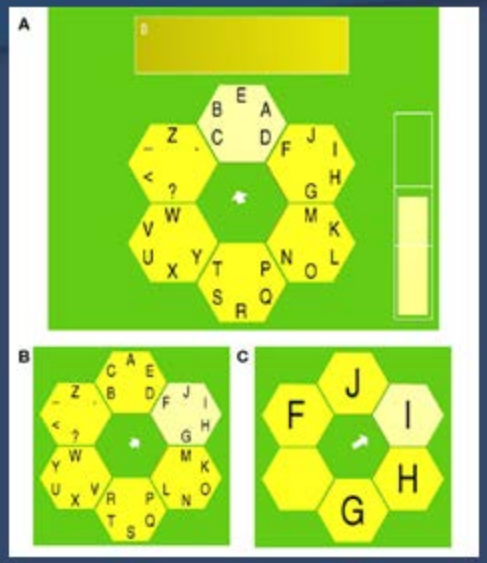
BCI for spelling: different paradigms

- Row-column presentation with oddball paradigm

Berlin BCI: Hex-o-spell with oddball paradigm



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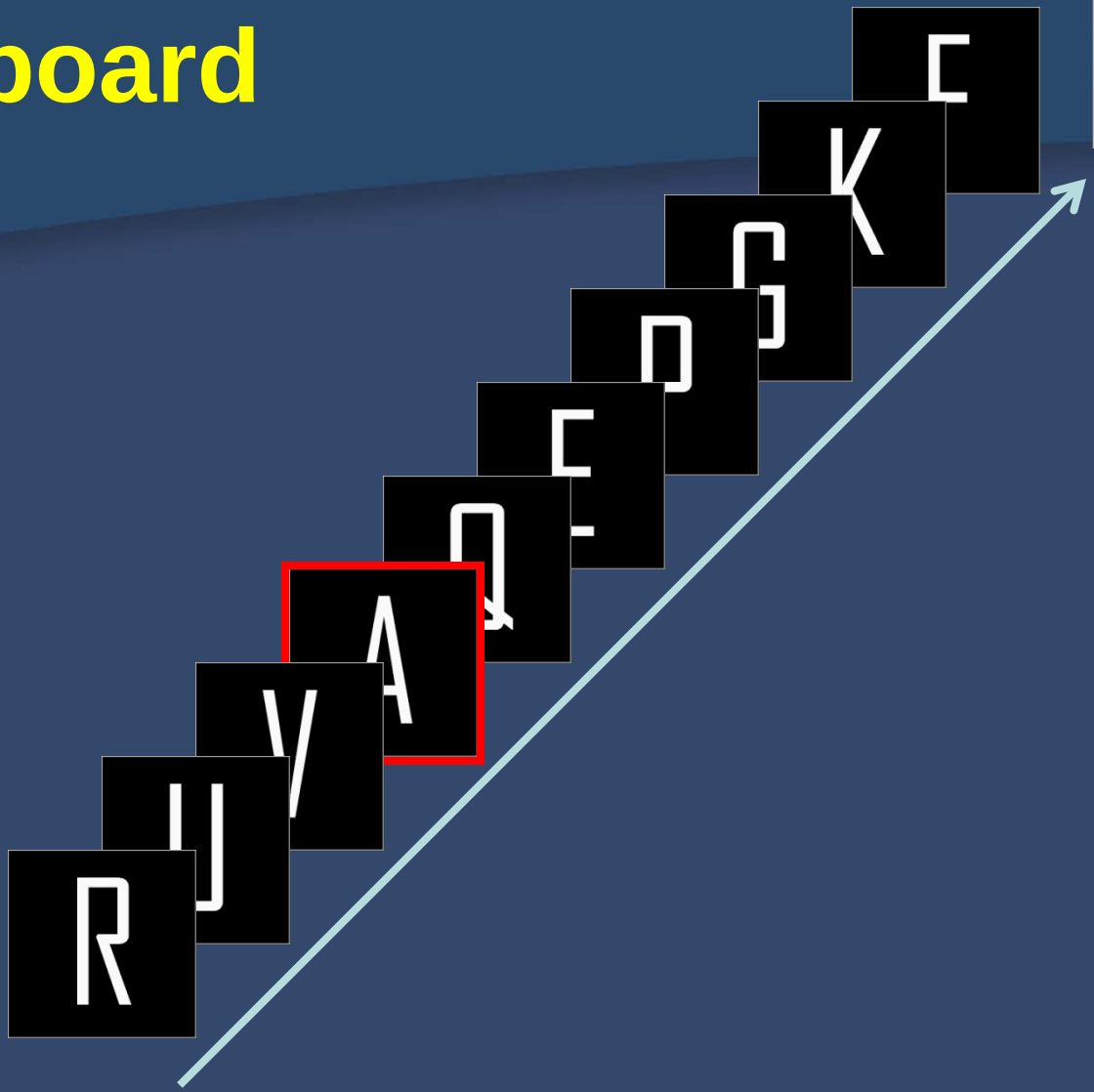
RSVP Keyboard



