

# Optimizing P300-speller sequences by RIP-ping groups apart

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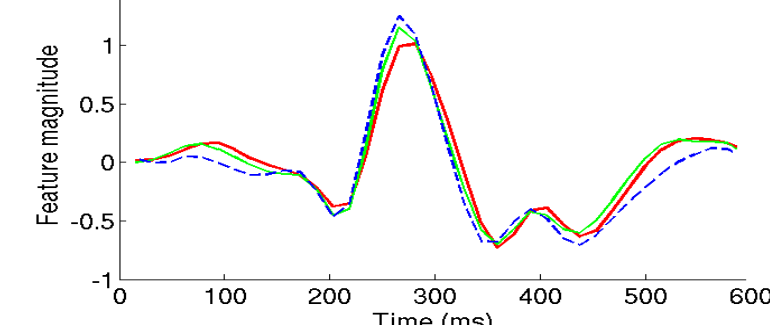
A new strategy for presenting P300-speller stimulations is introduced and validated. The method, which we refer to as RIPRAND, is inspired by the theory of Restricted Isometry Property matrices in Compressed Sensing. It can be applied to any display grid size, and for any target flash frequency allowing for a highly customizable interface both for the user and the application. In this study, the concepts behind the generation of these novel sequences are described and validated numerically. Further validation has been performed recently which shows that RIPRAND patterns are particularly effective as the size of the display grid increases (i.e. more characters are available for spelling).

## The P300 speller

Selection of a target character in the P300 speller can be described as a 2 stage process: P300 detection and evidence accumulation

The first stage consists in determining the presence of a P300 potential following a stimulus, based on the EEG. Typically, a linear classification rule is employed such as:

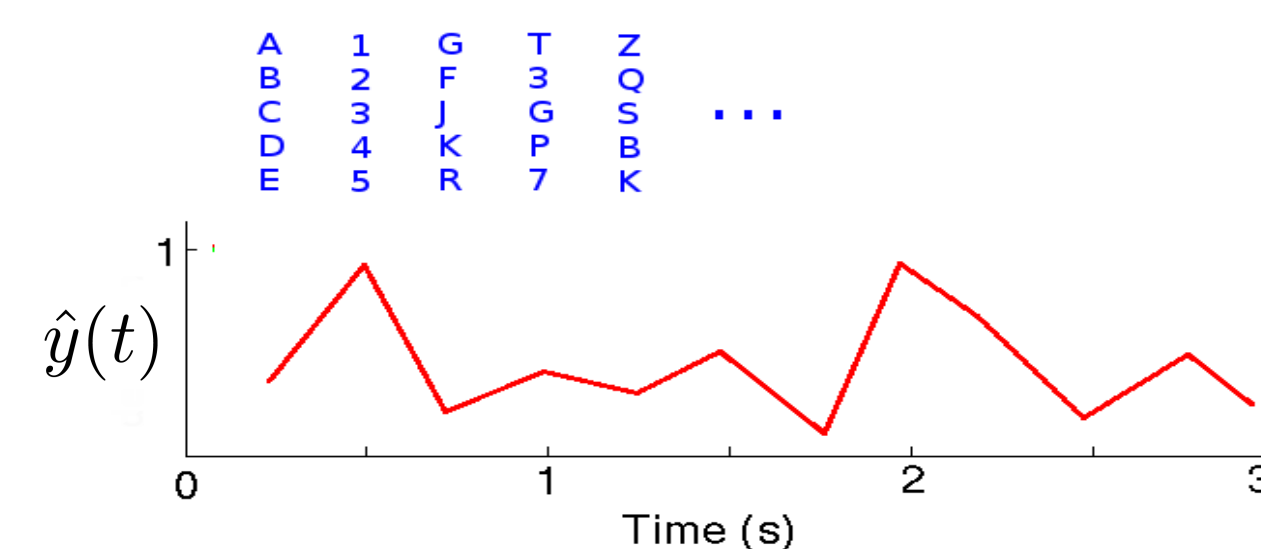
$$\hat{y}(t) = \omega^T x(t)$$



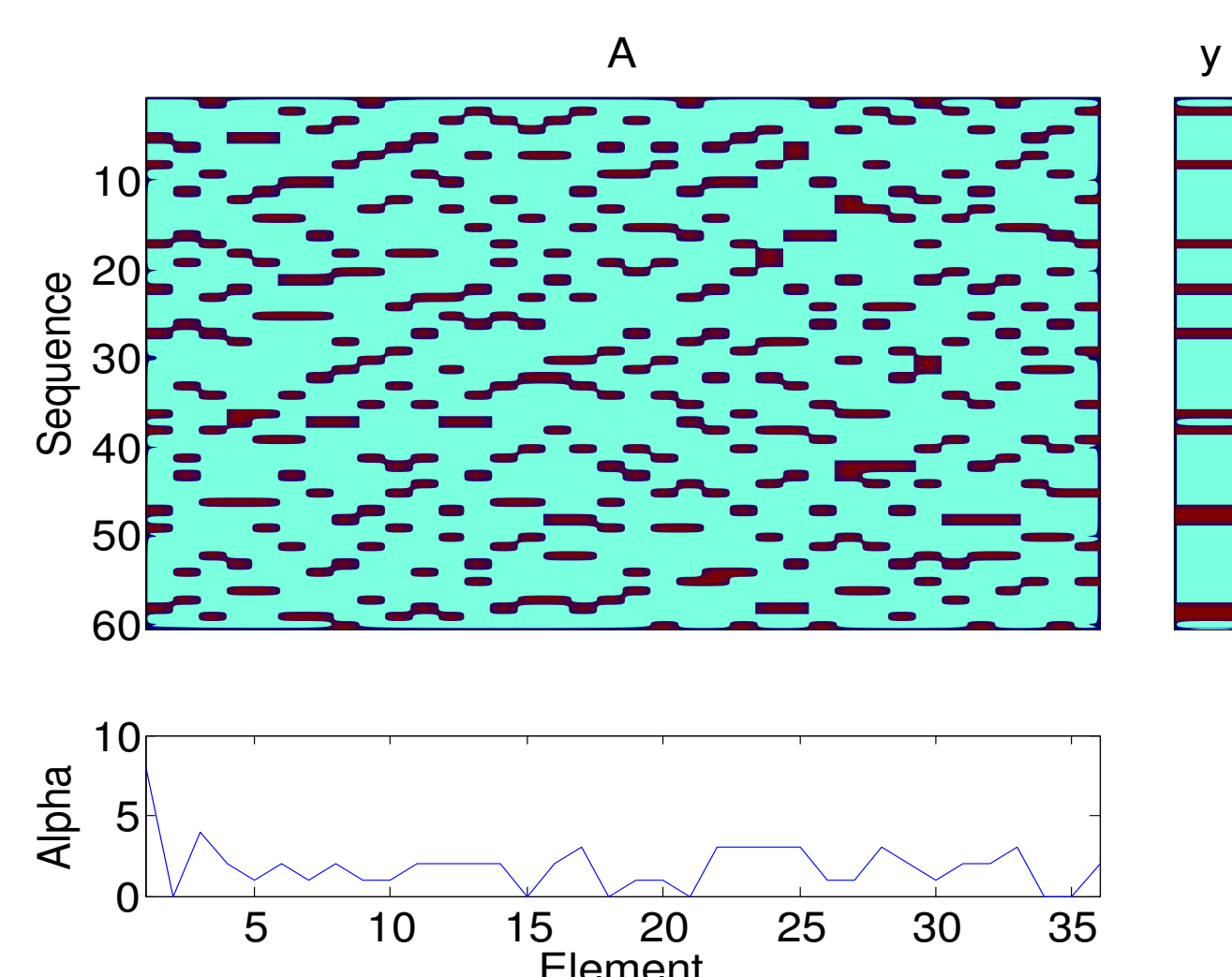
Based on the outputs of this stage, evidence is accumulated over multiple flashes in order to select a particular character:

$$\alpha(t) = \alpha(t-1) + a(t) \cdot \hat{y}(t)$$

Here, we optimise  $a(t)$ , that is the sequence in which characters are flashed onscreen.

