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March 27, 2019
7:00 PM Eastern

An introduction to non-invasive brain-computer interface techniques for AAC

Presenter:

Kevin Pitt, MS, Doctoral Candidate

Webinar Logistics

ASHA CEUs – live webcast

- Included for USSAAC members;
  $25 – non-USSAAC members
- Participant form and instructions on USSAAC website
- Can only receive CEUs for *live* webinar
- NOTE: You need to scan and send participant form to smeehan8@ku.edu by April 10, 2019

- Archived webcasts https://www.isaac-online.org/english/news/webinars/
- Enter questions in the chatbox. We will answer as time permits.

WHAT WILL YOU LEARN?

1) Different non-invasive brain-computer interface techniques.

2) Various considerations for brain-computer interface assessment.

3) Future directions for integrating brain-computer interfaces into clinical practice.

Supporters

USSAAC would like to recognize and thank our Institutional and Corporate Members for their support

An Introduction to Non-Invasive Brain-Computer Interface Techniques for Augmentative and Alternative Communication

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Disclosures

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Outline

1a) Emerging AAC access technologies
1b) What is a BCI?
2) What do stake holders think about BCI?
3) Work on the translation of Brain-computer interfaces (BCI) into clinical practice
4) Future research directions

Focus:

- Communication impairment due to severe physical impairment (SPI)
- Cerebral Palsy
- Amyotrophic lateral sclerosis (ALS)
- Locked in Syndrome

1a) AAC access technologies

- Brain-computer interface (BCI)
- Movement sensing technology
- Electromyography (EMG)
- Eye-gaze
- Head tracking
- *Multimodal*: Eye-gaze +

Movement sensing
Image taken from Fager et al., 2019

- Besides BCI: oculomotor/motor control
- Environmental restrictions

EMG switch - NeuroNode

- Need new access technologies along side existing methods
- Everyone has access method

1b) What is a BCI?

- Focus: Noninvasive BCI

- Record summed activity of thousands of neurons at the scalp using electroencephalography (EEG) – device control

- Common: For individuals unable to perform movements needed for conventional access

- Learning demands (e.g., Liberati et al., 2015)

- Support across life span

For more information see: Brumberg, J., Pitt, K., Mantie-Kozlowski, A., & Burnison, J. (2018). Brain-Computer Interfaces for Augmentative and Alternative Communication: A Tutorial. *American Journal of Speech-Language Pathology,* 1-12

