An affective BCI using multiple ERP components associated to facial emotion processing

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Project description: The P300-based brain computer interfaces (BCIs) have successfully demonstrated that attention to an oddball stimulus can enhance P300 component of the event-related potential (ERP) time-locked to this event. This study examined ERP responses to objects, faces, and emotional faces when subjects perform attention, face recognition and discrimination of emotional facial expression respectively using the oddball paradigm. The results revealed the significant difference between target and non-target ERPs for each mental task. In addition, the significant differences among the three mental tasks were observed for vertex-positive potential (VPP) ($p < 0.01$) over the fronto-central sites, late positive potential (LPP) / P3b ($p < 0.05$) over the centro-parietal sites and N250 ($p < 0.003$) over the occipito-temporal sites. These findings indicate a novel affective BCI paradigm can be developed based on detection of multiple ERPs reflecting face structure encoding and emotion processing. Due to the high classification performance for single-trial emotional face-related ERP, we also developed an online BCI system for controlling robot arm.

Experiment procedure: Subjects were presented with a 3×3 matrix of 9 arrows with gray color. Unlike the flashing letters in the classical P300 speller, one image randomly selected from emotional faces group was presented at one of nine positions in a random order and the subject was asked to perform emotion discrimination tasks whenever the desired target was intensified (see *Stimulus*). To investigate the different effects on ERPs under several different mental tasks, the subjects were also asked to silently count the number of flashing or perform the face identification tasks when the objects or neutral faces were used as stimuli. EEG signals were measured from 16 electrodes using the g.USBamp amplifier (g.tec, Austria) with sample rate of 256Hz.

ERP analysis: We focus on key components of ERPs elicited by faces such as the face-specific N170 (150-190 ms), VPP (140-200 ms), N250 (240-280 ms), P300 (250-350 ms), P3b/LPP (400-800 ms). Early components are thought to reflect basic structural encoding of faces, whereas later components may reflect categorization and attention to motivationally relevant information, including emotion, gender, or identity. For emotional face discrimination task, analysis of VPP amplitude revealed a significant effect of emotion information processing at Cz ($F(1,18)= 12.13$, $p < 0.003$) and Pz (200 ms) ($F(1,18)= 16.09$, $p < 0.0008$). The LPP are clearly larger for target compared to non-target at Cz ($F(1,18)= 27.97$, $p < 0.0004$), Pz ($F(1,18)=19.99$, $p < 0.0003$) and PO8 ($F(1,18)= 8.08$, $p < 0.011$). The ERPs and topography map are shown in Fig. 1. The VPP at Pz revealed the significant difference between objects (task 1) and faces (task 2, 3) stimuli ($F(2,27)= 5.9$, $p < 0.01$). The main effects of emotional faces at Pz and Cz indicates significant larger LPP (Cz: $F(2,27)= 3.94$, $p < 0.032$, Pz: $F(2,27)= 3.45$, $p < 0.05$) compared to faces and objects stimuli. The more detailed analysis and visualization of ERPs are provided in [2].

Performance: The online performance using faces as stimulus was analyzed in [1]. The accuracy of 5×5-fold cross-validation on single-trial ERP with the trial length changed from 100 ms to 800 ms are shown in Fig. 2A. The ROC curve is shown in Fig. 2B indicating that both emotional faces and faces paradigm are superior than objects paradigm, in particular, emotional faces paradigm greatly improved the performance for single-trial ERP as compared to the classical P300-based BCI.

Real-time robotic arm control: We developed an online affective BCI system for controlling a robot arm to deliver the food or drinks to the subject, which is potentially helpful for the locked-in patients [3].

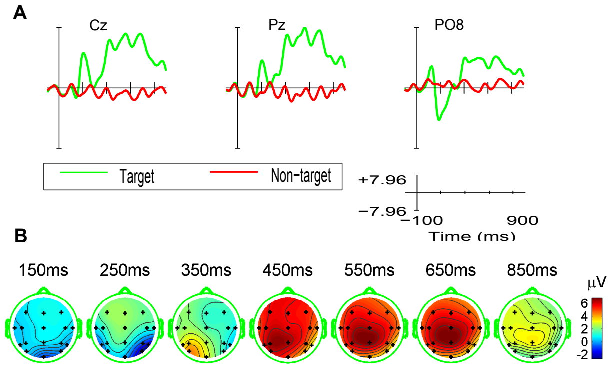

Figure 1: (A) Grand averaged ERPs (5 subjects) at Cz over fronto-central region, Pz over centro-parietal region and PO8 over occipito-temporal region to target (green) and non-target (red) emotional faces stimuli. (B) Topography of target ERPs for specific time points.

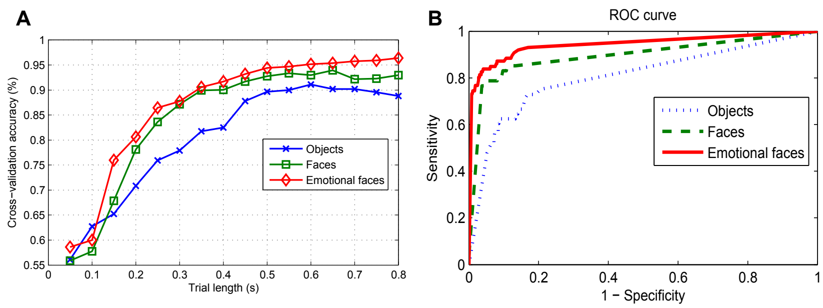

Figure 2: (A) Cross-validation accuracy for single trial ERP. (B) ROC curve for three different oddball paradigms.

In summary, our affective BCI paradigm and platform have the following features and advantages: (1) Due to applying emotional faces and optimization of visual stimuli, the classification accuracy is significantly improved and number of repetition is dramatically reduced as compared to the standard P300 using stimulus of letters or symbols; (2) Instead of the standard P300, we rather exploit emotion related multiple ERPs (VPP at Cz, LPP at Cz, N250 at PO8) - this allows us to increase reliability and performance of the visual stimuli driven BCI; (3) Our BCI system is relatively easy to use and to improve visual attention since emotional stimulus are more vivid than the symbols or letters, which also relieves fatigue for subjects. (4) Since the high level cognitive functions are involved to express the subjects' voluntary intention, our BCI is promising for rehabilitation of cognitive dysfunction rather than motor dysfunction. (5) Our BCI system has been extensively tested and implemented to control 7 DOF robot arm to perform complex task like delivering foods (by spoon) or drinks (assisting a disable person to eat and drink, delivering medicine etc.).

References

[1] A. Onishi, et al, Fast and Reliable P300-Based BCI with Facial Images, *Under review*, PDF

[2] Q. Zhao, et al, A novel oddball paradigm for affective BCI ususing emotional faces as stimuli, *In submission*, PDF

[3] Online BCI system for robotic arm control, the videos are available on `http://www.bsp.brain.riken.jp/bci/`, [Stimulus 1, Application 1, Stimulus 2, Application 2].