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- and Neural Repair, 28(4), 387-394. PMCID: PMC3989447.

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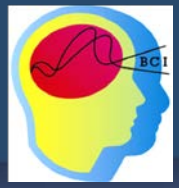
Translational R01 from NIDCD



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JS, participant with ALS

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Learner in the Loop:

What skills does the learner bring to the BCI task?

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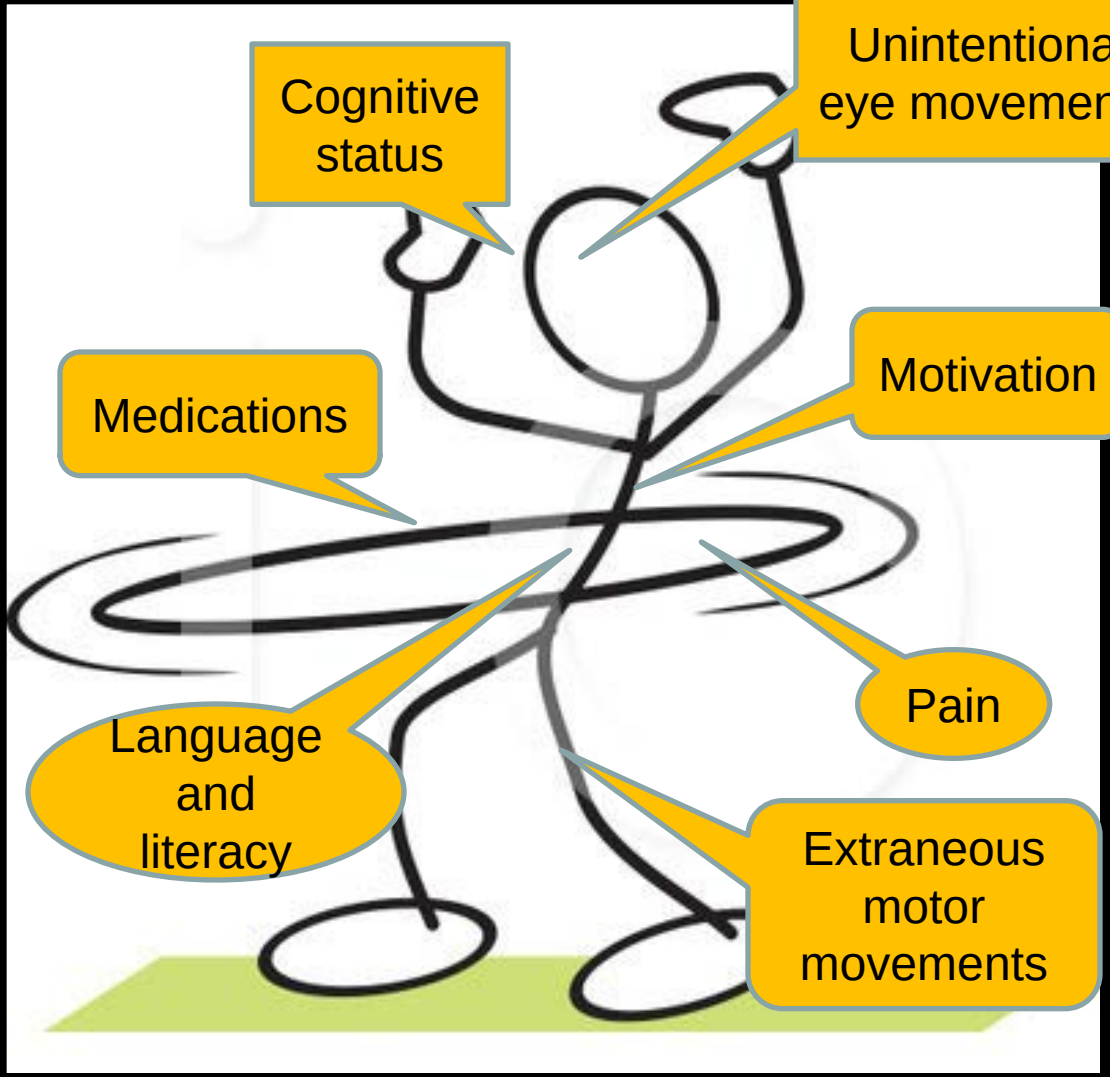
What cognitive skills are needed to use a BCI?