Non-invasive BCI overview

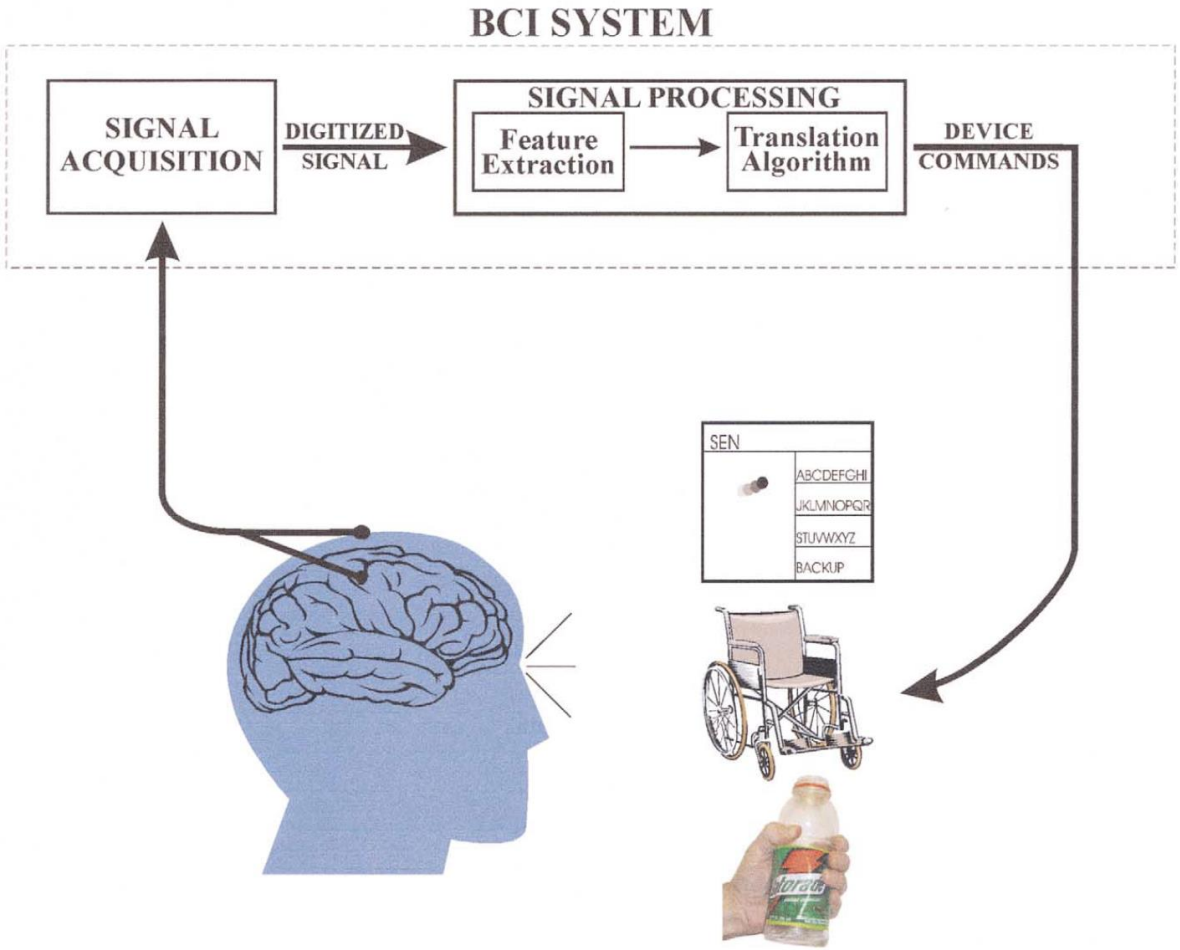


Image taken from: Wolpaw et al., 2002

2) What Do Stakeholders Think?

- Emerging research

- Overall, positive view of BCI technology individuals with neuromotor disorders (Liberati et al., 2015; Blain-Morales et al., 2012)

- Freedom, hope and connection, unlocking (Blain-Morales et al., 2012)

- 84% of individuals with ALS reported they were willing to wear an EEG cap (Huggins, Wren, & Gruis, 2011)

- Concerns noted by caregivers for long term wear ability (Liberati et al., 2015)

Stakeholder Opinions

- Impact of BCI on an individual's life with advanced ALS…
- Use of P300-BCI for over 2.5 years

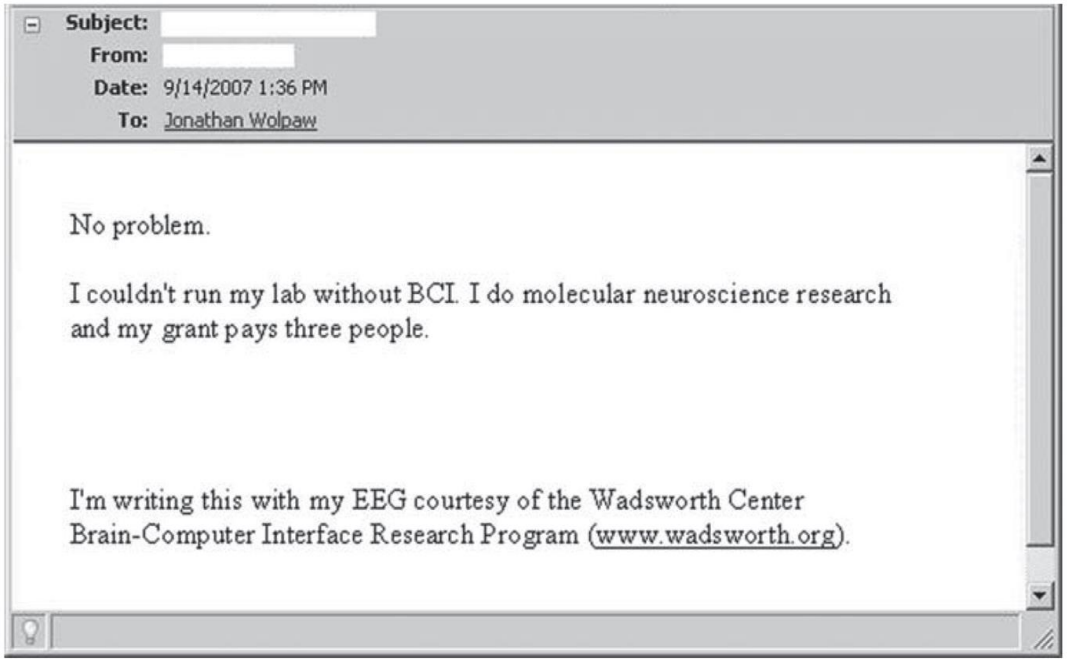


Figure taken from: Sellers, Vaughan, & Wolpaw (2010)

Limitations Noted

- Level of technology (e.g., Blain-Morales et al., 2012)
- Cognitive load/maintaining focus (e.g., Pasqualotto et al., 2015)
- Fatiguing (Blain-Morales et al., 2012; Liberati et al., 2015)
- Frustrating/ effortful at times (Blain-Morales et al., 2012)
- Set up is cumbersome (e.g., Miralles et al., 2015; Liberati et al., 2015)
- Need for increased reliability (around 70%; <70-90%)

(e.g., Brumberg et al., 2017; Marchetti & Priftis, 2015)

Rate

(for review see Brumberg et al., 2018)

- Current BCIs slower than existing AAC methods (e.g., 5-10 selections per minute).
- BCIs in development up to 33 characters/minute

(e.g., Townsend & Platsko, 2016 ; Chen et al., 2015)

