Comparison of EEG Blind Source Separation Techniques to Improve the Classification of P300 Trials

Zach Cashero and Chuck Anderson
Department of Computer Science, Colorado State University

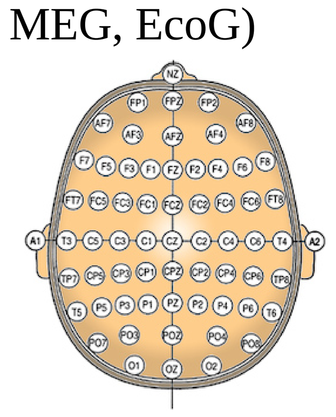
Objective

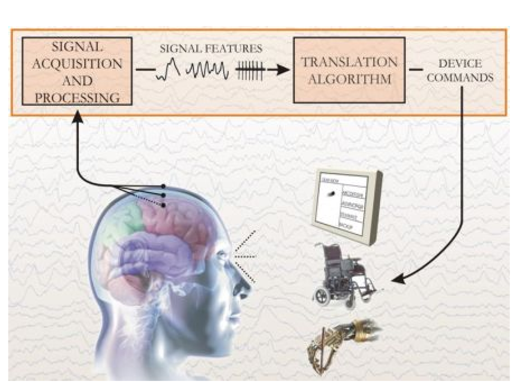
Locked-in syndrome is a condition in which a patient has become fully paralyzed to the point of losing all voluntary muscle control, even in the facial muscles. With no voluntary muscle control, the patient is left with no means of communication to the outside world. Specifically, amyotrophic lateral sclerosis (ALS) is a progressive, neurodegenerative disease that can cause paralysis while leaving the brain functions relatively intact. A brain-computer interface (BCI) attempts to establish a reliable communication channel using brain signals, in this case with electroencephalography (EEG).

Specifically, this work is focused on the P300 speller, which allows a user to type a single letter at a time by using external flashing stimuli to evoke a well-known brain response, called the P300 response.. The current state-of-the art system allows the user to type roughly 5-10 letters/min. Due to a very noisy signal in each P300 trial, many repetitions of the flashing stimuli are required in order to obtain the desired accuracy, which slows the communication rate. This research looks at a comparison of three different signal processing techniques in an attempt to extract the P300 signal from the background noise. The inclusion of temporal information is also analyzed as a means to provide more relevant information to signal processing algorithms. The main objective is to increase the classification accuracy in order develop a reliable system that requires fewer repetitions. This will effectively increase the communication rate, for the user.

What is a BCI?

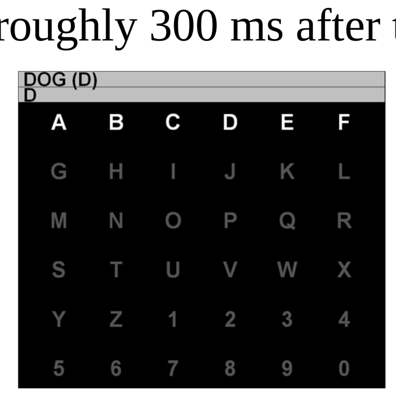
- Sensors record electrical brain activity (EEG, MEG, EcoG)
- The user voluntarily modulates brain waves (e.g. math task vs. visual task)
- Signal processing/classification
- Computer detects changes between tasks
- Translate this activity into a set of actions to control a wheelchair, mouse cursor, speller, prosthetic arm, etc.

