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Neural Interfaces and Brain Signal Decoding

Random Visual Evoked Potentials (RVEP) for Brain-Computer Interface (BCI) control

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Introduction – Issues in VEP BCI development

VEP generation

Most prominent parts of a VEP to a single stimulus lasts for approximately 250 ms post-stimulus. Successive stimuli within a lower time interval result in mixed VEPs and it is not entirely clear how this mix-up proceeds:

– Simple overlap of responses? [1,2]
– Does the brain entrain to the modulated stimuli? [3]

Modulation patterns

In order to get best classification performances it is required to find modulation patterns evoking brain responses which can be differentiated between others as effectively as possible.

Methods – RVEP model

General model description

Instead of using a static modulation pattern for each target, fully random patterns are used. A ridge regression model is trained using each 250 ms window of spatially filtered EEG data as predictors and the current random bits as responses.

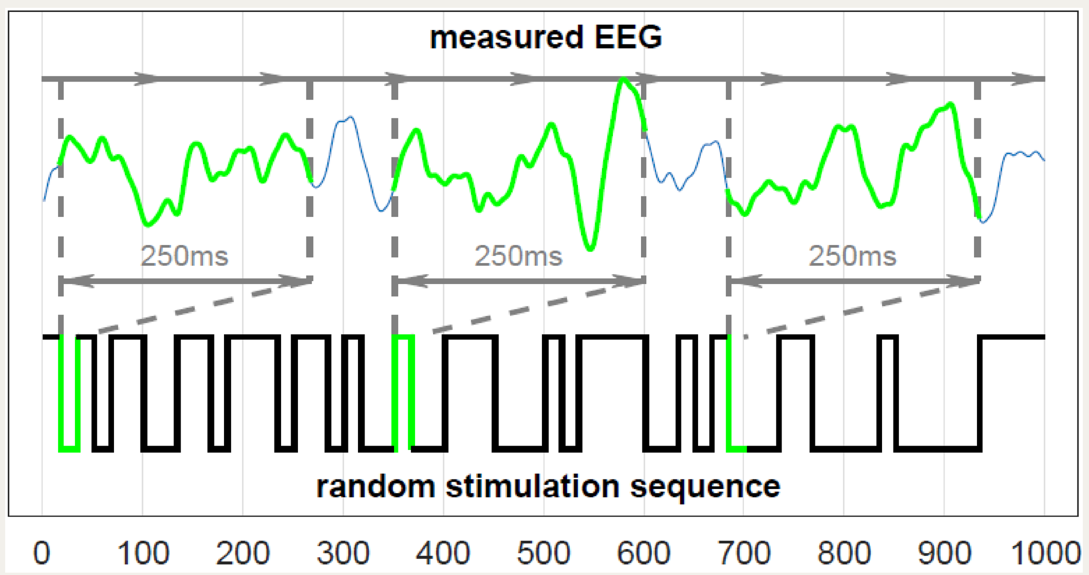

Figure 1: Training of the RVEP model. Each 250ms window of the spatially filtered EEG data will be projected to current bit (highlighted in green) of the corresponding random stimulation sequence.

Methods – Prediction

Bit prediction

Contrary to recent VEP BCIs predicting whole trials, the RVEP model predicts the modulation sequence continuously. For this, the regression model predicts a real number for each window of 250 ms of EEG data which in turn is transferred to a bit sequence by a threshold of 0.5.

Target prediction

The layout consists of a 8 x 4 keyboard matrix with 32 targets in total. For the target prediction we used two distance measures between all possible target modulation sequences and

– the predicted bit sequence (*Hamming distance*)
– the model prediction (*Euclidean distance*)

The target with lowest distance was selected.