However, Different BCI Experiences

- Not everyone feels the same about existing AAC methods…

Individuals with ALS experience P300 BCIs differently

- Workload ratings
- Comfort ratings
- Ease of use ratings
- Satisfaction ratings

(Peters, Mooney, Oken, & Fried-Oken, 2016)

- Performance linked? (e.g., Miralles et al., 2015)

- Consider factors on an individual basis

3) Translation of BCI into Clinical Practice

Research looking to support the transition of BCI into clinical practice

A. Feature matching assessment framework for BCI
   - Overview of different BCI paradigms
B. Development of BCI Screening tools
C. BCI access to commercial AAC devices and paradigms

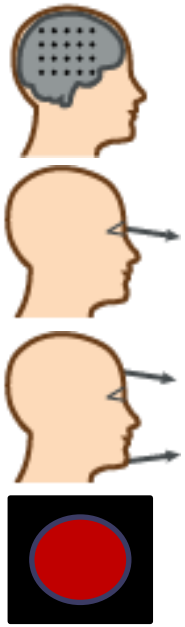
A) Feature matching

AAC Serves Heterogenous Populations:

- 40% mild impairment
- Varied: executive function defects (e.g., attention)
- Frontotemporal dementia, approximately 5 to 14%
- Differing BCI/AAC perspectives

Feature match an individual to a device

1. Current and future profile
2. Cognitive
3. Linguistic
4. Sensory
5. Motor
6. Trial based preference



New concept for BCI (e.g., Pitt et al., in press)

Different BCI paradigms

1. **P300 overview**

   - Feature matching considerations

2. **Steady state visually evoked potentials**

   - Feature matching considerations

3. **Motor (imagery) based systems**

   - Feature matching considerations

Visual Sensory BCIs: P300 Spellers

- All items randomly flash & generate a brain response when attending to desired item
- Repeat sequence many time (> 1, < 15) - select item with greatest response
- <u>Auditory-based</u>

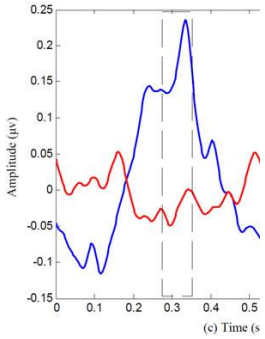
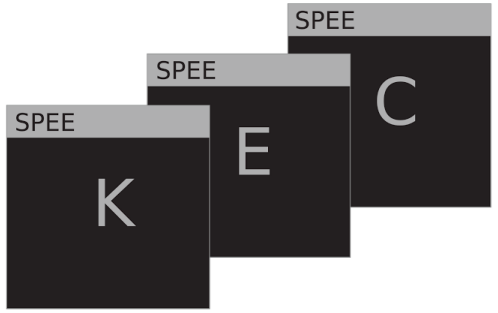


Image taken from Perseh & Kiamin (2013).

P300 Grid Speller

Donchin et al. (2000)

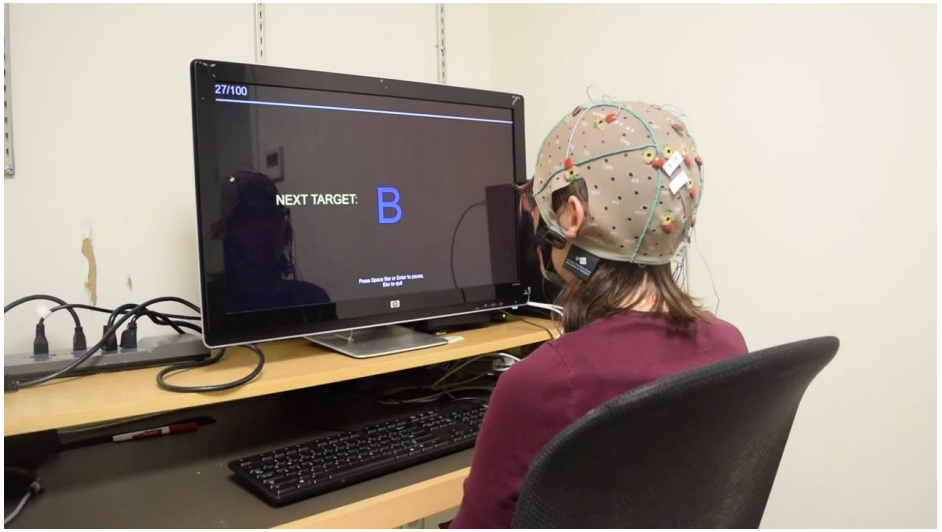
RSVP Speller



Acqualagna & Blankertz (2010)
Orhan et al. (2012)

