A novel BCI based on ERP components sensitive to configural processing of human faces.

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Background

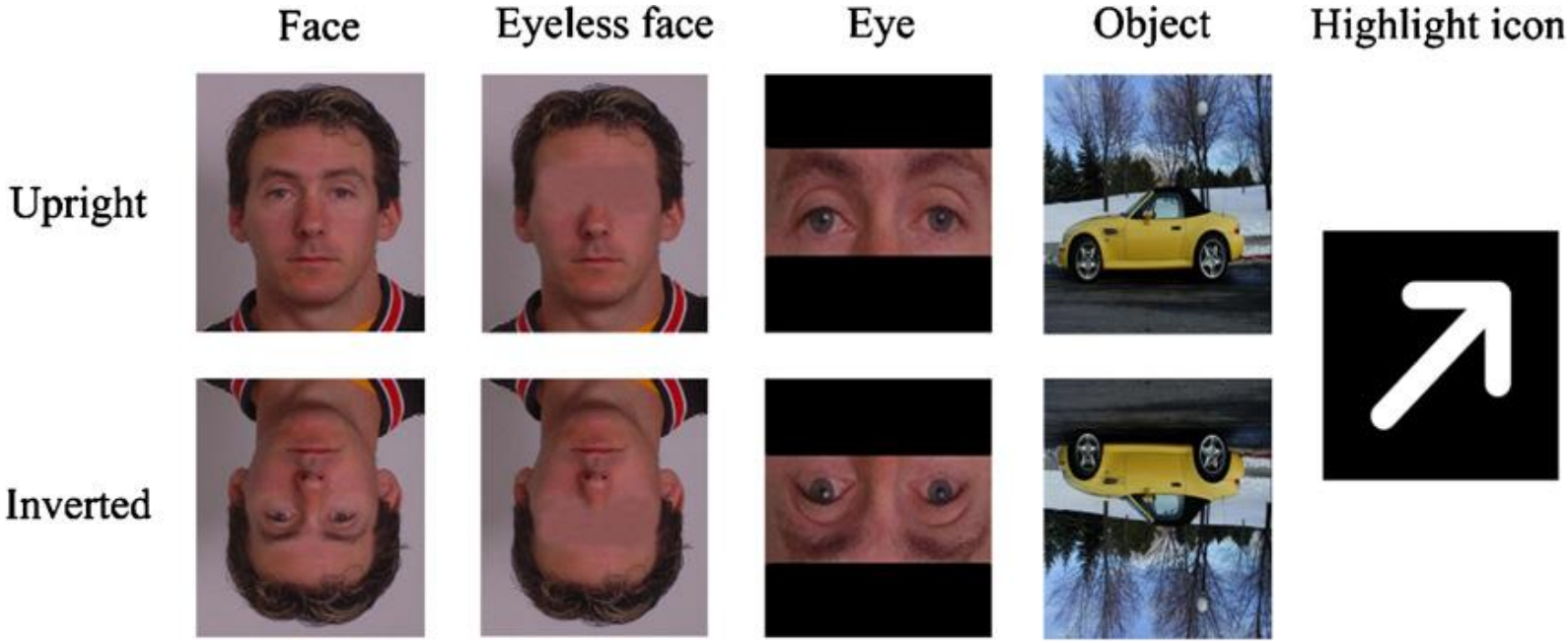
- Face-sensitive event related potentials(ERPs)
  - Related ERPs
    - N170 : a large negative component peaking at the lateral occipito-temporal sites between 140 ~ 200ms
    - VPP(Vertex Positive Potential) : a large positive component at the fronto-central sites with a similar latency to the N170
    - P1, N250
  - Previous study
    - Oddball paradigm-based BCI with stimuli of natural faces
    - Online accuracy reaches over 90% with two trials (better performance using facial images instead of using intensified icon stimuli)
    - The prominent features derived from the facial images at visual cortex, which may be associated with the cognitive components reflecting face perception.

Introduction

- Motivation
  - Face perception rely more on configural information rather than other visual object perception.
  - The inversion of a face can disrupt the configural face information, thereby making the face processing slower and more difficult.
  - The two components N170 and VPP are believed to reflect the configural processing of the face, their amplitudes and latencies can be modulated by the inversion of the face.
  - Could the signal modulation caused by the loss of configural face information be applied to the BCI using stimuli of facial images and improve the system performance?

