Control of 2D movement signal by a noninvasive BCI in humans

paper review

Arseny Povolotsky

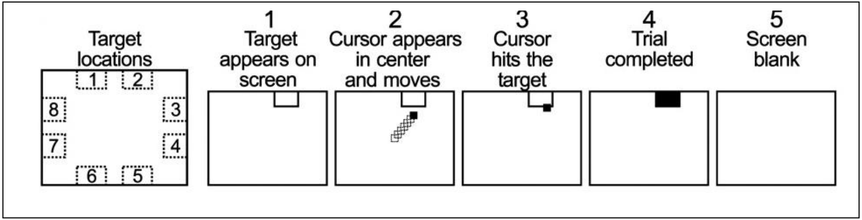
PIL

Outline

1. Methods
   - Study protocol
   - Control of cursor movement
   - Adaptive algorithm
2. Results
   - Comparison with previous non-invasive studies
   - Comparison with invasive studies
3. Potential improvements
4. Conclusion

Methods

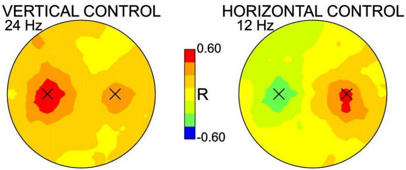
Study Protocol



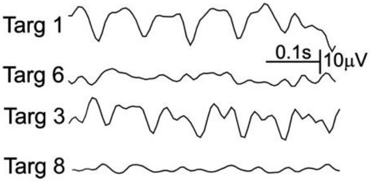
- Target appeared at one of the 8 locations on the periphery of the screen
- Target location were block-randomized
- One second later, the cursor appeared in the center of the screen
- Cursor was controlled by the user's EEG activity
- If cursor reached the target within 10 s, target flashed as reward
- Otherwise, cursor and target just disappeared
- The screen was blank for 1 s and next trial began

Methods

Control of Cursor Movement



Correlations of rhythms with target levels



Samples of EEG activity

Cursor moved every 50ms and was controlled as follows:

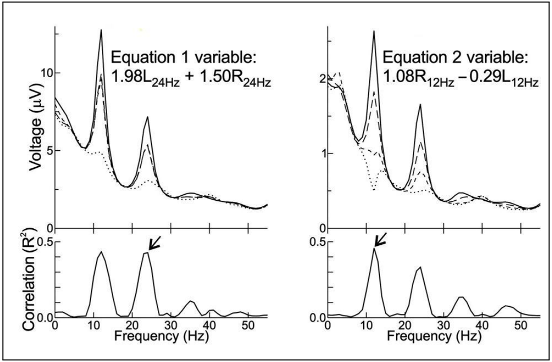
- Last 400 ms signal from C3, C4 locations
- Spatially filtered with large Laplacian filter
- Frequency analysis to determine the amplitudes in specific mu (8–12 Hz) and beta (18–26 Hz) bands

Used EEG features

- R_V, L_V amplitudes for vertical control
- R_H, L_H amplitudes for horizontal control

Cursor movements

- $M_V = a_V(w_{RV}R_V + w_{LV}L_V + b_V)$
- $M_H = a_H(w_{RH}R_H + w_{LH}L_H + b_H)$



Initial weights

- $w_{RV} := +1; w_{LV} := +1$
- $w_{RH} := +1; w_{LH} := -1$

Tuning step

- Each of the 8 possible target locations expressed as one of 4 possible vertical and one of 4 possible horizontal levels
- Least-mean-square algorithm to adjust the weights to minimize for past trials the difference between the actual target location and one, predicted by movement equations

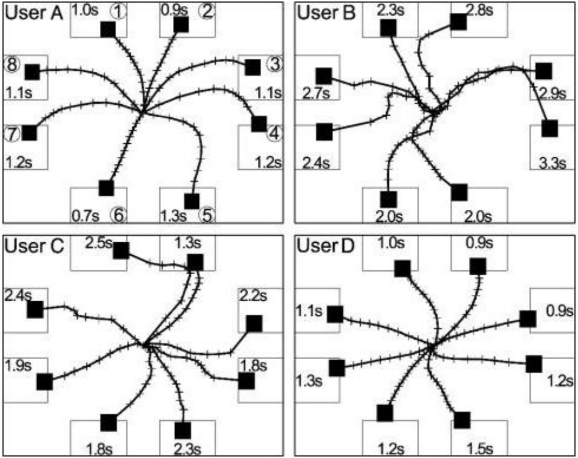
Adaptation effect

- Optimizing the online translation of EEG control
- Encouraging improvements in user's EEG control