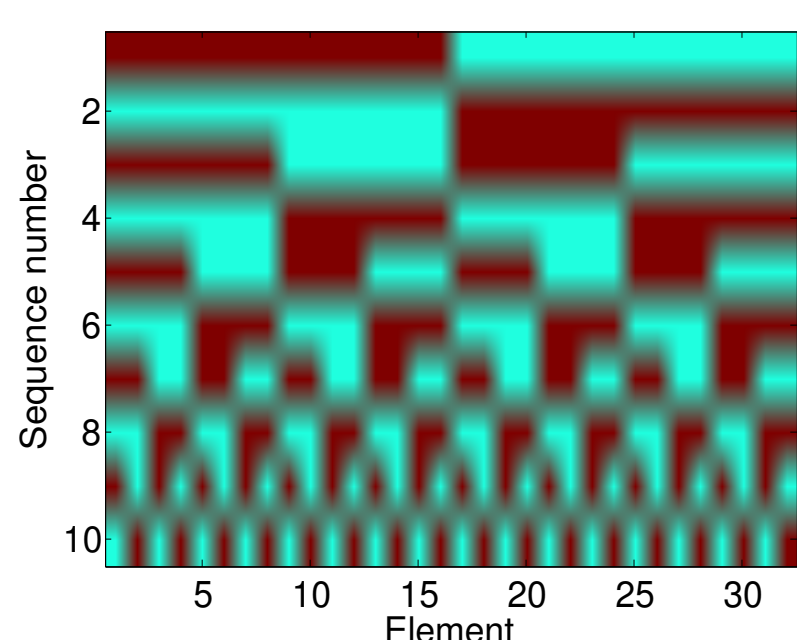


The aim of this study is thus to optimise the sequence of flashes to produce a faster and more accurate P300 speller by reducing the number of flashes required for character selection using an early stopping criterion, while reducing the number of incorrect selections.