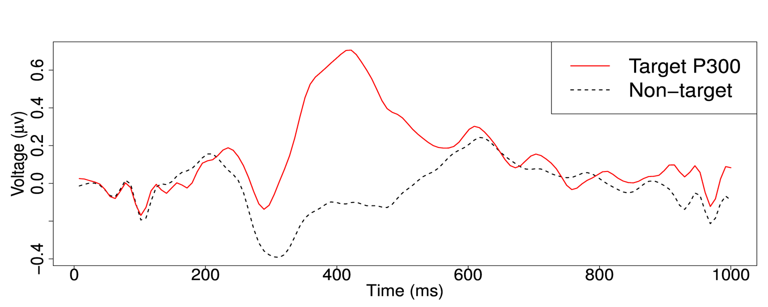




P300 Speller

- Grid of letters, numbers, and/or commands
- Rows and columns continuously flash in a random order
- User focuses on desired letter and counts flashes of the target
- Oddball paradigm: a rare, but expected target stimulus evokes a well-defined response, the P300, which is characterized by a positive peak roughly 300 ms after the stimulus

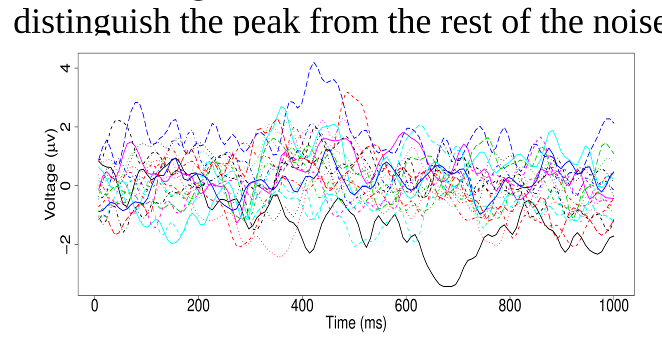


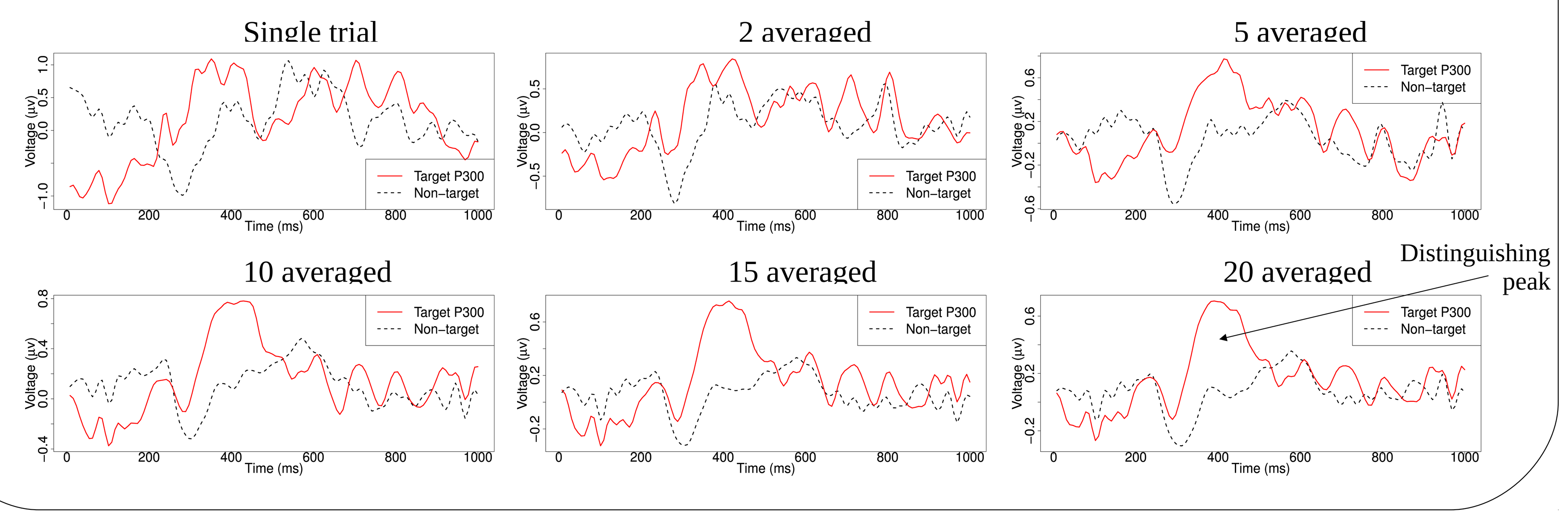


Challenges

- Very low signal-to-noise ration (SNR)
- Usually this is overcome by averaging together many trials to cancel out random variations from noise
- Noise = background brain activity
- More trials require more time to communicate one letter
- Goal: classify P300 trials using fewer averaged trials, or even using only single trials