- Sustained attention (vigilance)
- Selective attention
- Divided attention
- Working memory
- Speed of information processing

What affects user performance?

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



Polin and Kok, 1995
Nijober et al 2013

Preparing for independent BCI use at home: How can we help people learn to use BCI?

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

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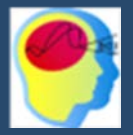
Attention Training for the RSVP Keyboard™



- 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.

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Pilot study: 2 participants

	KM	JS
Age	63	70
Gender	Male	Male
Diagnosis	ALS (bulbar onset)	ALS (limb onset)
Date of diagnosis	2007	2009
RSVP screening performance	100% on all tasks	100% on all tasks
Eye movement	Within normal limits	Within normal limits
Upper extremity movement	Severely impaired; able to click switch with fingertips on right hand	Impaired; able to control wheelchair joystick and computer trackball
Mobility	Power wheelchair with caregiver controls	Power wheelchair
Respiration	Tracheostomy & mechanical ventilation	Noninvasive ventilation (BiPAP with nasal pillow mask)
Speech	Anarthric	Within normal limits
Communication method(s)	Yes/no eye movement signals; SGD with eye tracking or switch scanning	Speech
Positioning for BCI use	Reclined in bed	Seated in power wheelchair

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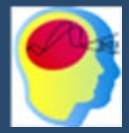
Participant Inclusion Criteria



- Dx of acquired neuromuscular or neurodevelopmental disorder
- 18 - 80 years of age
- Able to participate 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
- Pass the RSVP Keyboard™ screening tool

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Study design

- Small n study design: Multiple-baseline across participants
- Baseline performance established with 5+ weekly data-collection visits
- Length of baseline phase varies for each participant
- 6-week intervention phase begins after final baseline visit (home practice 3x/week)
- Weekly data-collection visits continue through intervention phase

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Data-collection visits

- Each visit includes:
  - PROMIS General Health questions
  - N-back task
  - RSVP Keyboard™ calibration
  - RSVP Keyboard™ Mastery task
  - User Feedback Questionnaire
- During intervention phase, researchers collect data on completion of home practice activities (from participant report and tracking software)

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General Health Questions

- Selected from PROMIS Global Health Short Form (PROMIS, 2014)
- Questions on:
  - Overall health
  - Physical health
  - Mental health
  - Emotional problems
  - Fatigue
  - Pain
- All answers on 5-point Likert scale, except pain
- Pain on standard 10-point scale

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N-back task

- Common working memory assessment task
- 20 series of 20 letters presented one at a time (RSVP format)
- In each series, the participant looks for an "*n*-back": a letter that matches the one presented *n* letters previously
  - 1-back: E H D A A V I W N P
  - 2-back: K R Q C I E L E P D
  - 3-back: P B M E B Y H I R L
- After each series, participant is asked, "Did you see an n-back?"