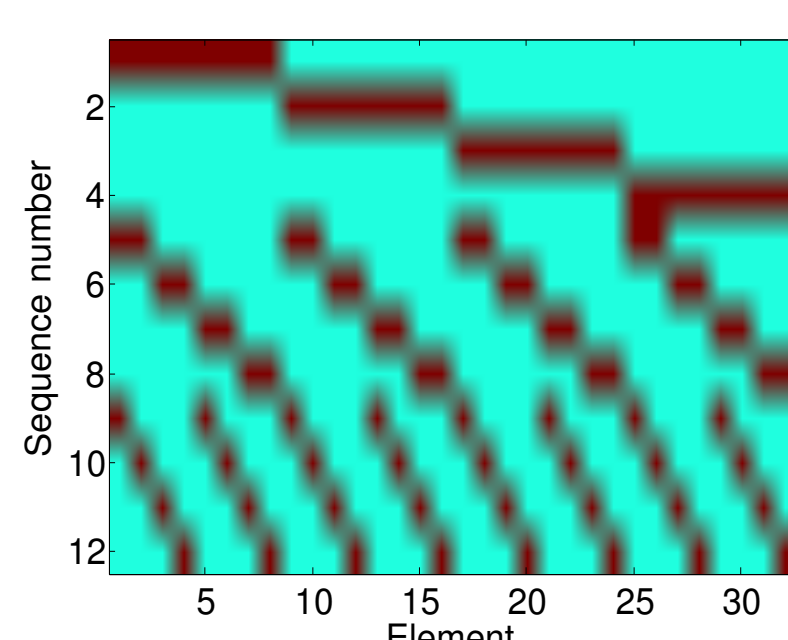


## Optimising the presentation of stimuli

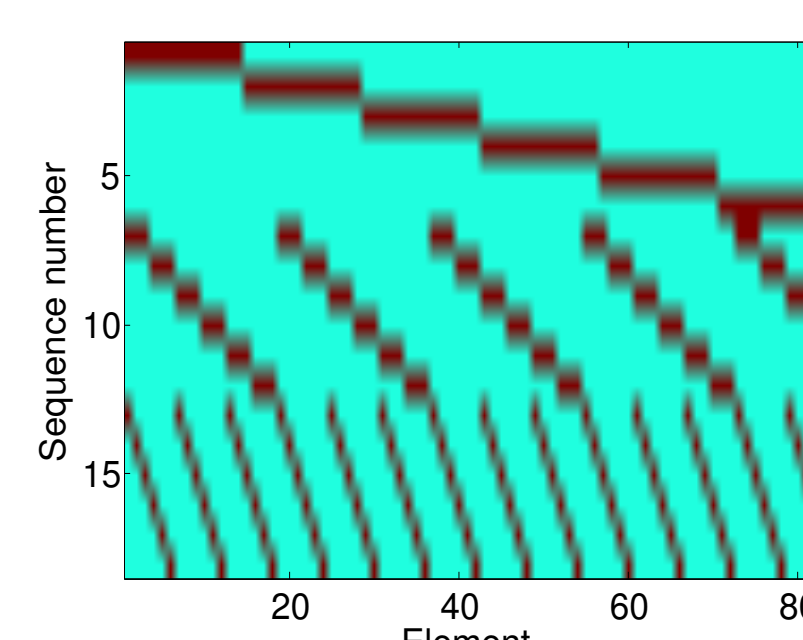
The procedure for generating the sequences is inspired by restricted isometry property (RIP) matrices, but can simply be described using dichotomic search as an analogy:



A 1 in 2 search strategy for a 32 element space. Note all elements are sensed uniformly



A 1 in 4 search strategy for a 32 element space.