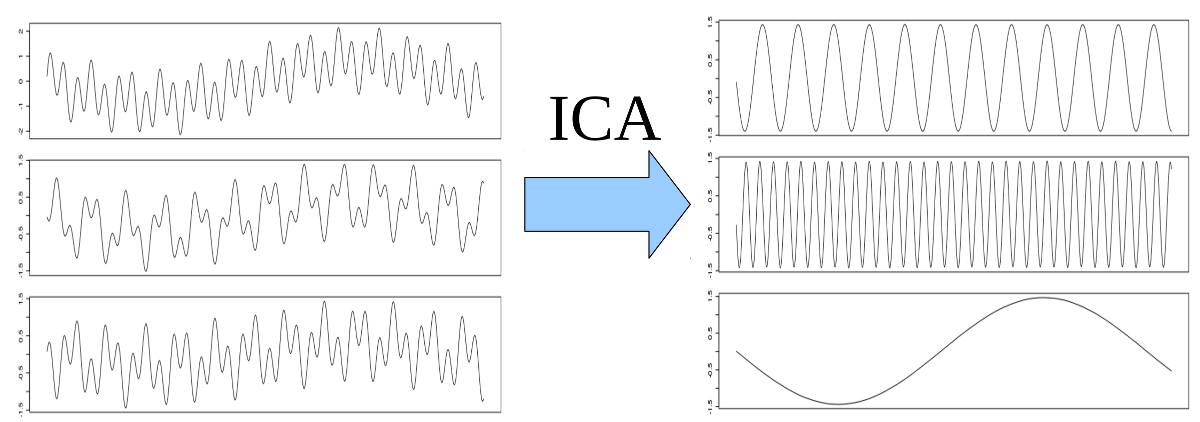
20 single P300 trials: it is hard to distinguish the peak from the rest of the noise





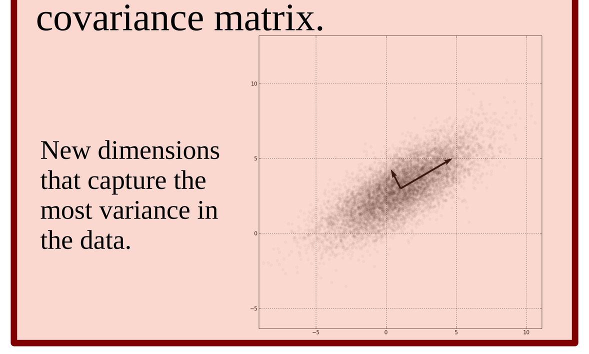
Spatial Blind Source Separation

Blind source separation (BSS): Assumes that a set of source signals are mixed together at each recording location. These algorithms attempt to transform the original recorded signals into the underlying source signals.



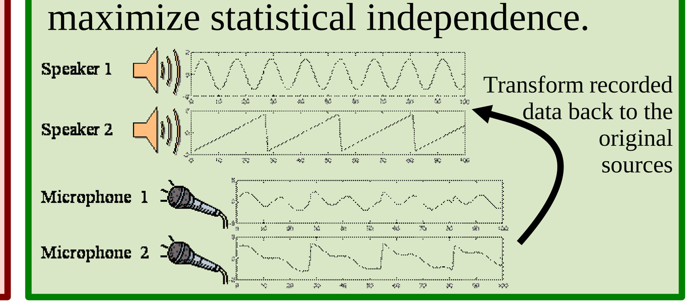
PCA

Principal component analysis: orthogonal transformation of data. Projects data onto new dimensions which maximizes the variance. Implemented with an eigenvalue decomposition on the covariance matrix.