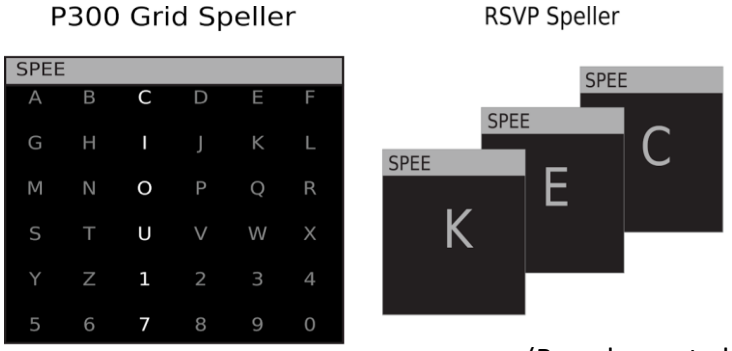
P300 Grid Video

Guger Technologies
https://www.youtube.com/watch?v=tI_CoJ8ICPA



RSVPKeyboard
https://www.youtube.com/watch?v=4cxaNXe9rVI&t=3s

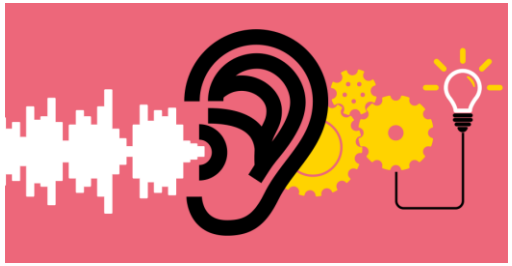
P300 Grid/ RSVP



(Brumberg et al., 2018)

Considerations	Concerns
Degree of oculomotor control for overt attention (Brunner et al., 2010) **Working memory** (Fried-Oken, et al., 2013; Sprague et al.,2015), **Selective attention/ temporal filtering:** Ability to attend to relevant stimuli amongst a stream of irrelevant or distracting stimuli) (Riccio et al., 2013) **Literacy** **Positioning** – headrest impedance (e.g., Fried-Oken, et al., 2013)	**Severe visual acuity impairment** **Severe oculomotor impairment** **History of seizures** (less than those associated with steady state visually evoked potential, due to moving stimuli)

Auditory P300



Considerations	Concerns
Auditory perception and stream segregation abilities are needed Tones may be **modified** to match hearing acuity/ range. Engages **attention**, **working memory** **Increased level** of attention and short term memory capacity for navigation. (Klobassa et al., 2009; Kübler et al., 2009).	**Currently,** normal visual acuity supports BCIs with visual feedback over auditory despite normal hearing (more mature methods).

Traditional view of BCI grid spellers

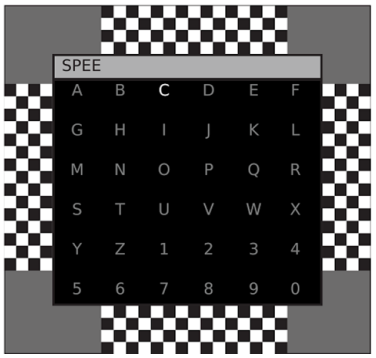
- *- Tactile (left vs right hand)*
- *- Less mature*

Steady State Visual Evoked Potential (SSVEP) & Auditory Steady State Response (ASSR)

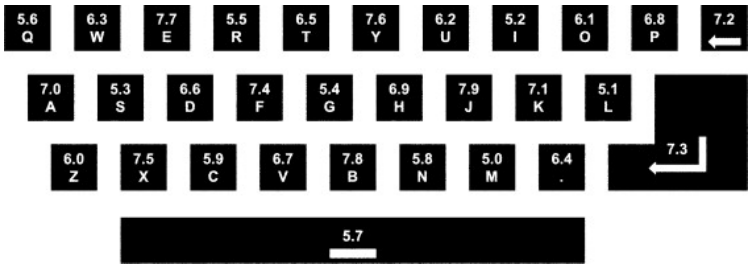
- SSVEP - Attending to a flicker stimuli ``tagged'' with a unique strobe frequency, generates recordable brain oscillations that contain the same frequency components.

- ASSR – **TWO** sound streams that containing different frequency modulations.

SSVEP (Directional)



(Brumberg et al., 2018)



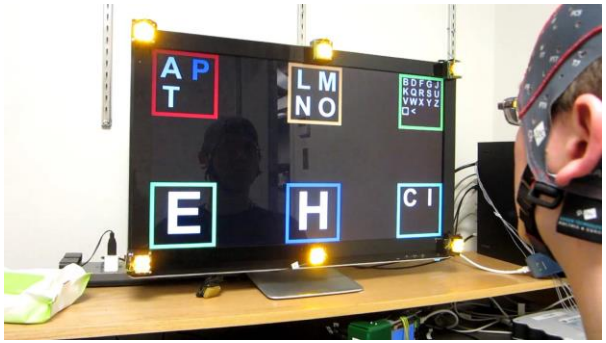
(Hwang et al., 2012)