Results

Cursor trajectories

Hit rate: 89%
Avg. time: 1.9s



Hit rate: 70%
Avg. time: 3.3s

Hit rate: 78%
Avg. time: 3.3s

Hit rate: 92%
Avg. time: 1.9s

Results

Two independent control signals

Correlation	User A	User B	User C	User D
$M_X \leftrightarrow X$	0.48	0.29	0.27	0.54
$M_X \leftrightarrow Y$	0.00	0.00	0.01	0.01
$M_Y \leftrightarrow X$	0.00	0.00	0.01	0.01
$M_Y \leftrightarrow Y$	0.44	0.31	0.40	0.54

$$\Downarrow$$

Each user developed two independent control signals:
one for horizontal and one for vertical movement

Results

Simultaneous 2D movement control

$$P_{XY} \approx P_X * P_Y$$

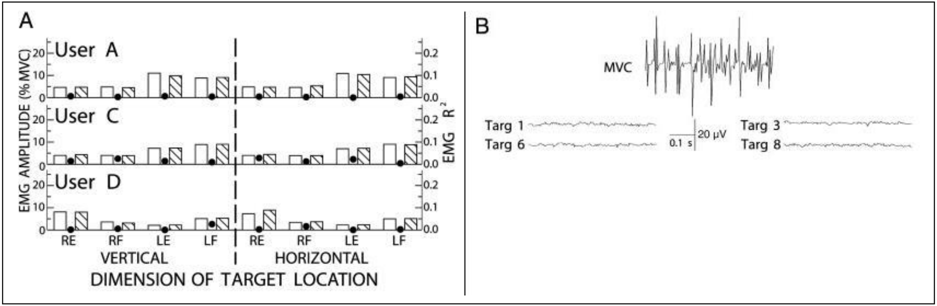
P_X — possibility of correct X-movement
P_Y — possibility of correct Y-movement
P_{XY} — possibility of correct both X-movement and Y-movement

$$\Downarrow$$

Users controlled movements
in both directions simultaneously

Results

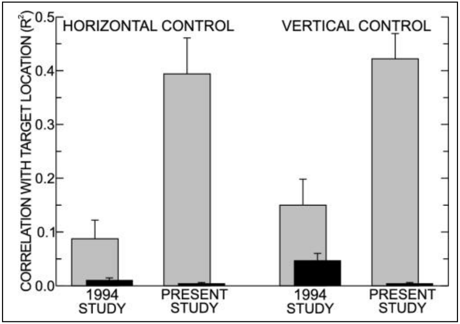
EMG activity is low and not correlated with target location



- EMG amplitude is low
  (< 10 % of maximum voluntary contraction)
- EMG amplitude is not correlated with
  vertical or horizontal levels of target locations

Results

Comparison with Previous Non-Invasive Studies



Two critical advances

- Changes in signal processing
- Adaptive algorithm

$\Rightarrow$

Significant improvement

- Correlation with appropriate dimension is much higher
- Correlation with wrong dimension is almost absent

Study	Movement time, s	Movement precision, target size as % of workspace	Hit rate, %
Serruya et al.	1.5	2.3	—
Taylor et al.	1.5	1.3	86
Carmena et al.	2.2	7.7	89
Wolpaw et al.	1.9	4.9	92

$\Downarrow$

Non-invasive BCI shows nearly the same results as invasive ones

Potential improvements

- Refining user training protocol
- Additional EEG recording locations
- Additional frequency bands and/or time-domain EEG features
- Improving the translation of EEG features into cursor movements
- Recording activity from cortical surface

Conclusions

EEG activity can reflect convey user's intent

People can learn to use scalp-recorded
EEG rhythms to control 2D cursor movement

Real-time efficiency

In movement time, precision and accuracy,
the results are comparable to those with invasive BCIs

A skill that user and system master together

- Control develops gradually over training sessions
- User acquires better EEG control
- BCI system focuses on rhythms user is best to control

Thank you!

User A

- A man age 41
- Complete T7 spinal cord injury since age of 15
- Participated in several studies of 1D cursor control

User D

- A man age 23
- Incomplete C6 spinal cord injury since age of 16
- Participated in one study of 1D cursor control for years earlier

User B

- A woman age 27
- No disabilities
- Participated in one study of 1D cursor control

User C

- A man age 31
- No disabilities
- No previous experience with BCI

Appendix B

EEG activity recording

- 64 standard electrode locations distributed over the entire scalp
- Channels are referenced to the right ear
- Bandpass 0.1 – 60 Hz
- Signals amplified by 20000
- Signals digitized at 160 Hz