ICA

Independent component analysis: assumes mixture of several underlying sources at electrodes. Applied to this problem by assuming that many distinct brain processes contribute to observed EEG (e.g. a P300 source). Finds components (sources) that maximize statistical independence.



MNF

Maximum noise fraction: a signal is composed of a source S and noise N:

$$X = S + N$$

Maximize SNR:

$$\max_{\alpha \neq 0} \frac{\|S\alpha\|}{\|N\alpha\|} = \max_{\alpha \neq 0} \frac{\|X\alpha\|}{\|N\alpha\|}$$

which is valid if S and N are orthogonal. The noise N is characterized by high frequencies, where $N^T N$ is the covariance of a signal and that same signal shifted by 1.

Adding Temporal Information

- Spatial BSS finds a linear unmixing of the n available channels

$$X(t) = [\, x_1(t),\ x_2(t),\ \ldots,\ x_n(t) \,]$$

- Create a new matrix lagged by τ time steps

$$X(t{+}\tau) = [\, x_1(t+\tau),\ x_2(t+\tau),\ \ldots,\ x_n(t+\tau) \,]$$

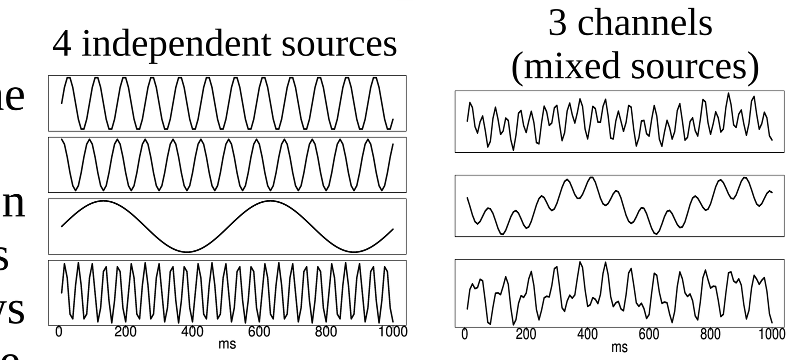
- Additional "channels" added by concatenating lagged data to original

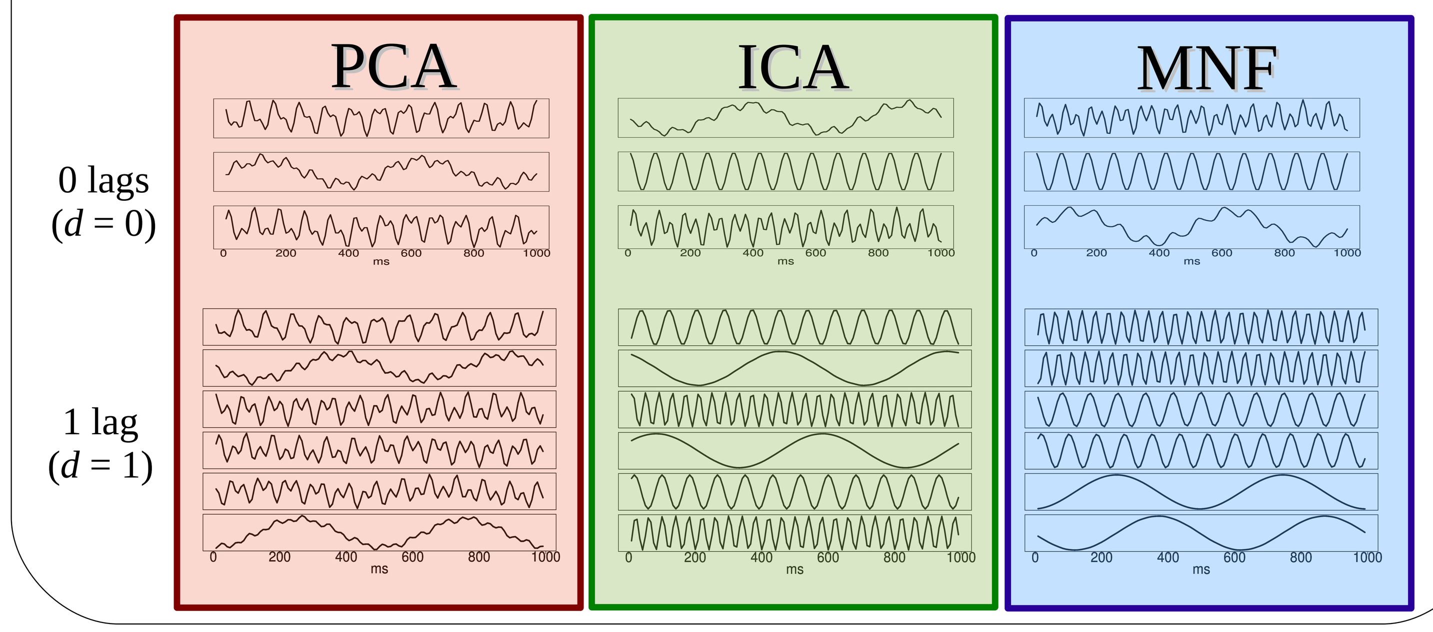
$$X^*(t) = [\, X(t),\ X(t+\tau),\ X(t+2\tau),\ \ldots,\ X(t+d\tau) \,]$$