SSVEP Videos

Shuffle Speller
https://www.youtube.com/watch?v=JNFYSeIlOrw&t=6s

https://www.youtube.com/watch?v=uunf3FDfEno&t=11s

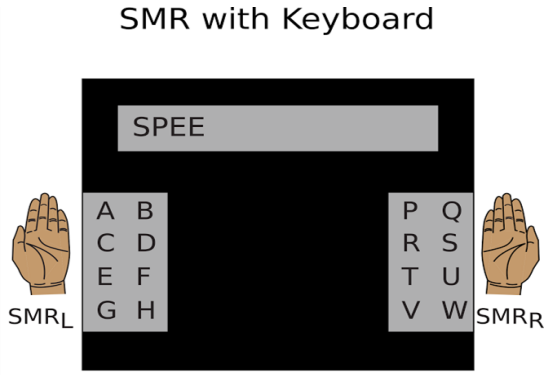
Steady State Visual Evoked Potential (SSVEP)



Considerations	Concerns
Degree of oculomotor control for overt attention (Brumberg, Nguyen, Pitt, & Lorenz, 2018; Peters et al., 2018) Selective attention However, the individual is **not required to make active decision**s about when a novel target is highlighted (versus P300). **Positioning** - Headrest impedance	**User history of seizures** (due to flickering stimuli). Visual Impairments - Interfaces can be **adapted** to suit user strengths (Brumberg et al., 2018) - Simulated visual impairment (legal blindness) able to use BCI comparably (NT; Peters et al., 2018).

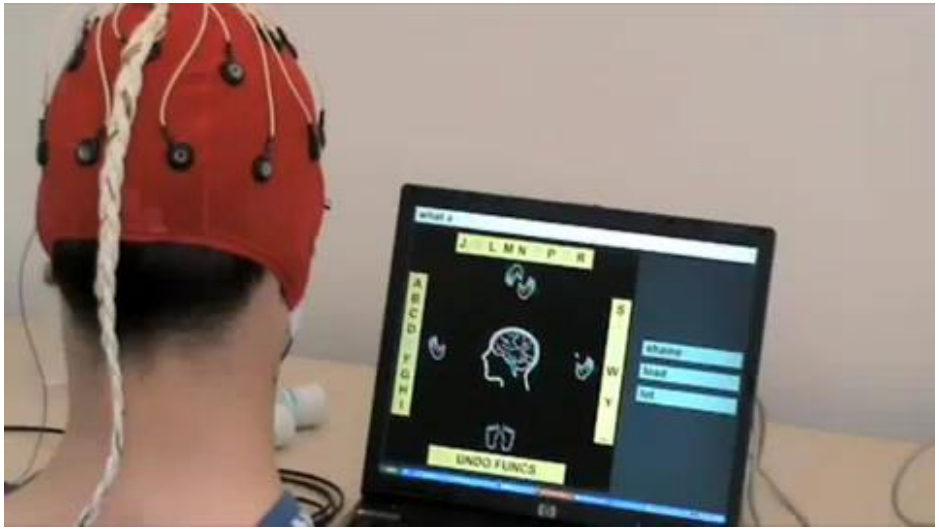
Motor & motor-imagery

- Provide access to AAC using changes in brain rhythms associated with:
  - Physical motor movements
  - Attempted movements (paralysis)
  - Motor imagery (mental simulation without movement; e.g., making a fist)
- **Versatile**
- Does not depend on external stimuli



(Brumberg et al., 2018)

Motor-Imagery Video



https://www.youtube.com/watch?v=R-tNE-y2QU0&t=63s

Berlin BCI:
https://www.youtube.com/watch?v=yhR076duc8M
e.g., Blankertz et al., (2006a; 2006b)

Motor Imagery

Considerations	Concerns
Task: 1st versus third person (e.g., Vuckovic & Osuagwu, 2013) **Does not rely** on sensory stimuli **Support**: poor selective attention, adaptions Motor imagery vs overt motor learning (Wander et al., 2013): - **Feedback/Practice** - **Executive function** related to motor learning (e.g., task switching, working memory, abstract reasoning skills, elf reflection. - *Increased training times vs P300 and SSVEP*	No presence of the sensorimotor rhythm during covert task performance (reported as **approximately 15 to 30%** of the population by Blankertz et al., 2010) **Increased training time/ initial preference** (Geronimo et al, 2014) Congenital paralysis? Lesions over motor cortex - Utilize 'other' tasks (e.g., mental tasks, word association, rotation)?

Extrinsic Factors

Environmental noise

- Ventilators
- Distractors/ movement

(Sellers, Kubler, & Donchin, 2006)

Caregiver support

- BCI set up, trouble shooting, monitoring device use, training

(Brumberg et al., 2018; Wolpaw et al., 2018)