Methods

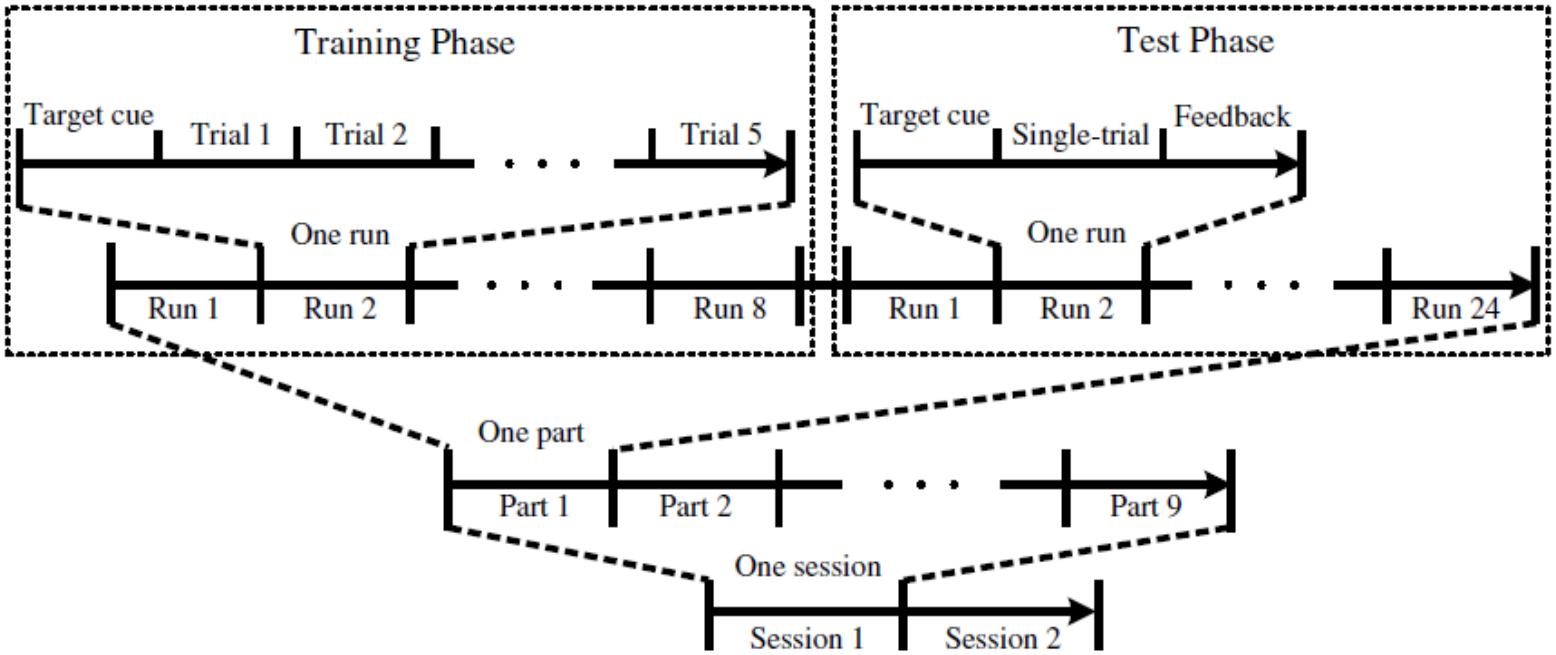
- Subjects
  - 7 healthy right-handed volunteers (aged from 24 to 49, all males)
- Stimuli
  - 9 types of stimuli on ERP components(N170, VPP, and P300)



  - 4 natural human faces(2 females) : face-related stimuli
  - 4 objects(car, ship, bicycle and house) : object stimuli

Methods

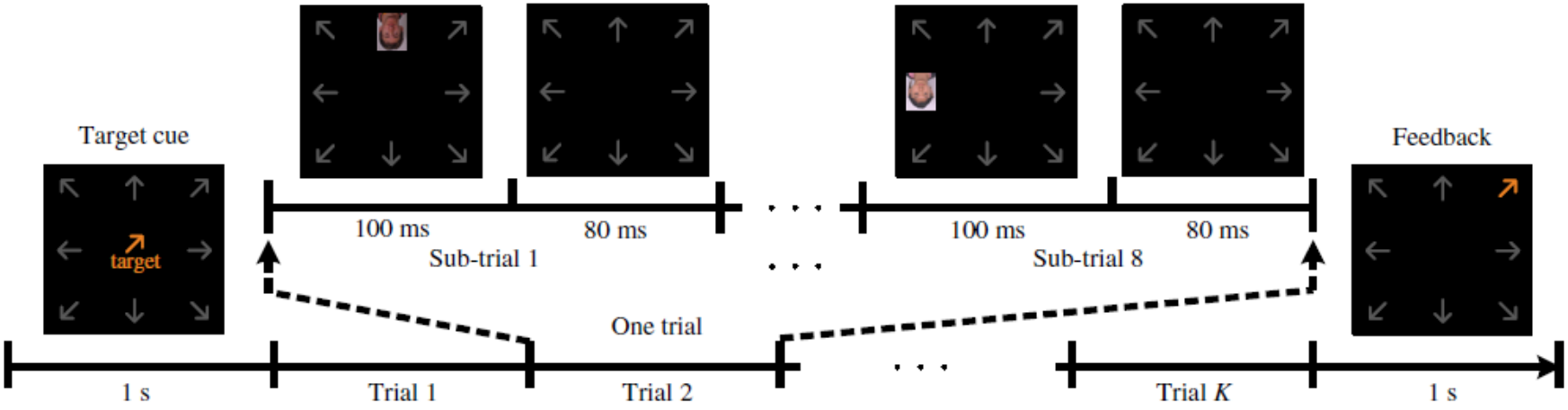
- Paradigm
  - Each subject completed two experimental sessions on two separate days. (interval : less than three days)
  - Each part being tested with same stimulus type.