- BSS applied to X^* now finds unmixing of original n channels and lagged channels
- Now it uses information from a window in time across the n channels (spatio-temporal)
- Vary the characteristics of the window by changing τ and number of lagged channels d
- **Advantages**: allows BSS to find phase-delayed coherence between two channels
- **Disadvantages**: more computationally intensive and increases complexity of the problem

Spatio-temporal BSS Examples

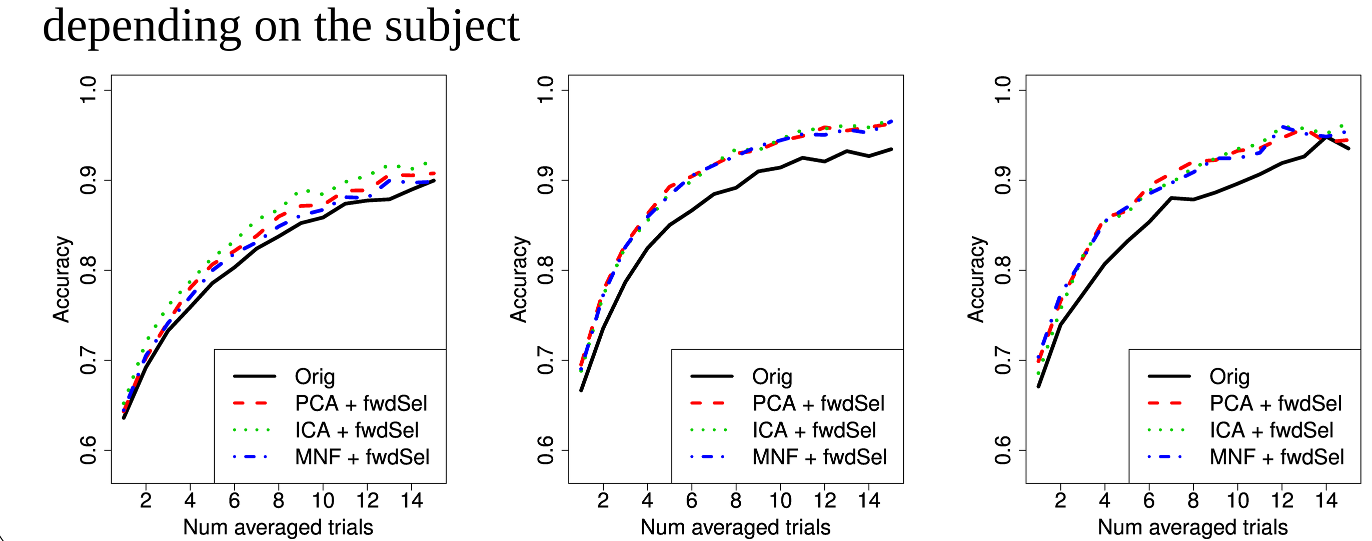
- Artificially mixed sources
- 4 sources but 2 of them are the same with a phase delay
- Purely spatial information cannot distinguish phase delays
- Temporal information allows BSS to combine into one source