Influence of intrinsic and extrinsic factors

			Attention Modulated Visually based BCIs			Attention Modulated Auditory Only			Motor Imagery based BCIs		
	Unique profile/ features of the client	**Check rows that match their profile**	**Visual P300 Grid**	**Modified P300 Grid/ RSVP**	**SSVEP**	**Auditory P300**	**Auditory P300: Rt & Lt Steams**	**ASSR: Rt & Lt Steams**	**Motor Imagery Audio/ Visual**	**Motor Imagery Audio**	**Motor Imagery Visual**
Sensory	No-mild imp: visual acuity		1	1	1	0	0	0	1	0	1
Sensory	Mod-severe imp: visual acuity		0	0	0	1	1	1	0	1	0
Sensory	No-mild imp: hearing		1	1	1	1	1	1	1	1	1
Sensory	Mod-severe imp: hearing		1	1	1	0	0	0	0	0	1
Mecical	Without a history of seizures		1	1	1	1	1	1	1	1	1
Mecical	With a history of seizures		-0.5	-0.5	-1	1	1	1	1	1	1
Motor	No-mild imp: eye movement		1	0	1	1	1	1	1	1	1
Motor	Mod-severe imp: eye movement		0	1	1	1	1	1	1	1	1
Imagery	No-mild imp: 1st person motor imagery		1	1	1	1	1	1	1	1	1
Imagery	Mod-severe imp: 1st person motor imagery		1	1	1	1	1	1	0	0	0
Cognition	No-mild imp: audio and/or visually based selective attention tasks		1	1	1	1	1	1	1	1	1
Cognition	Mod-severe imp: audio and/or visually based selective attention tasks		0	0	0	0	0	0	1	1	1
Cognition	No-Mod imp: working memory		1	1	1	1	1	1	1	1	1
Cognition	Severe imp: working memory		0	0	0	0	0	0	0	0	0
Cognition	No-mild imp: cognitive motor learning/ performance factors (e.g. task switching, self monitoring. abstract reasoning, etc)		1	1	1	1	1	1	1	1	1
Cognition	Mod-severe imp: cognitive motor learning/ performance factors		1	1	1	1	1	1	0	0	0
	TOTAL number of feature matches Add all values in each column matching their profile										
Lit.	Literacy (reading and spelling) impairment?	Yes / No	Yes / No	Yes / No	Yes / No	Yes / No	Yes / No	Yes / No	Yes / No	Yes / No	Yes / No

Figure & following cases taken from: Pitt, K., & Brumberg, J. S. (2018a).

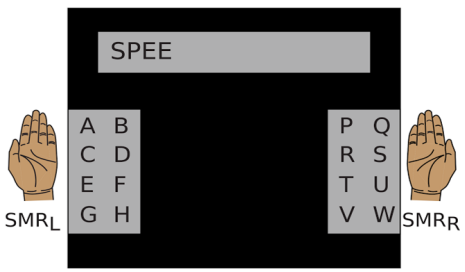
Clinical application case study

Following a brainstem stroke, Mrs. Holden (a 70 year old female) received a diagnosis of locked-in syndrome. An AAC evaluation revealed:

- **Strengths in** visual acuity, literacy, and selective attention / working memory skills.
- **Weaknesses in** cognitive-motor learning tasks (e.g., task switching, problem solving), low self-ratings on first person motor imagery, and an absent sensorimotor rhythm.
- Limited range of eye (oculomotor) movement.
- No history of seizure activity
- Posterior electroencephalography electrode recordings were largely unimpeded by her wheelchair headrest.

BCI images from Brumberg et al., (2018)

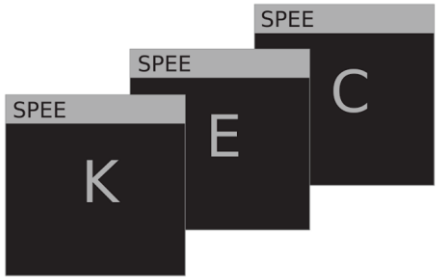
SMR with Keyboard



SSVEP (Directional)

P300 Grid Speller

RSVP Speller



Case Study (trials)

			Attention Modulated Visually based BCIs			Attention Modulated Auditory Only			Motor Imagery based BCIs		
	Unique profile/ features of the client	**Check rows that match their profile**	**Visual P300 Grid**	**Modified P300 Grid/ RSVP**	**SSVEP**	**Auditory P300**	**Auditory P300: Rt & Lt Steams**	**ASSR: Rt & Lt Steams**	**Motor Imagery Audio/ Visual**	**Motor Imagery Audio**	**Motor Imagery Visual**
S	No-mild imp: visual acuity	X	1	1	1	0	0	0	1	0	1
MC	Without a history of seizures	X	1	1	1	1	1	1	1	1	1
M	Mod-severe imp: eye movement	X	0	1	1	1	1	1	1	1	1
MI	Mod-severe imp: 1st person motor imagery	X	1	1	1	1	1	1	0	0	0
Cog	No-mild imp: audio and/or visually based selective attention tasks	X	1	1	1	1	1	1	1	1	1
Cog	No-Mod imp: working memory	X	1	1	1	1	1	1	1	1	1
Cog	Mod-Severe imp: cognitive motor learning/ performance factors (e.g. task switching, self monitoring, abstract reasoning, etc)	X	1	1	1	1	1	1	0	0	0
	TOTAL number of feature matches Add all values in each column matching their profile		6	7	7	6	6	6	5	4	5
Lit.	Literacy (reading and spelling) impairment?	Yes / No	Yes / No	Yes / No	Yes / No	Yes / No	Yes / No	Yes / No	Yes / No	Yes / No	Yes / No

Figure taken from: Pitt, K., & Brumberg, J. S. (2018a). Guidelines for Feature Matching Assessment of Brain-Computer Interfaces for Augmentative and Alternative Communication. *American Journal of Speech-Language Pathology,* 1–15.