  - Total 48 direction commands were implemented for each subject in the online test phases of the two sessions

Methods

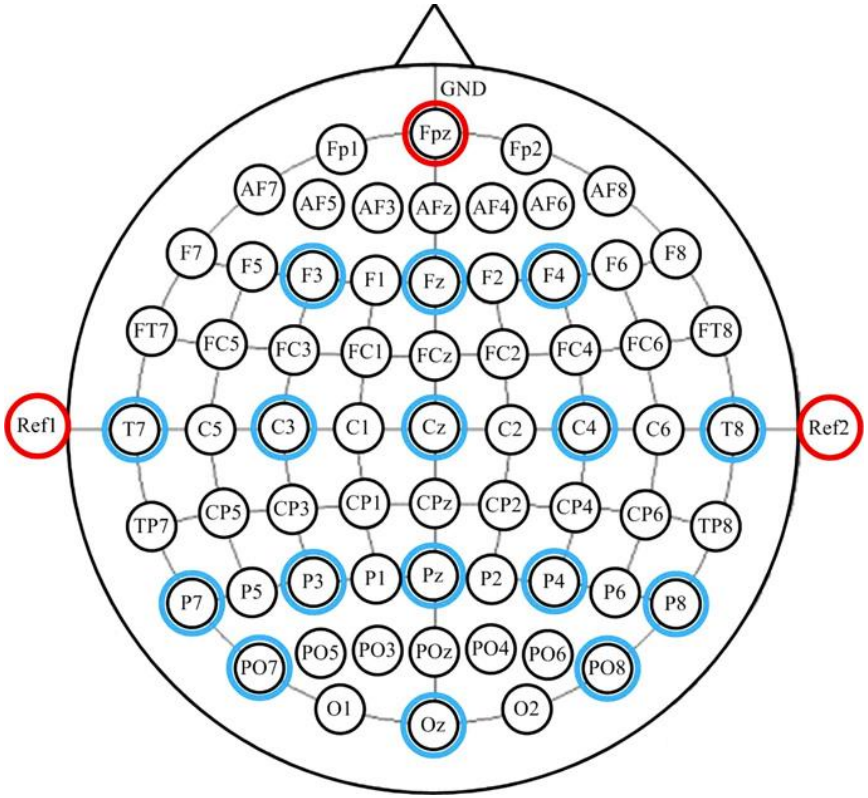
- Paradigm
  - The timing of one run



- Training phase : K=5, each run consisted of 40 flash sub-trials (5 targets and 35 non-targets) with no feedback
- Online test phase : k=1(single trial), feedback was provided.

Methods

- EEG acquisition
  - 256 Hz sampling rate with the g.USBamp amplifier (high-pass and low-pass filters 0.1Hz and 30 Hz; a notch filter 50 Hz)
  - 16 electrodes were used (F3, Fz, F4, T7, C3, Cz, C4, T8, P7, P3, Pz, P4, P8, PO7, PO8, Oz, two ear references, and one ground on the Fpz)



Methods

- Feature extraction
  - 700 ms data segment after baseline corrected (100 ms pre-stimulus interval was extracted)
  - Total 320 such data segments consisting of 40 targets and 280 non-targets were derived from each part during the training phase.
  - Each data segment was downsampled to 21 Hz after 12-point moving average.
  - A spatiotemporal feature vector with dimension of 240 (i.e. 16 channels × 15 sampling points)
  - 320 feature vectors were collected for each type of stimulus.
- Classification
  - Linear discriminant analysis(LDA) was used.
  - Procedure
    - Eight spatiotemporal feature vectors were extracted during the single trial.
    - Calculate their posterior probabilities belonging to the target class.
    - stimulus direction with the maximal posterior probability was detected and presented to the subject as feedback.
  - Classification accuracy was averaged over the two sessions.

Methods

- Evaluation
  - Information transfer rate(ITR)

$$ITR = M\left\{\log_2 N + P\log_2 P + (1-P)\log_2\left(\frac{1-P}{N-1}\right)\right\} bits/\min$$

    - N possible choices in which each choice is equally probable to be selected by the user.
    - The probability (P) that the desired choice will indeed be selected remains invariant.
    - Each error choice has the same probability of selection.
    - M denotes the number of commands per minute.
  - One-way analysis of variance(ANOVA)
    - ANOVA is a collection of statistical models used to analyze the differences between group means and their associated procedures (such as "variation" among and between groups)
    - ANOVAs are useful in comparing (testing) three or more means (groups or variables) for statistical significance.

