A New Technology for AAC: An Overview of Brain-Computer Interfaces (BCIs)

Kevin Pitt., PhD, CCC-SLP
University of Nebraska-Lincoln
kevin.pitt@unl.edu

AAC TRANSLATION LAB

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Introduction

Assistant Professor at the University of Nebraska-Lincoln

AAC TRANSLATION LAB

- Translate the latest AAC access advancements such as brain-computer interfaces out of the laboratory setting by incorporating current clinical procedures (e.g., feature matching) and *stakeholder* input.
- Develop guidelines governing AAC assessment and treatment (e.g., feature matching and stimuli presentation) for access methods such as eye-gaze and switch scanning to support AAC success in a variety of contexts (e.g., activities of daily living, social), and lay the foundations for the translation of the latest AAC access methods.
- Support the implementation of AAC technology by training AAC stakeholders (e.g., professionals, caregivers and those who use AAC) through the implementation of scholarship of teaching and learning along with multidisciplinary collaborations (e.g., with special education, engineering).

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Disclosures

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Outline

1) **What is a BCI?, and where does it fit into AAC?**
2) **What do stakeholders 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

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1) What is a BCI?, and where does it fit into AAC?

Lots of cool stuff happening in Nebraska and around the country!

1) Eye gaze research
2) Hybrid research
3) Movement sensing switches
4) Electromyography

Import to consider BCI as just another communication access method alongside existing methods.

Movement sensing
Image taken from Fager et al., 2019

EMG switch
NeuroNode

Eye-gaze
tobiipro.com

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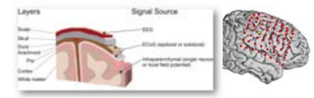
Ways Brain Signals are Recorded

Invasive BCI
-Record brain activity at cortex (on or in brain surface)
-Less mature than non-invasive
-Couple of current research approaches
-Algorithms decode brain activity associated with 1) recorded speech
-2) Motor movements of articulatory tract (e.g., move tongue up)



Schalk, G., & Leuthardt, E. C. (2011).

Non-invasive
-Does not require surgery
-More mature **(focus of this talk)**
-Parallels existing AAC, takes a non speech signal (e.g., switch press) and translate to communication (e.g., item selection)

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Recording Techniques

BCIs don't read minds! ☺

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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
- Currently undergoing long term in home trials (e.g., Wolpaw et al., 2018)

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

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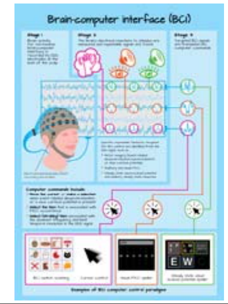

Image taken from Pitt, Brumberg, Burnison, Mehta and Kidwai, in press

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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)

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Stakeholder Opinions

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


Subject:
From:
Date:
To:

No problem.

I couldn't run my lab without BCI. I do molecular neuroscience research and my grant pays three people.

I'm writing this with my EEG courtesy of the Wadsworth Center Brain-Computer Interface Research Program (www.wadsworth.org).

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

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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)

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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

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Perspectives on BCI alongside eye gaze

Individuals with ALS experience both BCI and eye gaze differently

P300 and SSVEP supported by oculomotor control similar to eye gaze…

- P300 cognitive workload higher vs eye tracking
- Fatigue and frustration < BCI. However, mental and physical effort higher
- Ease of P300 and Eye gaze was about equal
- P300 may allow for improved performance with smaller icons

- *As with existing AAC protocols, an individuals unique preference for a BCI or other AAC technique is based upon a range of factors* (e.g., Pitt & Brumberg, 2018; Light & McNaughton, 2013)

- Importance of qualitative approach, and including stakeholder

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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

B. Development of BCI Screening tools

C. BCI access to commercial AAC devices and paradigms

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3A) Feature matching assessment framework for BCI

I. P300 overview
A) Overview of the brain signal
B) How it applies to BCI use
C) Assessment considerations for the BCI type

II. Steady state visually evoked potentials

III. Motor (imagery) based systems

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I) Visual Sensory BCIs: P300 Spellers
A) The P300 Event Related Potential

Event related potentials (ERPs) are small voltage changes recorded over time, which are generated in response to specific events (e.g., stimulus onset)

Bigger = increased neurological response

P300 first described by Sutton, Braren, Zubin, & John (1965)

Oddball paradigm (background and novel stimulus)

Conscious discrimination of stimulus **(auditory, visual, tactile)**

P300 = positive going deflection 300ms after target presentation

- Neural allocation of attentional resources and memory access (P3a)

- Context updating/ revision of underlying representation (P3b)

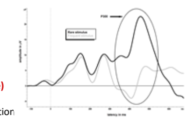

Image taken from Pitt, et al., in press

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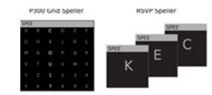
B) How the P300 Applies to BCI Use

P300 BCIs are designed to elicit P300 ERP via the oddball paradigm

Target letter = oddball

Brain signals are small, averaging (> 1, < 15)

BCI selects item with greatest response



Donchin et al. (2000)

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

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P300 Videos

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

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

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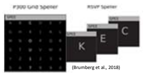
C) P300 Assessment Considerations



(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)

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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).