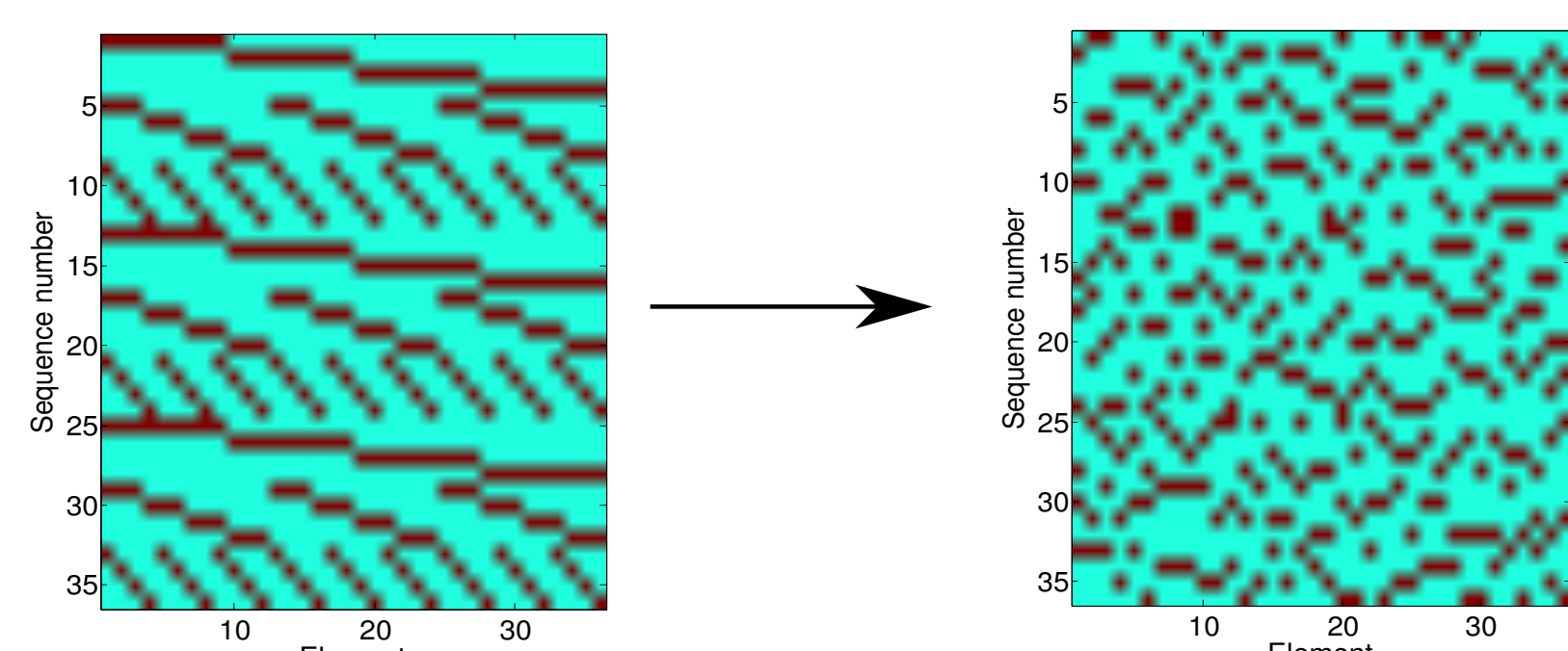


A 1 in 6 search strategy for a 81 element space.

Thus, the RIP inspired strategy used here is a form of dichotomic search with constraints that **all characters are sensed uniformly over a repetition** and **the number of characters sensed at once is limited**.

By randomising the patterns over the elements, the patterns appear random to the user, however they preserve the beneficial properties of the RIP template: **uniform flashing of elements**, a **reduction of double flashes** and **minimisation of elements being flashed together repeatedly**.

For each repetition of the template matrix, a new randomisation over the elements is applied to generate patterns which appear random visually.