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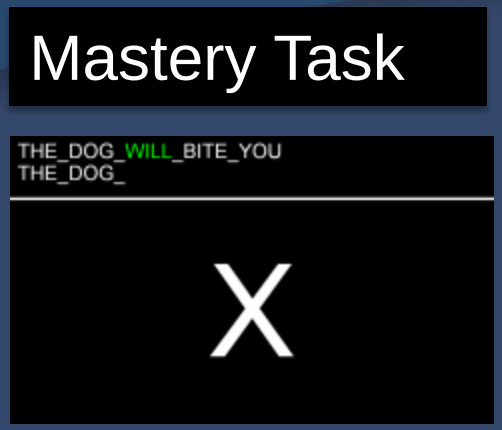
The Mastery Task for Copy-Spelling



- 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.

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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)

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User Feedback Questionnaire

- Adapted for RSVP Keyboard™ based on Bates' AT assessment questionnaires (2006)
- Questions on:
  - Workload (physical effort, mental effort, time pressure, frustration, overall effort)
  - Comfort (headache pain, eye strain, discomfort in facial muscles or neck, overall comfort)
  - Ease of use (accuracy and speed of letter selection)
  - Overall satisfaction
- All answers on 7-point Likert scale

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Variables

- N-back score
- Calibration AUC (area under the curve of true positive vs. false positive rate for target vs. non-target classification)
- Highest mastery task level completed
- Selection accuracy: $\frac{\#\ of\ correct\ selections}{total\ \#\ of\ selections}$
- Typing rate: $\frac{\#\ of\ correct\ selections}{minute}$
- Covariates:
  - Health, emotional state, pain, fatigue (PROMIS)
  - Workload, comfort, satisfaction (UFQ)

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Pilot study results: KM

- Completed 4 baseline sessions
- Demonstrated excellent performance on all tasks, including typing with RSVP Keyboard™
- Completed level 5 Mastery Task in weeks 1 & 2; moved on to picture description free spelling in subsequent 2 visits.
- Did not complete intervention phase – no need for attention training to improve performance

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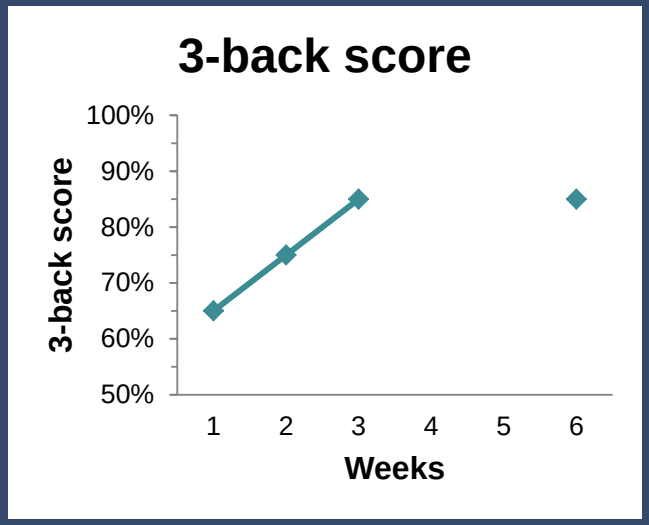
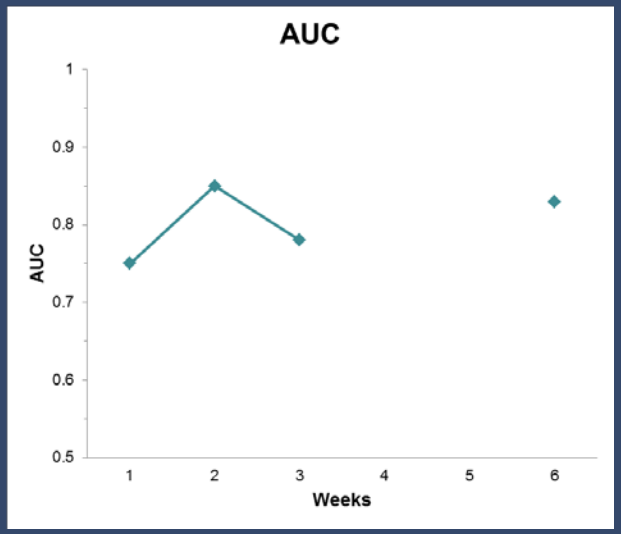
Pilot study results: KM N-back and AUC

Reached 85% accuracy on 3-back task (very difficult)

Mean: .80
Range: .75-.85
Scores > .75 are typically sufficient for accurate RSVP Keyboard™ typing





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KM teaches us that there are individuals who are excellent BCI users for whom attention training is not necessary.