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

Steady State Evoked Responses are rhythmic brain oscillations driven by repetitive stimulus such as a strobe.

During SSVEP paradigms the individual attends to a repetitive SSVEP stimuli
- Synchronous neural firing at the same rate as visual stimulus (e.g., 12hz)

Multiple stimuli are presented simultaneously at different stimulation frequencies - -
- Attended frequency induces a greater magnitude of neural synchrony (energy)

ASSR parallels SSVEP
- Auditory cortex
- String of clicks, amplitude modulated tones

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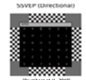
B) How the SSVEP and ASSR Applies to BCI Use

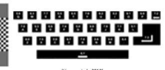
SSVEP
- Attending to a flicker stimuli "tagged" with a unique strobe frequency, generates greater neural synchrony and timing in the EEG signal compared to unattended items.

- BCI selects target item with the frequency band associated with the highest energy and temporal resolution.
- Cursor, keyboard

ASSR
- Early stages of research
- TWO sound streams that containing different frequency modulations



(Brumberg et al., 2018)


(Hwang et al., 2012)

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SSVEP Videos

Shuffle Speller

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

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

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C) Assessment Considerations

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).

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III Motor and Motor Imagery
A) The Sensorimotor Rhythm

Sensorimotor activity in the brain
When the brain is relaxed = idling state
Idling rate of the brain is 8-12Hz (alpha/mu; *sensorimotor cortex*)
Synchronous neural firing
Possibly govern inhibitory and excitatory cortical processes to manage energy use

Event Related Synchronization (ERS)
- High energy levels

Event Related Desynchronization (ERS)
- Energy level decrease
- Processing cognitive, sensory and/or motor-based information
- Neurons begin firing at different rates to accomplish the given task.

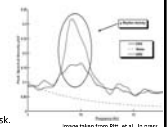

Image taken from Pitt, et al., in press

Beta (~18-26 Hz), also associated with motor actions
- May modulate along with mu

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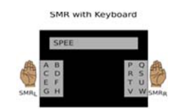
C) How the Sensorimotor Rhythm Applies to BCI Use

BCI detects a change in sensorimotor power and translates that into a computer command.

- Real
- Imagined (mental simulation without execution)
- Attempted (paralysis)

Versatile

Does not depend on external stimuli



(Brumberg et al., 2018)

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SMR Videos

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)

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Assessment Considerations

Considerations	Concerns
Task: First 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)?

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			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
	Mod-severe imp: visual acuity		0	0	0	1	1	1	0	1	0
	No-mild imp: hearing		1	1	1	1	1	1	1	1	1
	Mod-severe imp: hearing		1	1	1	0	0	0	0	0	1
Medical	Without a history of seizures		1	1	1	1	1	1	1	1	1
	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
	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
	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
	Mod-severe imp: audio and/or visually based selective attention tasks		0	0	0	0	0	0	1	1	1
	No-Mod imp. working memory		1	1	1	1	1	1	1	1	1
	Severe imp. working memory		0	0	0	0	0	0	0	0	0
	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
	Mod-severe imp: cognitive motor learning/ performance factors		1	1	1	1	1	1	0	0	0
	TOTAL number of feature matches										
	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).

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3B) 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.

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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 (anxiety/modularity)
- Across life span/course (e.g., Pitt et al., 2019)
- Hybrid
- Focus: BCI switch for row/column scanning
  - Familiar starting point
  - 12 sessions

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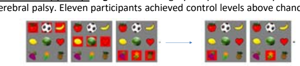
Sensorimotor BCI as a switch

Established history of BCI research regarding the utility of BCI techniques as a form of switch. Early efforts for scanning…

1) Friedrich et al., (2009): **10 sessions** for 8 typical and 2 participants with an NMD. Variable BCI performance, mean accuracy increasing from 35% (S.D. = 14) in session one, to its peak in session eight (57%, S.D. = 20, chance accuracy 25%).

2) Scherer et al., (2015): **Single** session imagery BCI performance by 14 adults with cerebral palsy. Eleven participants achieved control levels above chance levels.



3) Brumberg et al., (2016): Offline imagery BCI accuracy for motor imagery switch access to a commercial Tobii-Dynavox page set during a **single** training session. Neurotypical participants accuracy of 60% (range 55.7 to 63.55), and the individual with ALS 62.6%.