Results

- Online accuracy and ITR

Stimulus	Performance	Subject S1	S2	S3	S4	S5	S6	S7	Average
Upright face	Acc	83.3	81.3	75.0	81.3	50.0	83.3	85.4	77.1 ± 12.4
	ITR	32.8	31.0	25.9	31.0	10.4	32.8	34.7	28.4 ± 8.39
Inverted face	Acc	**93.8**	**87.5**	**85.4**	**89.6**	**70.8**	**95.8**	**97.9**	**88.7** ± 9.08
	ITR	**43.4**	**36.7**	**34.7**	**38.8**	**22.8**	**45.9**	**48.7**	**38.7** ± 8.63
Upright eyeless face	Acc	85.4	79.2	81.3	79.2	58.3	87.5	93.8	80.7 ± 11.2
	ITR	34.7	29.3	31.0	29.3	14.8	36.7	43.4	31.3 ± 8.83
Inverted eyeless face	Acc	89.6	77.1	**85.4**	79.2	54.2	**95.8**	95.8	82.4 ± 14.5
	ITR	38.8	27.6	**34.7**	29.3	12.5	**45.9**	45.9	33.5 ± 11.8
Upright eye	Acc	91.7	70.8	75.0	72.9	45.8	87.5	79.2	74.7 ± 14.9
	ITR	41.1	22.8	25.9	24.4	8.43	36.7	29.3	26.9 ± 10.6
Inverted eye	Acc	89.6	68.8	77.1	70.8	41.7	81.3	87.5	73.8 ± 16.2
	ITR	38.8	21.4	27.6	22.8	6.69	31.0	36.7	26.4 ± 10.9
Upright object	Acc	70.8	75.0	64.6	66.7	37.5	77.1	81.3	67.6 ± 14.5
	ITR	22.8	25.9	18.6	20.0	5.08	27.6	31.0	21.6 ± 8.45
Inverted object	Acc	77.1	66.7	75.0	58.3	39.6	70.8	83.3	67.3 ± 14.6
	ITR	27.6	20.0	25.9	14.8	5.86	22.8	32.8	21.4 ± 8.92
Highlight icon	Acc	48.3	68.8	41.7	43.8	33.3	47.9	45.8	47.1 ± 10.8
	ITR	9.58	21.4	6.69	7.56	3.65	9.39	8.43	9.53 ± 5.61

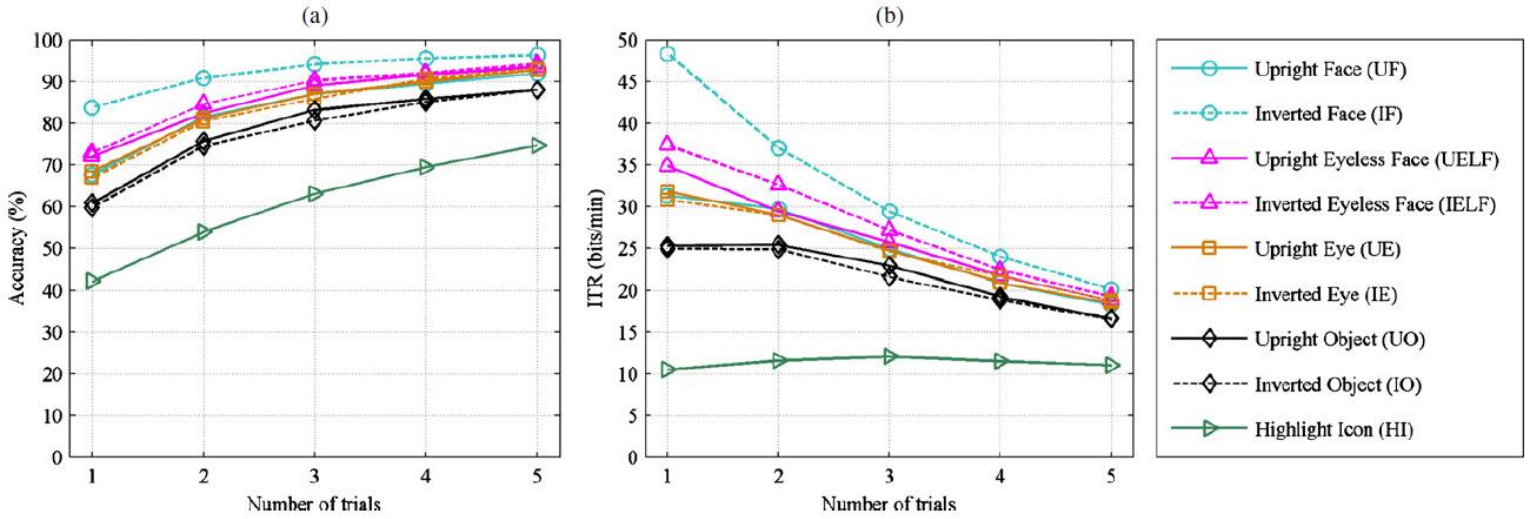
  - The best performance with accuracy of 88.7% and ITR of 38.7 bits min−1 was yielded by the inverted face.

Results

- Online accuracy and ITR
  - Accuracies
    - Compared with the highlight icon (accuracy of 47.1%), other stimuli achieved significantly higher accuracies.
    - While the accuracy had no significant difference between upright and inverted for all face-related stimuli and objects, the difference was marginally significant for the inverted face in contrast to the upright face.
    - Comparing the face-related stimuli with the object, only the inverted face generated significantly higher accuracy than that of the object.
  - ITRs
    - Both the face-related stimuli and the object achieved significantly higher ITRs than the ITR 9.53 bits min−1 of the highlight icon.
    - The inverted face yielded significantly higher ITR than that of the upright face while there was no significant difference between upright and inverted for the eyeless face, eye and object.
    - The inverted face also significantly improved the ITR in comparison to the object.

