Brain-Computer Interface Speller
Write your thoughts using your brain signals!

A **brain–computer interface** (BCI) allows the selection of symbols without any muscular movement. It records brain activity using EEG electrodes placed on the scalp. This technology unlocks communication without relying on motor output and can even restore speech for individuals who are unable to move, such as patients with ALS.

In this demonstration, a cap with gel-based EEG electrodes is placed on the head to measure neural activity. The computer learns the user's brain patterns and is calibrated to infer which symbol the user is focusing on, allowing to form sentences and even synthesize speech.
Please, individuals with epilepsy or a history of epilepsy cannot participate in the demonstration.

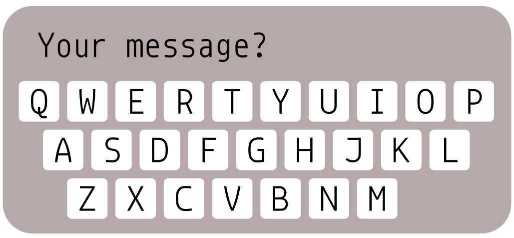
1 **Introduction** (3 minutes):
You will be fitted with an EEG cap equipped with 8 gel-based electrodes that record your brain activity. It feels like a futuristic device and is completely painless.

2 **Live EEG** (5 minutes):
On the screen, you will see a real-time visualization of your own brain activity. You can observe eye blinks and eye movements, as well as how active your brain becomes when you are concentrating or in a resting state.

3 **Training** (2 minutes):
The system is calibrated to your unique neural patterns. You will be asked to look at a symbol ten times, after which all symbols will flash for four seconds. This allows the machine learning to recognize how your brain responds to the stimuli.

4 **Calibration** (1 minute):
In this step, no action is required from you. The computer automatically learns to recognize your brain signals based on the labeled training data. This process also generates a compelling visualization of how your brain reacts to the flashes.

5 **Writing a message** (5 minutes):
Now comes the most enjoyable part. The system is ready to interpret your brain activity and infer which symbol you are focusing on. It can select a symbol in as little as 0.5 to 4 seconds, which is then added to a sentence displayed at the top of the screen and can even be spoken aloud. You decide what you want to express, how long you continue, and when you stop. How cool is that?



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c-VEP BCI Speller Scientific Explanation

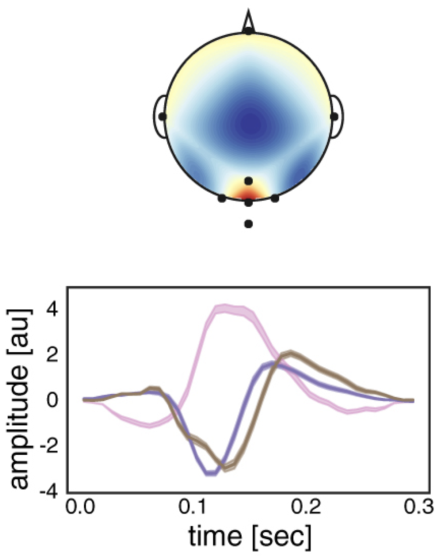
Brain activity is recorded using electroencephalography (EEG), which is highly practical compared to many other measurement techniques. With EEG, we cannot directly determine whether someone is looking at or thinking of a specific symbol. However, what we can detect reliably is whether, and at what moment, a flash has been seen. Here is where the interesting part begins: each symbol is associated with its own characteristic sequence of flashes, functioning like a unique barcode.

The expectation is that the brain responds differently when a person focuses on one symbol compared to another because each symbol has a different flashing pattern. Thus, we are not reading directly from the brain which symbol is being viewed or imagined, but rather detecting which flash pattern the user has seen. Since we know which pattern corresponds to which symbol, we can select the correct symbol on the user's behalf.

The system, however, must first learn to adapt to the user's individual neural responses. Every person reacts slightly differently to the flashes, and EEG measurements contain substantial noise. To handle this, we rely on machine learning algorithms that learn to recognize patterns within the data.

Compared with other approaches worldwide, the method developed in Nijmegen is particularly distinctive. It matches the performance of the fastest non-invasive BCI available today, yet requires very limited data to operate effectively. The key insight lies in the following idea:

Even though all flash patterns differ, they share one essential element: a single flash. Instead of learning the brain responses to an entire 4-second flash sequence, we model the neural activity elicited by a single flash. In the illustration on the right, the response to three types of flashes lasts roughly 300 milliseconds. This shorter response window allows many flashes to occur within 4 seconds. Crucially, this means we do not need to model all 32 possible flashing sequences individually, because they all consist of the same type of flashes, merely occurring at different points in time.



If you would like to read more about this topic, here are some relevant references:

- Thielen, J., van den Broek, P., Farquhar, J., & Desain, P. (2015). Broad-Band visually evoked potentials: re(con)volution in brain-computer interfacing, **PLOS ONE**. https://doi.org/10.1371/journal.pone.0133797
- Thielen. J. Marsman, P., Farquhar.J.& Desain, P.(2021), From full calibration to zero training for a code-modulated visual evoked potentials for brain-computer interface. **Journal of Neural Engineering**. https://doi.org/10.1088/1741-2552/abecef
- Verbaarschot, C., Tump, D., Lutu, A., Borhanazad, M., Thielen, J, van den Broek, P.,.... & Desain, P. (2021). A visual brain-computer interface as communication aid for patients with amyotrophic lateral sclerosis. **Clinical Neurophysiology**. https://doi.org/10.1016/j.clinph.2021.07.012
- Martinez-Cagigal, V., Thielen. J., Santamaria-Vazquez, E., Pérez-Velasco, S., Desain, P., & Hornero, R. (2021). Brain-computer interfaces based on code-modulated visual evoked potentials (c-VEP): A literature review. **Journal of Neural Engineering**. https://doi.org/10.1088/1741-2552/ac38cf
- Dold, M., Pereira, J., Sajonz, B., Coenen, V. A., Thielen, J., Janssen, M. L., & Tangermann, M. (2025). Dareplane: a modular open-source software platform for BCI research with application in closed-loop deep brain stimulation. **Journal of Neural Engineering**, 22(2), 026029. https://doi.org/10.1088/1741-2552/adbb20

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