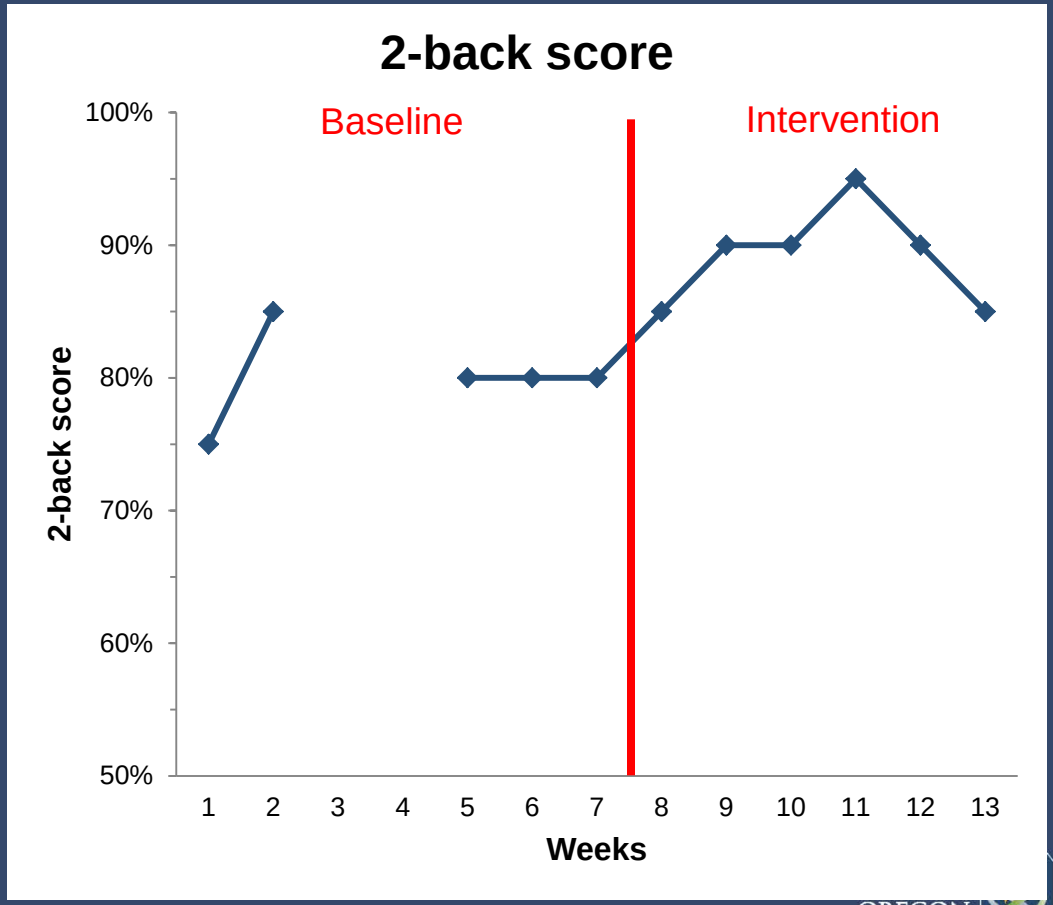
Pilot study results: JS

- Completed 5 baseline sessions

- Began intervention phase

Pilot study results: JS
Slight improvement in N-back

- Stable baseline ≈80% on 2-back task
- Improved to 85-95% in intervention phase