B) Development of BCI Screening tools

- Little standardization in BCI research for assessment

- First: RSVP-speller by Fried-Oken, et al., 2013.

Lab Expansion:
- ***Multidisciplinary:*** *PT, SLP, OT, Neuroscientist, BCI engineer*
- Feature matching across devices
- Sensory-cognitive-motor imagery domains (e.g., attention, working memory, following directions, cognitive motor learning, motor-imagery)

- Binary/yes no response, <60 mins, minimal fatigue
- N=12, feasible for completion.

- Both screeners are a **first step,** skill presence
- Ongoing assessment + EEG

Pitt, K., & Brumberg, J. (2018b). A screening protocol incorporating brain-computer interface feature matching considerations for augmentative and alternative communication. *Assistive Technology*, 1-12.

C) BCI access to commercial AAC devices

- BCI custom made paradigms and software
- Utilization of AAC advances over past 40 years.
- Learn a whole new system (modularity)
- Across life span/course (e.g., Pitt et al., in press)

D) BCI access to commercial AAC devices

Early efforts to access commercial AAC/AT paradigms and software

1) **Row/column scanning via BCI 'switch'**
- Adults with CP, and Neurotypical adults and those with ALS
- Tobii-Dynavox AAC device (Brumberg et al., 2016)
- Promising results
  - e.g., 62.2% *single session* offline accuracy (Brumberg et al., 2016)
  - Continuing research

(image take from Scherer et al., 2015)

2) **Assistive technology software**
- QualiWorld, QualiLife Inc. Paradiso-Lugano, CH (e.g., Zickler et al., 2011)
- Dynawrite text-to-speech (Thompson, Gruis & Huggins, 2013)

A heightened focus on utilizing commercially available technology:
- Promote collaborations and help navigate barriers to funding

4) Future Research Directions

A) BCI access for children

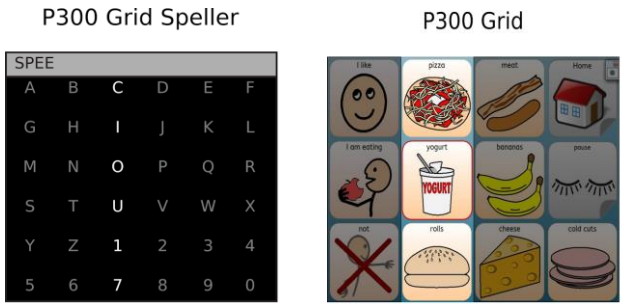
B) Engaging displays for children and adults

C) Technical barriers to BCI implementation (e.g., set up)

D) BCI availability and funding

A) BCI access for children

- Emerging (e.g., Norton, Mullins, Alitz, & Bretl 2018)
- Need more data EEG and developing brain. (e.g., Huggins et al., 2017)
- EEG signals for individuals with congenital paralysis
  - Muscle artifacts
- Literacy and symbols
- Design ('cool', motivating themes, functions, social image)
  - Play, artistic expression, colors, characters (Light & Drager, 2007)

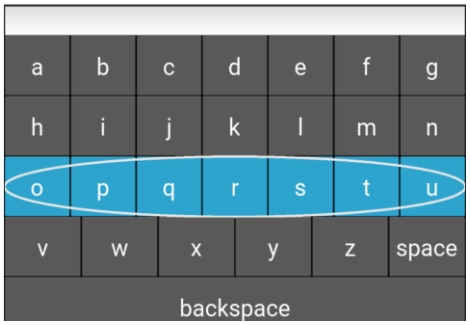


BCI images from Brumberg et al., (2018)

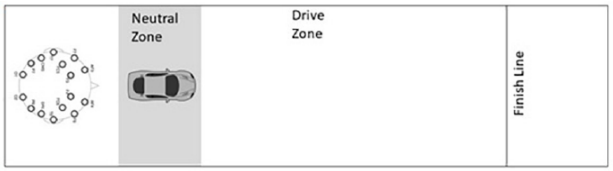
Image taken from http://blog.gtec.at/unlimited-wireless-eeg/

B) Engaging displays for children and adults

- Sterile
- Task Engagement (e.g., Pitt et al., in press)
  - Look to learn (https://thinksmartbox.com/product/look-to-learn/)
  - Timocco (https://www.timocco.com)
- BCI-AAC generalization?
- Feedback effects on performance/boredom/fatigue



Brumberg & Pitt (2019)



Zhang et al., (2019)

Image from Look to Learn; Smart Box Assistive Technology

C) Technical barriers to BCI implementation

- Set up (gel application)
- Dry electrode technology
- Toward wireless systems
- Number of electrodes
- BCI processing algorithms (reliability)
- Artifact removal (e.g., muscle) in real time

(Guger et al., 2012, Zander et al., 2011)

(e.g., Brumberg et al., 2018;
Miralles et al., 2015;
Blain-Moraes et al.,2012;
Nijboer, 2015)