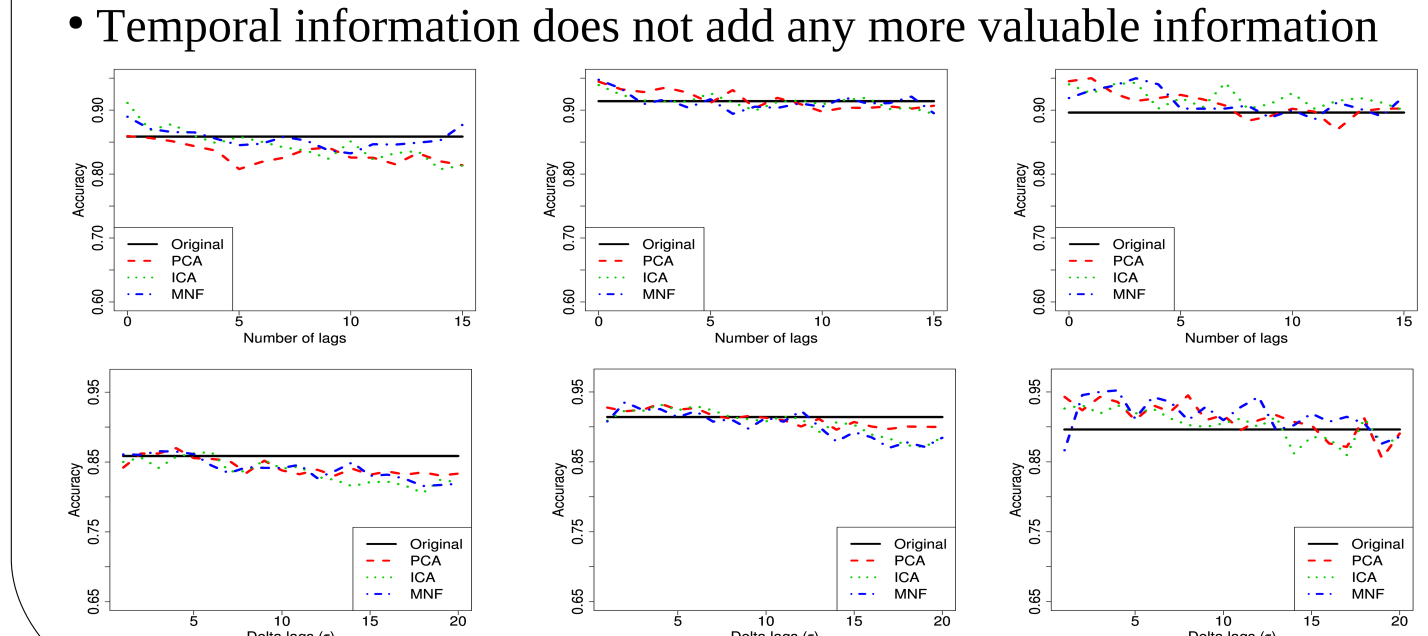
Spatial BSS Results

- 3 subjects using 8 electrodes each (Fz, Cz, Pz,Oz, P3, P4, PO7, PO8)
- BSS applied to 8 channels; sources selected through forward selection
- Results show improvements from using BSS transformation
- When using all 64 channels (not shown), performance decreases depending on the subject



Spatio-temporal BSS Results

- As number of lags d and delta lags τ increase, performance decreases
- Temporal information does not add any more valuable information



Conclusions

- BSS transform on the data increases the performance in all subjects
- More effective with a smaller subset of 8 electrodes than using all
- Temporal information adds too much complexity to the problem
- May be more effective with even fewer electrodes (2 or 3)
- More emphasis is required on the selection of the most relevant sources