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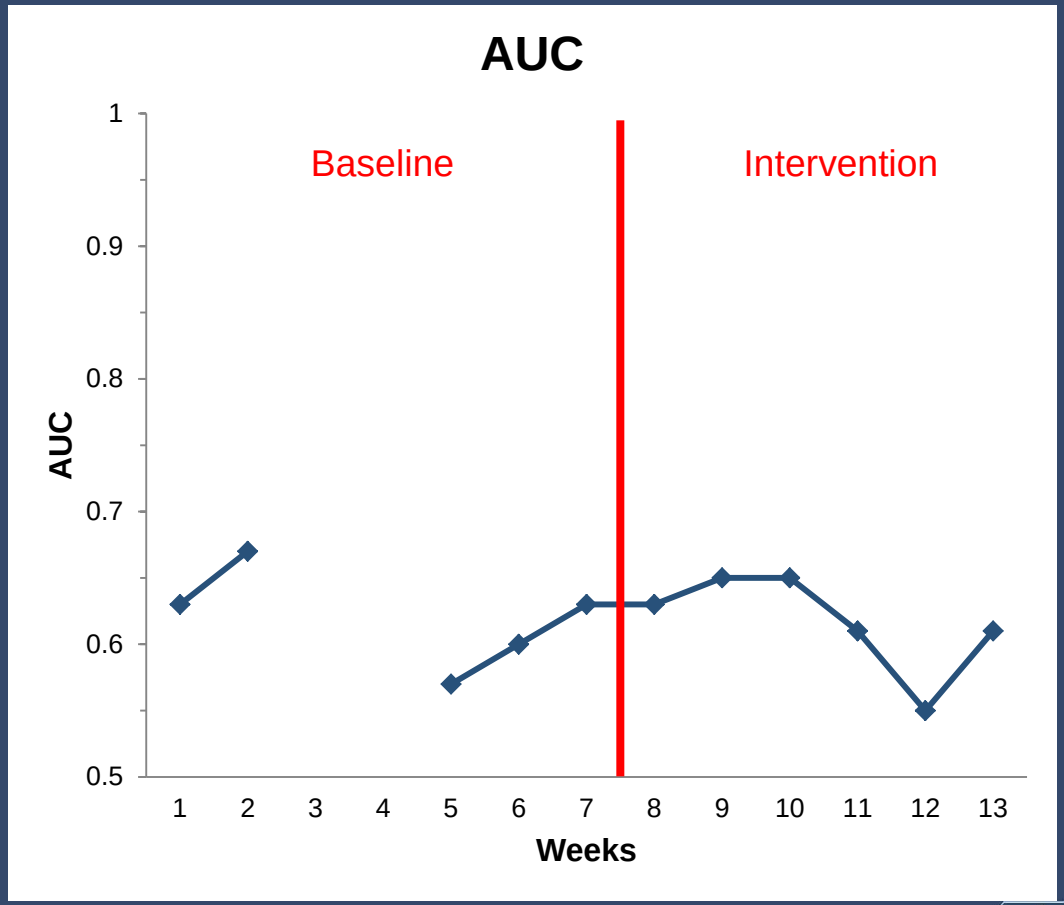
Pilot study results: JS
No improvement in AUC

- BL Mean: .62
- BL Range: .57-.67
- No improvement in intervention phase
- Scores < .70 are typically not sufficient for accurate RSVP Keyboard™ typing