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Sensorimotor BCI as a switch

Calibration

Training Interface (feedback)

Motor execution (SMR) for feasibility testing

No individualizations made between participants

Project credit: Dr. Jonathan Brumberg
PI: Speech and Applied Neuroscience Lab
University of Kansas

Tobii-Dyanvox

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BCI-AAC

"sm…" (smile)
Bilateral leg movement

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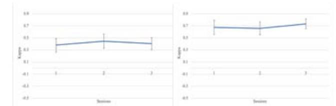
BCI-AAC

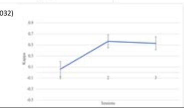
Cohen's Kappa
- 0 to 0.20 indicates no to slight agreement between the BCI output and user intention
- 0.21 to 0.4 as fair agreement
- 0.41 to 0.6 as moderate agreement
- 0.61 to 0.8 as substantial agreement
- 0.81 to 1 as almost perfect agreement (e.g., McHugh, 2012).
Negative kappa values indicate performance below chance levels.

Mean Kappa and 95% confidence intervals



0.412 (range: 0.3825–0.4465; *SD* = .032)

0.689 (substantial; range: 0.6574–0.7339; *SD* = .04)



0.387 (range: 0.0615–0.568; *SD* = .283) / Substantial (~7; 95%)

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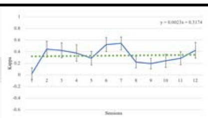
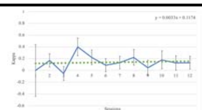
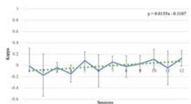


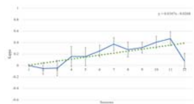
Least motor impairment
Cognitive impairment
0.333 (moderate; range: 0.020–0.544; *SD* = .151)
95% -> substantial



Unstable BCI performance
No cognitive impairment
0.139 (slight; range: -.051 –0.340; *SD* = .117)
Ridicava/ Low intake (9.72 hours)
Better with p300?



Most motor impairment
No cognitive impairment
-0.01 (no-slight; range: -.017 –0.13; *SD* = .096) i95% -> substantial
Learning trajectory
Even severe impairment may learn to use device
Adaptions – P300?



Second least motor impairment
Cognitive impairment
.199 (slight range: -0.05–0.47; *SD* = .177) → moderate agreement
Learning trajectory

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BCI-AAC Summary

Switch access to row column scanning by BCI feasible.

More research needed to understand
- Factors influencing variability
- Length of BCI trials (in this case informed decisions around 5 sessions, extending as needed)

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Clinical Considerations

1) Early/timely intervention
- Cognitive impairment traditionally impairs BCI performance (e.g., Geronimo et al., 2016)
- Our study, these individuals did best – low motor
- Support across disease course

Hwang et al., 2009

2) Modeling/ support
- Problem for BCI as facilitator does not have access to system
- P300 – laser pointer for overt attention (e.g., Pitt et al., 2019)
- Realtime feedback of target brain activity?

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4) Future Research Directions

A) BCI access for children

B) Engaging displays for children and adults: Visual scene displays

C) Technical barriers to BCI implementation

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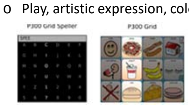
A) BCI access for children

- Emerging (e.g., Pitt et al., 2019; 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 (e.g., for P300)
- 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/

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B) Engaging displays for children and adults: Visual scene displays

- P300 spellers: decontextualized grid
- Visual scene varying spatial relationships.

- Motion vs 'box' highlighting in AAC
- Increase attention and AAC performance (e.g., McCarthy & Boster, 2017; Jagaroo & Wilkinson, 2008)

- P300 and BCI performance?
- Need for research on varying displays and intensification methods


Image from: Lingraphica


Image from: McCarthy & Boster (2017)

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C) Technical barriers to BCI implementation

- Set up (gel application)
- Dry electrode technology (Guger et al., 2012, Zander et al., 2011)
- Toward wireless systems
- Portability! (focus of my lab)
- Number of electrodes
- BCI processing algorithms (reliability)
- Artifact removal (e.g., muscle) in real time

(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

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Thank you!

- All our study participants!

- NSLHA
- Janet Seelhoff
- Dr. Jonathan Brumberg, Chavis Lickvar-Armstrong and the Speech and Applied Neuroscience Lab at the University of Kansas.

Questions?

Email: **kevin.pitt@unl.edu**

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Ahani, A., Wiegand, K., Orhan, U., Akcakaya, M., Moghadamfalahi, M., Nezamfar, H., ... & Erdogmus, D. (2014). RSVP Icon Messenger: icon-based brain- interfaced alternative and augmentative communication. *Brain-Computer Interfaces,1*:3-4, 192-203.

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