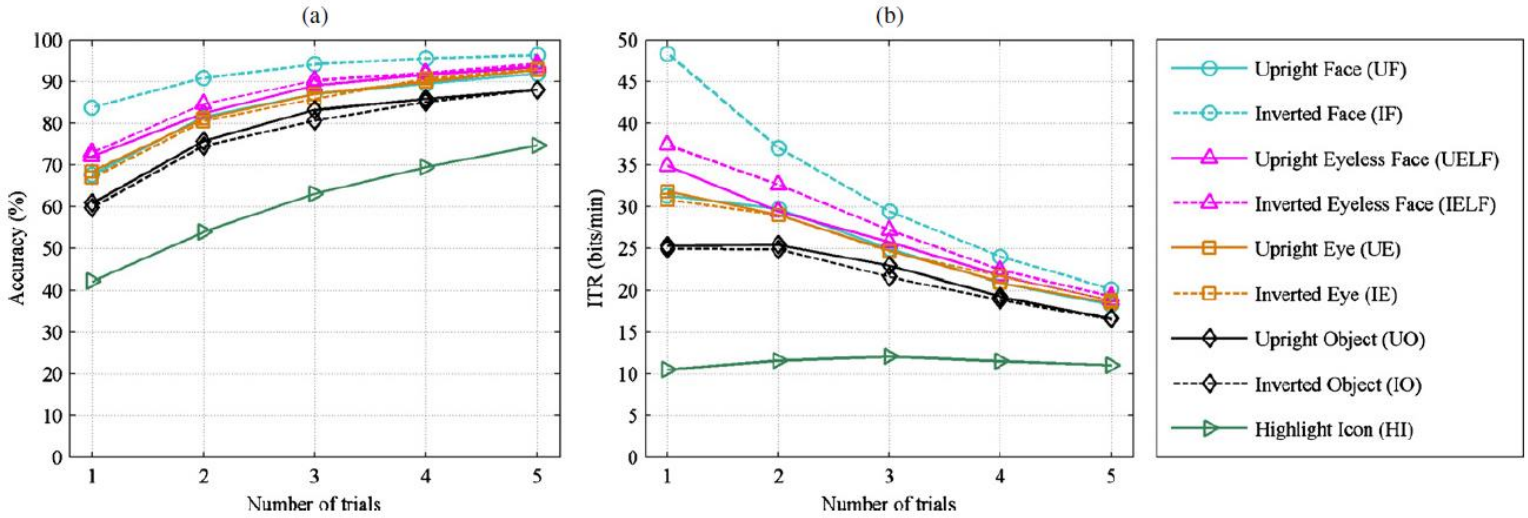
Results

- Offline analysis
  - Why performance improved for the inverted face?
  - Methods
    - For each type of stimulus, 8 runs were randomly selected from the 16 runs (5 targets and 35 non-targets in each run) of the two experimental sessions for the classifier training.
    - The remaining 8 runs were used as test data.
    - Such procedure was repeated 100 times and the average classification accuracy and ITR were then calculated.