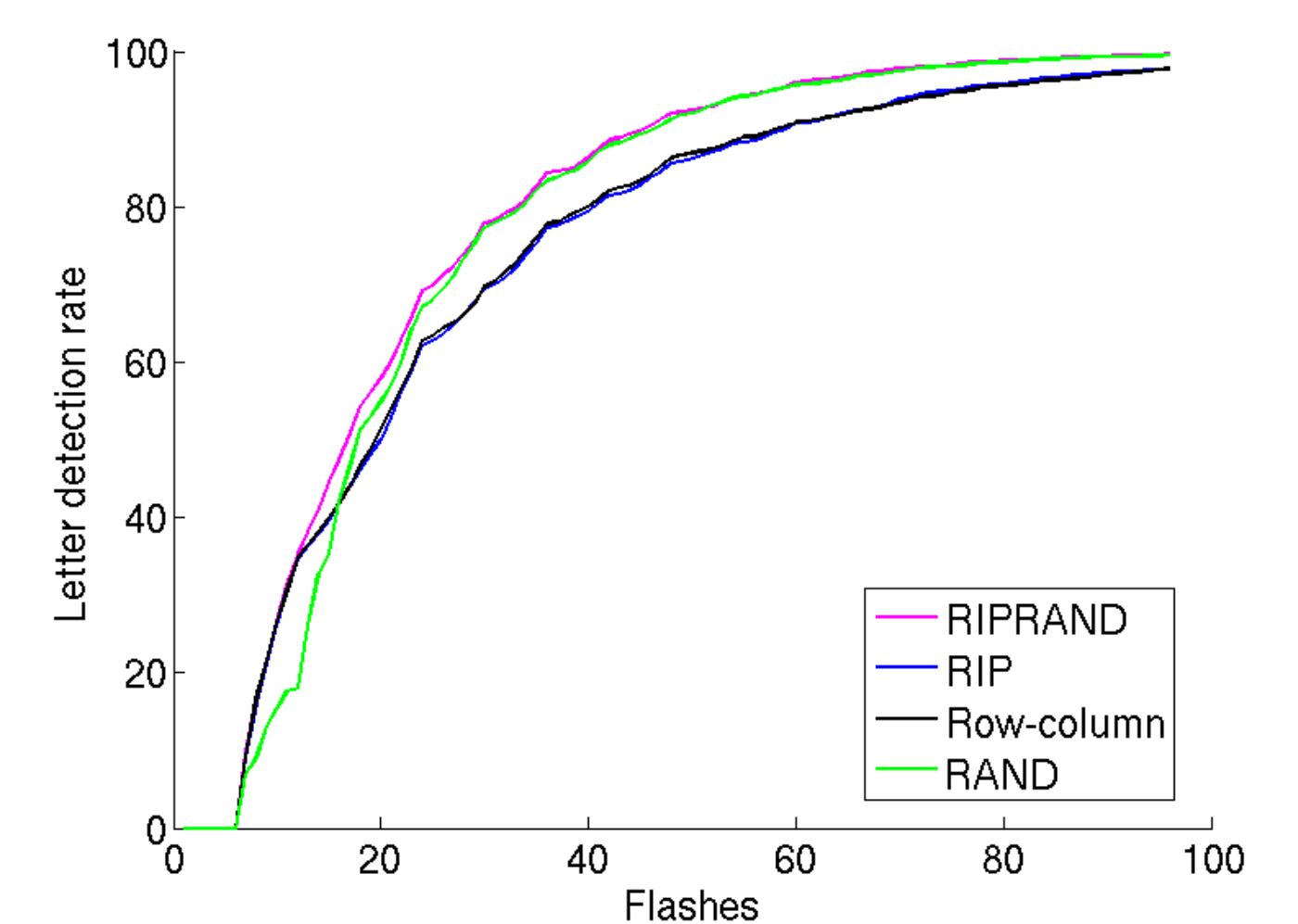


## Results and conclusions

The results of this study are primarily verified in simulation, based on a simulated P300 detection stage calibrated on real data. In particular, the performance of different types of sequences was investigated.

### Simulation results:

Note RIPRAND achieves the highest letter classification rate overall, notably performing better than purely random sequences (RAND) from 6-20 flashes, and outperforming row-column and purely RIP patterns after the first repetition (12 flashes).