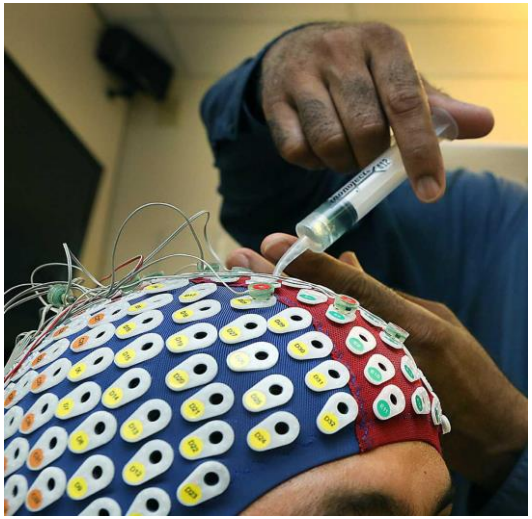


Image taken from:
https://www.mysanantonio.com/news/local/communities/stone-oak/article/Researchers-try-to-catch-a-brain-wave-5728289.php

D) BCI availability and funding

BCI mostly in laboratory setting though undergoing in home trials with promising results (e.g., Wolpaw et al., 2018)

Availability of commercial/portable systems:

- **g.tec P300 Intendix speller:** ~$12,500

http://www.gtec.at/Products/Complete-Solutions/intendiX-Specs-Features

Funding

- Unknown
- Commercial partners/ documented need
- Increased reliability

(Huggins & Kovacs, 2018)

Some labs performing BCI research

1) East Tennessee State University; Johnson City, Tennessee.
https://www.etsu.edu/cas/psychology/bcilab/
2) Oregon Health & Science University; Portland, Oregon.
https://www.ohsu.edu/xd/research/centers-institutes/institute-on-development-and-disability/reknew/
3) Penn State Hershey Medical Center; Hershey, Pennsylvania.
https://alsadotorg.wordpress.com/2016/06/02/bringing-brain-computer-interface-home/
4) Speech and Applied Neuroscience Lab; Lawrence, Kansas.
https://sanlab.ku.edu/
5) University of Michigan; Ann Arbor, Michigan.
http://www.umich.edu/~umdbi/
6) University of Pittsburgh; Pittsburgh, Pennsylvania.
http://www.herl.pitt.edu/node
7) Wadsworth Center and the National Center for Adaptive Neurotechnologies; Albany, New York.
https://www.wadsworth.org/news/national-center-for-adaptive-neurotechnologies-ncan-open-house

Thank you!

- All our study participants!
- United States Society for AAC
- Dr. Stephanie Meehan
- Franklin Smith and ISAAC
- Dr. Jonathan Brumberg and Chavis Lickvar-Armstrong

Questions?

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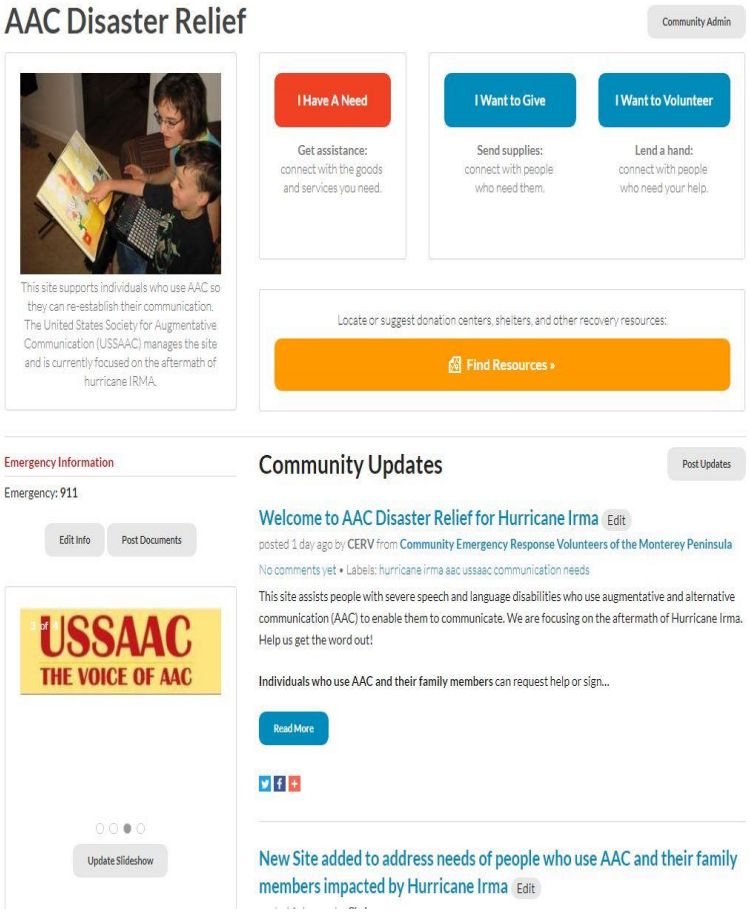

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