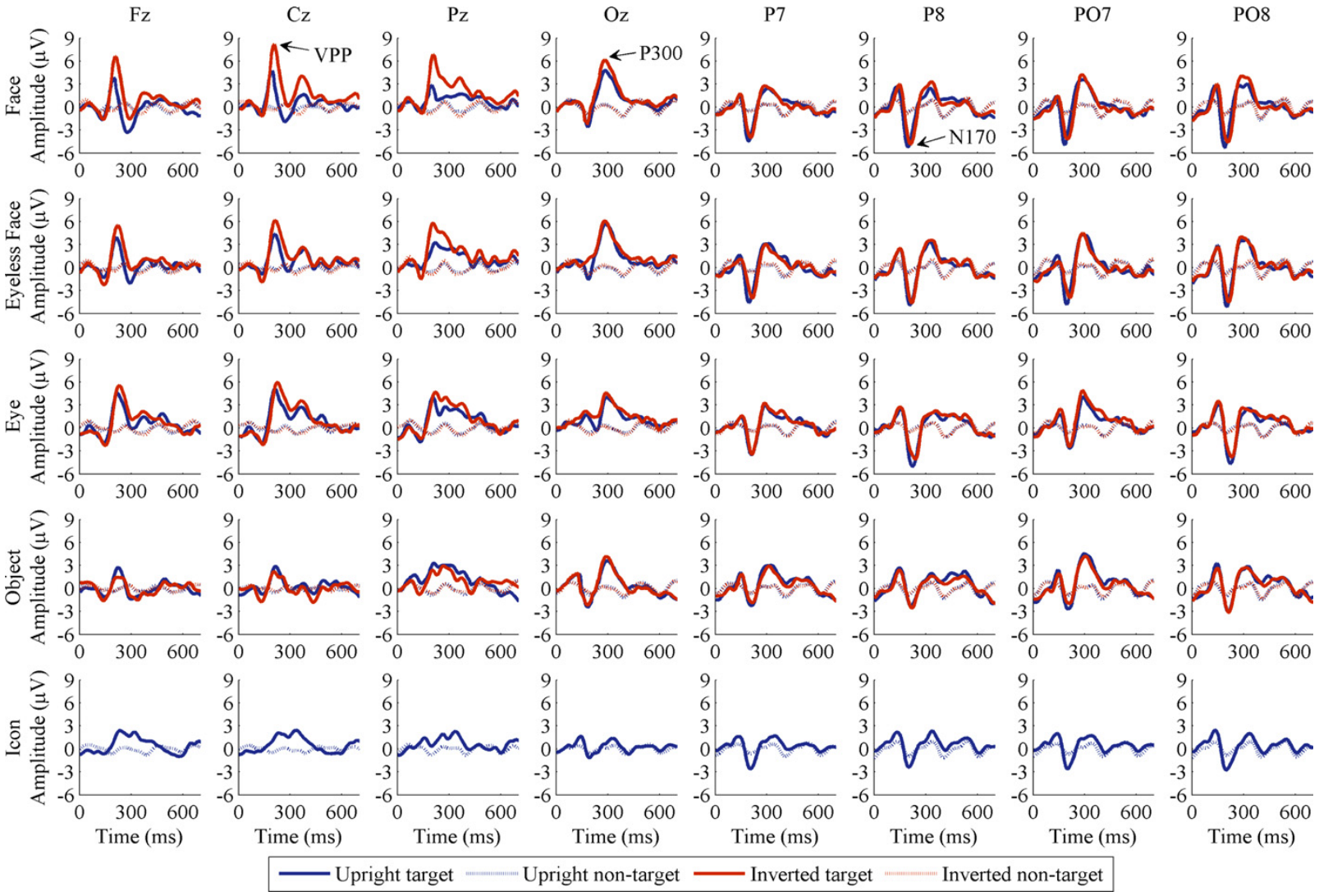
Results

- Offline analysis
  - Comments
    - The inverted face yielded higher accuracy and ITR than those of the other stimuli across various trials.
    - The face-related stimuli obtained a performance exceeding that of the object, while both of them performed better than the highlight icon.
    - There was no big difference between upright and inverted for the eyeless face, eye and object, whereas the inverted face was noticeably better than the upright face.