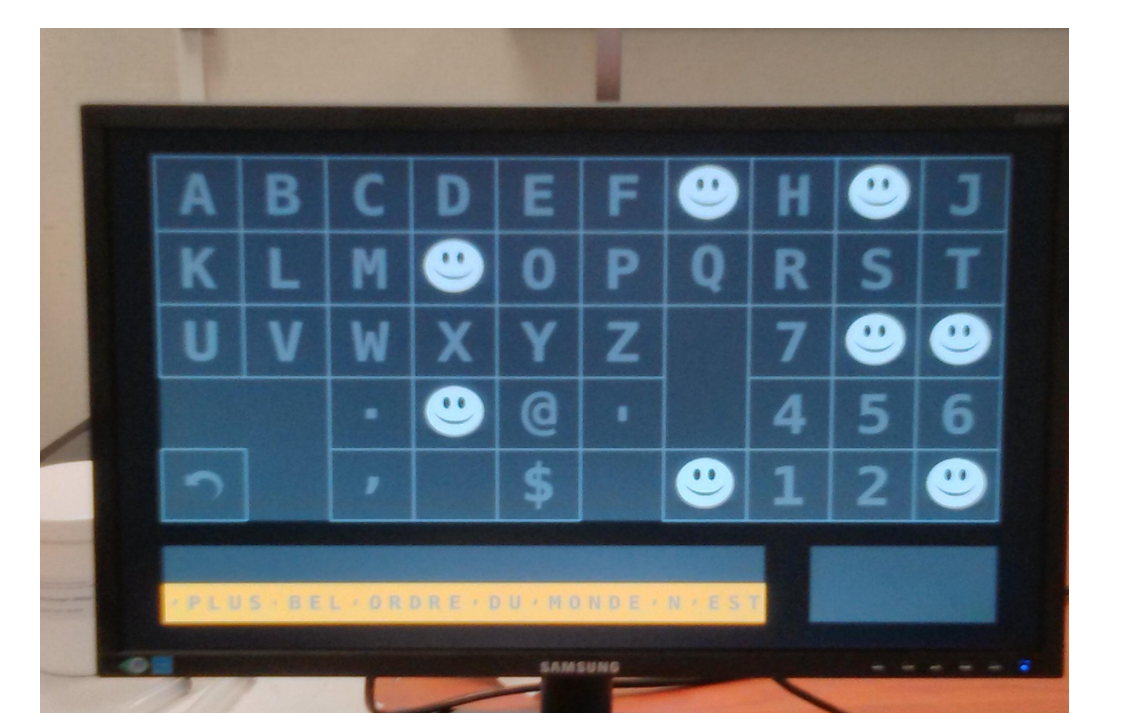


Type	Accuracy	Flashes	Bit-rate
6x6 RIPRAND 1/6	94.5%	34.2 (13.9)	62.8
6x6 RAND 1/6	94.2%	35.6 (14)	60.5
6x6 RIP 1/6	93.6%	43.7 (18.6)	47.6
6x6 Row column	93.7%	43.7 (18.3)	47.9
9x9 RIPRAND 1/6	93.9%	42.9 (15.2)	63.8
9x9 RIPRAND 1/9	91.4%	53.1 (19.3)	49
9x9 RAND 1/6	93.1%	42.9 (15.4)	62.8
9x9 RIP 1/6	91.2%	59.5 (21)	43.9
9x9 Row column	87.2%	66.9	37

The system employs early stopping to maximise bit-rate and subject engagement. In simulation, it can be seen that RIPRAND in particular achieves very high theoretical bit-rate due to high accuracy and a low number of flashes required. Note that the difference between RIPRAND and row-column is particularly pronounced on larger grids.

### Online performance:

The online system uses smiley based flashing, early stopping and a Bayesian framework for accumulation. Videos of the interface are available on the Athena Inria youtube channel.



The system has been validated online on 20 subjects showing high bit-rates and accuracy.

	Accuracy	Flashes	Bit-rate	Theo. Bit-rate
6x6 Row-Col	92.2%	21.6	30.1	71.3
6x6 RIPRAND 1/6	93.3%	21.6	31.2	72.7
6x6 RIPRAND 1/5	93.3%	24.9	28.7	62.7
6x6 RIPRAND 1/4	92.2%	20.7	30.8	74.1
9x9 Row-Col	74.5	53.8	18	30.8
9x9 RIPRAND 1/9	86	48.4	23	39
9x9 RIPRAND 1/6	88	42.1	26.5	47.9
9x9 RIPRAND 1/5	83.5	41.6	24.6	45.9

## Further and future work

A novel method of generating flashing patterns for P300 speller stimulation are proposed and validated here. The benefits of the method are as follows:

- 1) Applicable to any size or shape of display grid.
- 2) Complete control over flashrate.
- 3) Significant reduction of double flashes.
- 4) Improvement in bit-rate as compared to row-column, particularly for larger display grids.
- 5) Designed to be used with early stopping, which creates a more dynamic, and thus engaging, interface.

High bit-rates have been achieved over 20 subjects (31b/s on a 6x6 grid and 26b/s on a 9x9 grid) which is competitive with the state of the art. Current work is focused on reducing the calibration time and updating the classification algorithm online to improve performance and usability over long-term usage.

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