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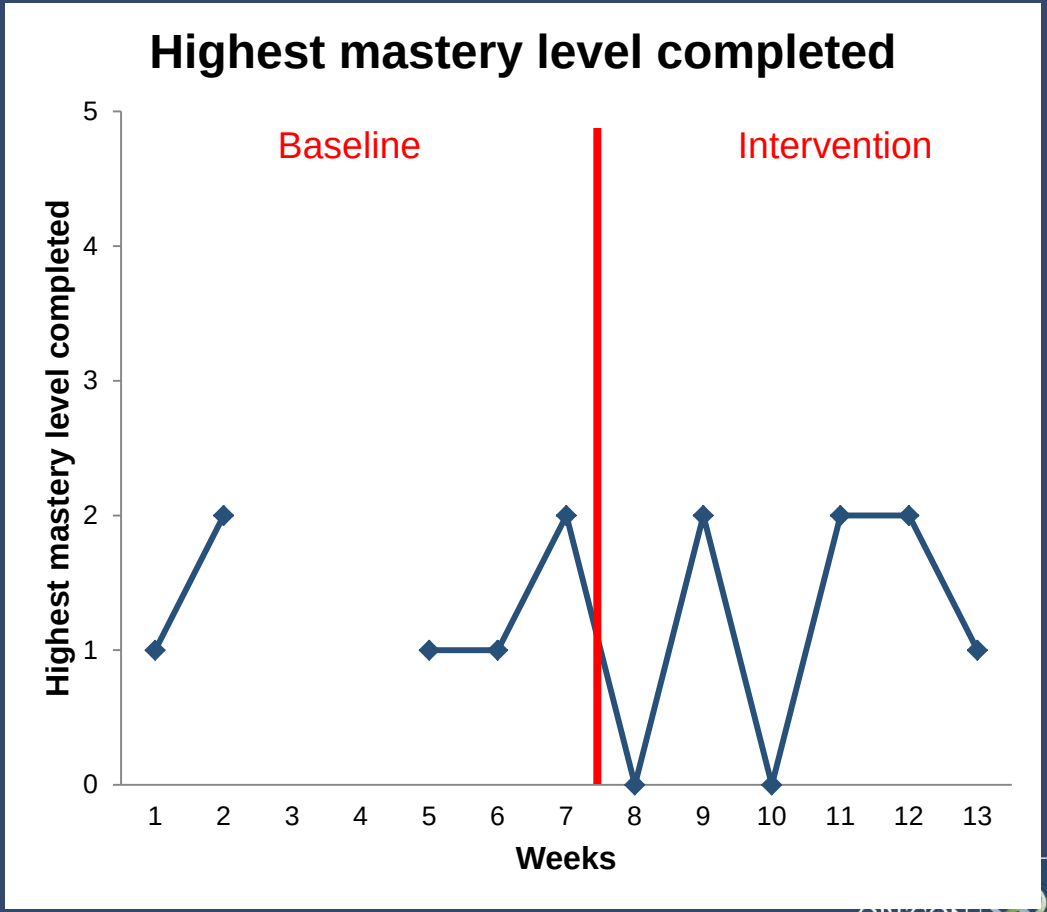
Pilot study results: JS
Highest mastery level completed

- BL: completed level 1 or 2
- No improvement and inconsistent performance in intervention phase



Preliminary Analysis

- n-back score increased
- AUC did not change
- Inconsistent performance on Mastery task.
- Unclear how to interpret results because there are artifacts that could confound system use.

Next steps

- Complete study with 5+ participants and look for patterns across users

- Explore other interventions
  - Mindfulness meditation
  - Modified stimuli (e.g. colorful letters)

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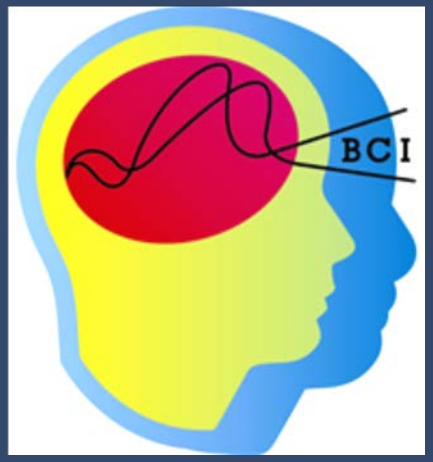
“BCI also can open new doors, which is hard to do when you’re literally locked-in.” GB



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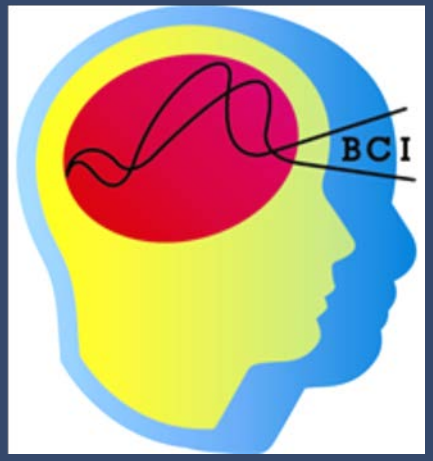

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