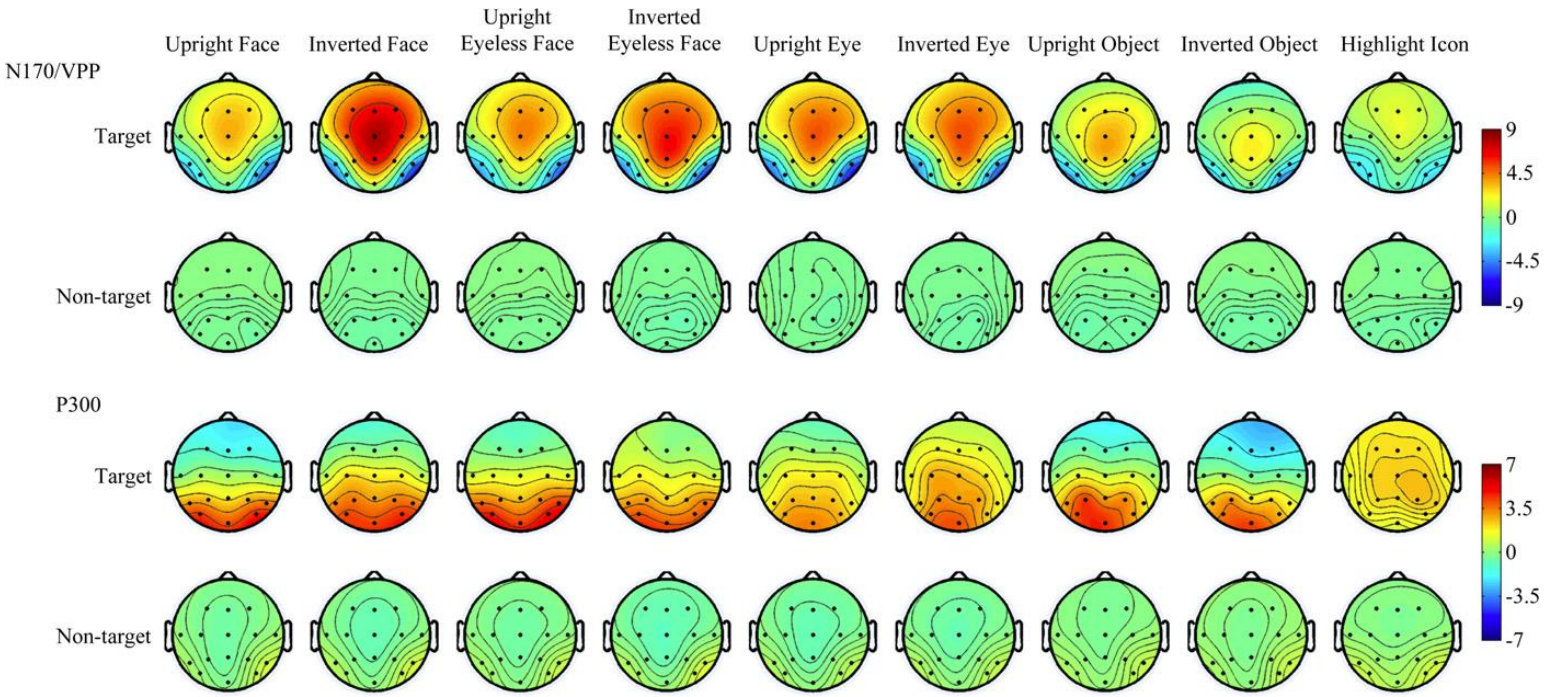
Results

- ERP analysis



Results

- ERP analysis



	N170		VPP		P300	
Paradigm	Amplitude	Latency	Amplitude	Latency	Amplitude	Latency
Upright face	−6.36 ± 2.64	200.9 ± 16.4	5.17 ± 1.10	199.2 ± 13.2	5.40 ± 1.15	274.1 ± 59.8
Inverted face	−6.18 ± 2.34	217.1 ± 11.7	8.37 ± 1.71	214.9 ± 7.81	6.68 ± 1.17	279.6 ± 44.6
Upright eyeless face	−6.19 ± 2.39	204.8 ± 12.9	5.36 ± 1.06	206.3 ± 12.7	6.44 ± 1.02	284.1 ± 30.1
Inverted eyeless face	−5.83 ± 2.13	218.8 ± 7.80	7.12 ± 1.94	218.3 ± 8.80	6.58 ± 1.24	281.6 ± 37.2
Upright eye	−5.60 ± 1.87	207.6 ± 9.30	6.22 ± 2.11	208.7 ± 9.10	5.15 ± 1.36	282.3 ± 45.8
Inverted eye	−5.22 ± 1.18	217.1 ± 10.7	7.06 ± 2.40	219.3 ± 8.10	5.20 ± 1.31	276.3 ± 25.2
Upright object	−3.44 ± 1.61	208.7 ± 11.0	3.43 ± 1.47	201.5 ± 26.1	5.19 ± 1.13	290.7 ± 35.9
Inverted object	−3.54 ± 1.24	209.8 ± 10.7	3.15 ± 1.79	199.2 ± 31.0	5.16 ± 1.03	294.0 ± 24.4
Highlight icon	−3.25 ± 1.79	199.8 ± 11.8	2.79 ± 1.86	205.4 ± 32.3	3.57 ± 1.44	301.5 ± 37.4

Results

- ERP analysis
  - N170
    - Larger N170 amplitudes evoked by the face-related stimuli than by the highlight icon.
    - No significant difference was found among the face-related stimuli and between the object (both upright and inverted) and highlight icon.
    - A longer N170 latency was observed for the inverted than the upright.
  - VPP
    - A larger VPP amplitudes evoked by the face-related stimuli than by the highlight icon and by the object.
    - The inverted face elicited significantly larger VPP than the upright face.
    - A longer VPP latency was observed for the inverted than the upright.
  - P300
    - A larger P300 amplitudes evoked by the face-related stimuli and the object than by the highlight icon, especially at the parietal-occipital and occipital sites.
    - The inverted face yielded higher P300 amplitude than that of the upright face.
    - the P300 amplitude evoked by the eyeless face (both upright and inverted) was higher than by the upright face.
    - the P300 amplitudes derived from the inverted face and eyeless face were significantly higher than that of the object.

Results

- Discriminative feature analysis
  - r^2-value(squared pointwise biserial correlation coefficients)
    - Pointwise biserial correlation coefficient
      - Definition

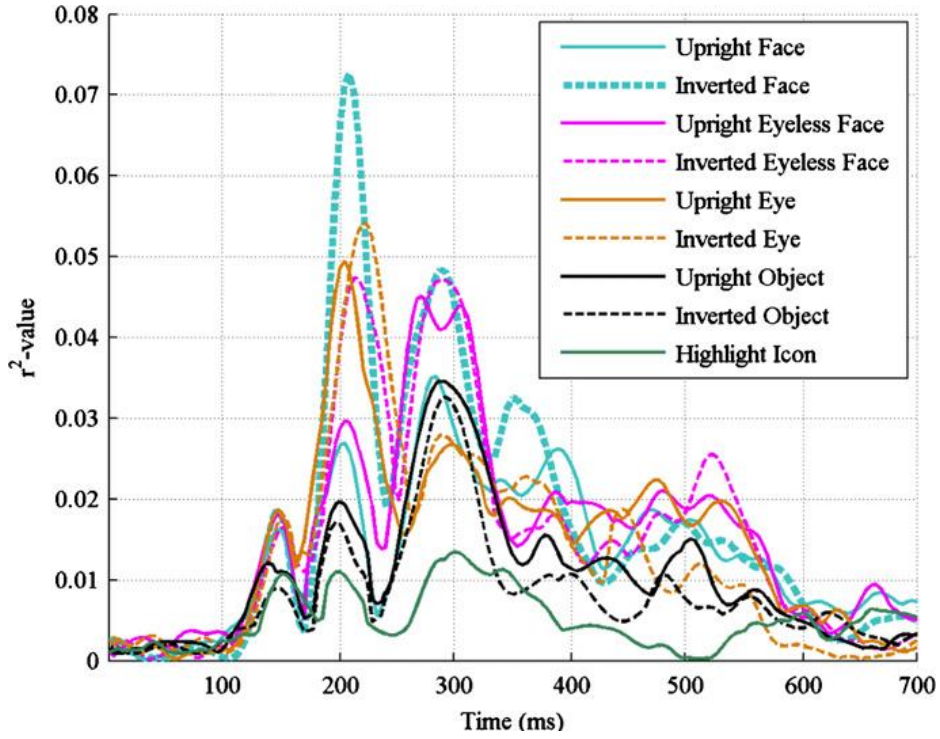
$$r(x) = \frac{\sqrt{N_1 N_2}}{N_1 + N_2} \frac{\text{mean}\{x_i | y_i = 1\} - \text{mean}\{x_i | y_i = 2\}}{\text{std}\{x_i | y_i = 1, 2\}}$$