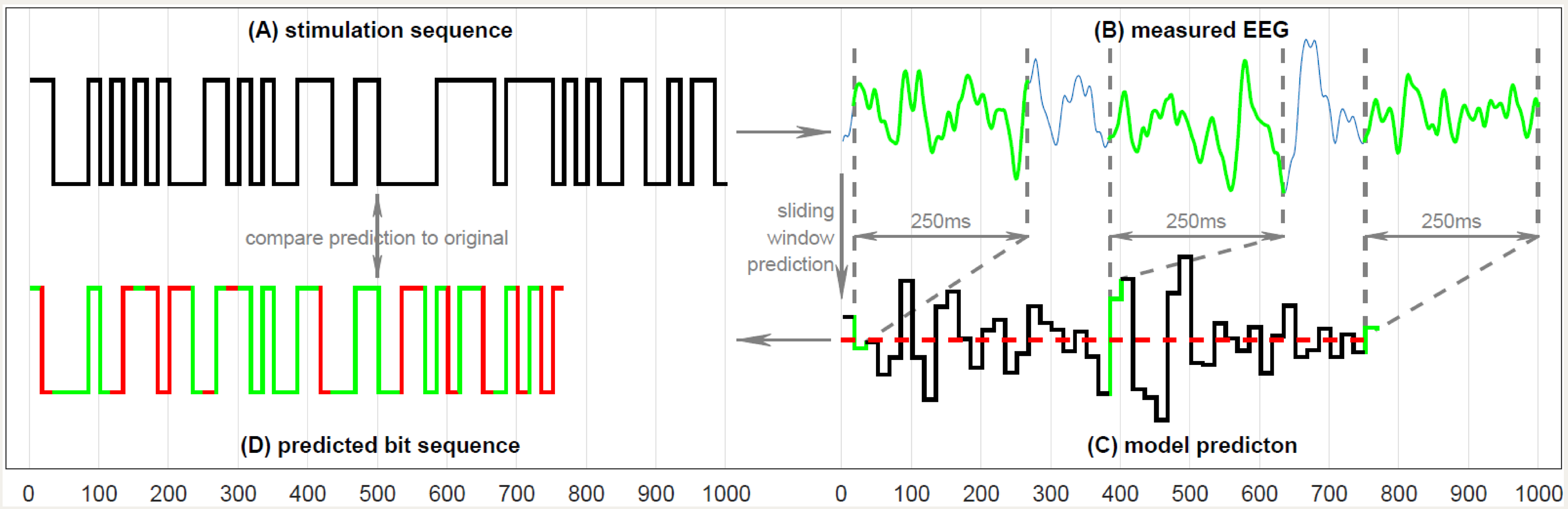

*Figure 2: Schematic of the RVEP bit and target prediction. **A** Random stimulation sequence of a target. **B** 250ms windows (highlighted in green) are slided sample-wise over the spatially filtered EEG signal. **C** Regression model predicts a real number for window (again, highlighted in green). The red dashed line indicates the threshold of 0.5. **D** Each value above 0.5 is interpreted as 1, and 0 otherwise. Predicted bit sequence can be compared to the stimulation sequence (match = green, mismatch = red).*

Results – Bit prediction

Subject	ACC (%)	ITR (bpm)
S1	54.8	24.3
S2	60.6	116.7
S3	57.2	55.3
S4	62.9	174.5
S5	58.2	70.6
S6	58.3	72.5
S7	60.0	104.0
S8	55.9	35.6
S9	**63.7**	**197.2**
Mean	**59.1**	**94.5**