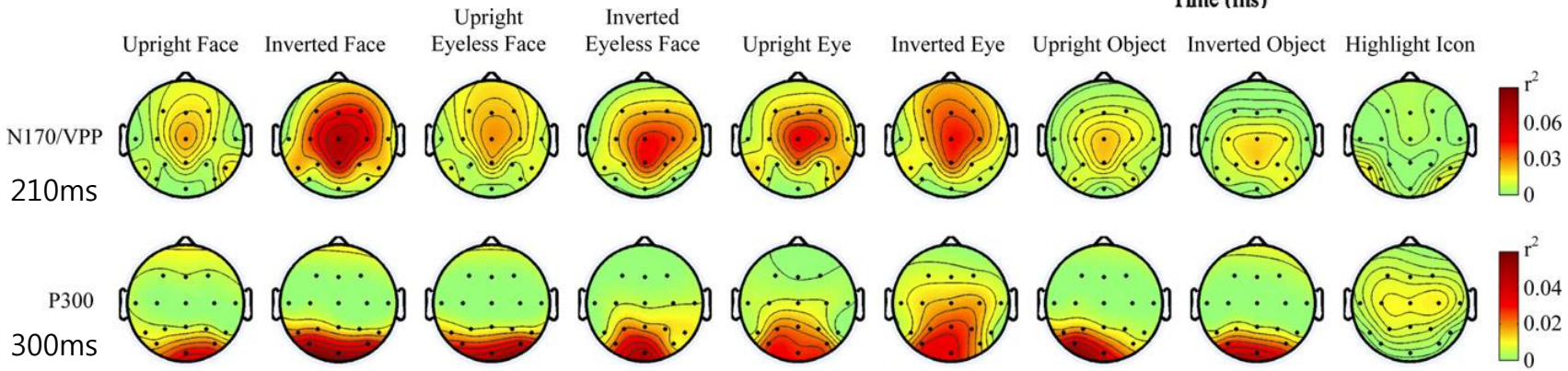
Where N1 and N2 are the numbers of variables belonging to class 1 (target) and class 2 (non-target), xi and yi are the value and class label of the ith variable.

    - The r2-value is equal to the squared of r(x).
    - Larger r2-value indicates higher separability of distributions.

Results

- Discriminative feature analysis
  - Temporal and spatial distributions of the most discriminative information for the nine stimuli





Results

- Discriminative feature analysis
  - Comments
    - Almost all of the face-related stimuli and the object yielded more discriminative features than the highlight icon from 200 to 500 ms after stimulus onset.
    - The most outstanding components in the features were found around 200 and 300ms, which just correspond to N170/VPP and P300.
    - The discriminative features around 200 ms for the face-related stimuli and the object were mainly located at the fronto-central sites(Cz)
    - the P300 distributions for the face-related stimuli and the object were mainly located at the parietal-occipital sites, compared with the centro-parietal distribution of P300s elicited by the highlight icon

Discussion

- Advantages of facial images based BCI
  - A high luminance contrast is usually required to elicit a prominent visual evoked potential for the visual stimuli, and this may cause visual fatigue and discomfort for the user.
  - The facial images are more vivid than icons, letters or symbols, they may resist fatigue and discomfort to improve the visual attention for subjects.
  - Loss of configural information makes face perception more difficult and associated with higher cognitive functions. This encourages subjects to focus attention on the target more actively.
- Performance
  - Both the face related stimuli and the object yielded significantly higher accuracies and ITRs than that of the highlight icon.
    - This implies that stimuli with higher cognitive task requirement, such as face and object perception, are more effective than the intensified stimuli of dull icons for the P300-based BCI system.
  - The ITR derived from the inverted face was significantly higher than that of the upright face.
    - This suggests that the loss of configural face information assists in improving the performance of the BCI system.

Conclusion

- They proposed a novel BCI system using multi-component ERPs sensitive to configural processing of human face with an oddball paradigm.
- The performance of the proposed BCI is significantly improved in comparison to the conventional P300-based BCI with stimuli of intensification pattern.
  - The online performance of classification accuracy 88.7% and ITR of 38.7 bits min−1 obtained by the LDA classification using only single trial without any optimization of algorithm for feature extraction.