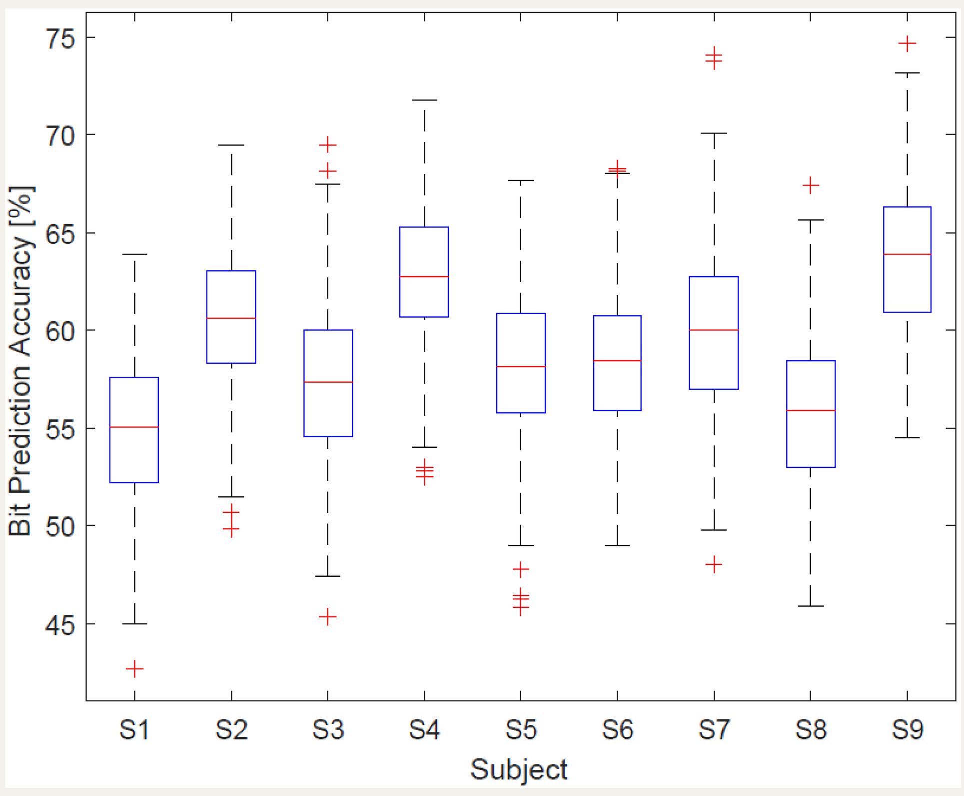

Table 1 and Figure 3: Results of the bit prediction of all trials of all 9 subjects. Each trial lasts for 2 seconds (120 bit). The accuracy is given in percentage of correctly predicted bits and the information transfer rates (ITR) were estimated excluding the inter trial time. The table shows the average accuracies of all trials per subject, whereas the figure shows a box plot of all trials of each subject.

Results – Target prediction

Subject	Hamming ACC (%)	Hamming ITR (bpm)	Euclidean ACC (%)	Euclidean ITR (bpm)
S1	28.1	17.5	31.9	21.7
S2	78.4	95.4	87.8	115.8
S3	47.8	42.5	51.6	48.1
S4	91.6	124.9	93.1	128.9
S5	53.1	50.4	59.7	60.9
S6	52.2	49.0	65.6	71.0
S7	69.1	77.2	76.9	92.3
S8	33.1	23.1	37.8	28.9
S9	**91.9**	**125.1**	**97.8**	**142.2**
Mean	**60.6**	**67.3**	**66.9**	**78.9**

Table 2: Results of the target prediction of all trials of all 9 subjects using the Hamming distance and the Euclidean distance to identify the target, respectively. The keyboard layout had 32 targets and each trial lasts for 2 seconds (120 bit). The information transfer rates (ITR) were estimated excluding the inter trial time for comparison.

Summary and Discussion

– We introduced a new approach to predict arbitrary VEP modulation sequences
– Random modulation codes are used as we assume they will cover most possible "mixed" VEPs
– Using the bit prediction we got ITRs of up to 197.2 bpm and a target prediction with an ITR of up to 142.2 bpm
– Trials can have an arbitrary length and phase-lock is not required, therefore, it can simply be used for an asynchronous BCI
– The method can be used to identify modulation sequences (or properties of them) which result in well distinguishable VEPs
– Variances between subjects are high, later we found that this was the result of synchronization errors due to the windows display driver model (WDDM)

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