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Lie detection with contingent negative variation

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Abstract

Topographies of contingent negative variation (CNV) were recorded in a paradigm of delayed response with feedback for three kinds of faces: familiar, strange and target. Subjects made responses to the faces according to whether the faces were familiar or not, but also, gave deliberately deceptive responses to target faces to 'cheat the computer'. Subjects were told that the computer could judge whether they were being honest or not. For each trial of the experiment, if subjects cheated the computer successfully and their responses were judged as honest and they were given a reward, otherwise they received a penalty. In this simulated lie detection test, CNV exhibited more negative shifts for target than those for non-target (familiar and strange). These differences could be accounted for by subjects' motivation and uncertainty about passing the test. With the results of further paired t-tests between target and non-target faces at each electrode, CNV was demonstrated as a reliable indicator for lie detection. In addition, vector length was used to capture global CNV information and was found to be a very good indicator, even better than the CNV information at the individual electrode sites.

Keywords: Lie detection; Contingent negative variation; Event-related potentials; Guilty knowledge test (GKT); Control question test (CQT); Vector length

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1. Introduction

The detection of deception has a long history. The first proposed technology was the polygraph, which recorded autonomic arousal and was used in the determination of guilt or innocence. The validity of polygraph lie detection has been repeatedly challenged (Saxe et al., 1985) because of a high frequency of false positives, (i.e. indications that persons are guilty when they are in fact innocent, Lykken, 1979). Obviously, the fundamental basis of this problem has been that the physiological processes that are induced by the autonomic nervous system do not necessarily reflect corresponding psychological processes.

As windows on the brain and cognition (Coles, 1989), event related potentionals (ERPs) are sensitive to a variety of cognitive processes and even some unconscious processes that cannot be inhibited by subjects (Leiphart et al., 1993). ERPs reflect the activities of central nervous system related to information processing rather than emo-

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tion-dependent activities of autonomic nervous system. Considering the advantages of ERPs, researchers began to use the components of ERPs to detect guilty knowledge, such as P300 (Fang and Shen, 1998; Rosenfeld, 2002) and N400 (Boaz et al., 1991). All these studies focused on the ERP components with latency less than 1000 ms. These components, P300 and N400, mainly reflected the cognitive processing of stimulus. After processing the stimulus, subjects make a response decision, then execute this response. It is very straightforward to think there would be some differences in cognitive processing prior to making honest and deceptive responses. This kind of difference is what we wanted to address in this study.

The contingent negative variation (CNV) (Walter et al., 1964) is a slow negative EEG shift which develops in the interval between two stimuli. The first stimulus, the 'S1' or 'cue' is a warning signal and the second one, the 'S2' or 'imperative stimulus,' that signals the subject to make a response. The CNV is characterized as a sustained negativity over wide areas of the scalp. It varies systematically in its distribution across the scalp as a function of stimulus modality, task parameters and response requirements. The CNV is presumed to highlight the functional equivalence of underlying processes, such as cortical excitability, arousal, attention, uncertainty, preparedness, receptiveness, resource mobilization, level of effortful involvement and motivation, however, no consensus has been reached (see review McCallum and Curry, 1993). For longer inter-stimulus intervals, two components can be distinguished: an early initial component (iCNV) with a maximum over anterior regions(Simons et al., 1983) and a late terminal component (tCNV), immediately preceding S2, with a central maximum shifted contralaterally to the side of the responding hand (Brunia and Damen, 1988). iCNV is thought to reflect the ongoing processing of information provided by S1(Gaillard and van Beijsterveldt, 1991) and probably indicates activity related to response selection (van Boxtel et al., 1993). tCNV, is largest at the vertex and is similar to the readiness potential preceding self-paced movements; it has been assumed to reflect response preparation (Rohrbaugh and Gaillard, 1983). Other sources can also contribute to the tCNV, such as the anticipation of S2 (Kotani and Aihara, 1999), working memory activity (Honda et al., 1996) and effort invested in the task (Wascher et al., 1996). Verleger et al. (2000) suggested that tCNV consists of a centro-parietal component, reflecting the assembling and maintenance of stimulus-response links to the expected S2 alternatives and also reflects a fronto-central component, indicating activation of the hand–motor area. Given the complex properties and distribution of CNV, Brunia and von Boxtel (2001) suggested that CNV is the result of concerted activity in a number of cerebral networks.

In our experiment, the methodological paradigm was a delayed response to the face picture with the subject responding to indicate familiarity with the face when the imperative stimulus appeared. Feedback was given by the computer in the form of, a reward or penalty, to indicate whether the subject's response was judged to be honest or not. If a deceptively responding subject wanted to be judged as responding honestly, certain cognitions will occur before a response was made; in this case the subject would have a strong motivation to pass the test, but would still be uncertain about the effectiveness of their response. Accompanying the feelings of motivation and uncertainty, arousal and effortful involvement might also be experienced by a subject that is responding deceptively. As mentioned previously, these cognitive processes would be reflected in the CNV, thus making the detection of deception with the CNV feasible.

2. Methods

2.1. Subjects

Fourteen right-handed undergraduates (nine male) participated in this experiment. All of them had normal or corrected vision and did not have any history of neurological disease. Participants were naive to the experimental design. The mean age was 20 years (range 18–22). Data from two subjects were discarded because of too many artifacts or machine failure.

2.2. Materials

Nine face pictures were used in this experiment: three familiar, three strange and three target pictures. All subjects were familiar with the target pictures. Each of these pictures was presented 10 times. The presentation sequence was randomized.

2.3. Procedure

In the experiment, subjects would be seated in a dimly lit, electrically shielded, sound-attenuating chamber. Upon a subject's arrival, three target face pictures were presented simultaneous in the monitor of PC-586 outside the chamber the subject was given the following instructions:

'Please remember these faces in the monitor as target faces, be certain that you are very familiar to them. The monitor in the chamber will present face pictures to you, some will be familiar ones and others will be strange ones. You should respond to the faces by pressing one of the two buttons on the response board. Generally, if you are familiar to the face, press the left button, otherwise press the right button. The goal in this experiment is lie detection. You will need to make deceptive responses to target faces. Although the target faces will be familiar, you should press right button to indicate that they are strange to you. The equipment will record your EEG and finger responses. By analyzing the EEG for each trial, the computer will tell me whether you are familiar with a face or not and by combining your responses, will judge if you have told a lie. We hope you would try your best to deceive the computer and let it make an incorrect judgment. Since EEG reflects the brain activities, to deceive the computer successfully, you need to keep your mind as calm as when you are not familiar with the faces. Being judged as honest will offer you a reward of 0.5 RMB, otherwise you will be penalized 2 RMB. The baseline of honorarium is 30 RMB.' (1 US dollar = 8.3 RMB).

This experiment consisted of 90 trials, including 30 trials with familiar faces, 30 trials with strange faces and 30 trials with target faces. A fixation point was always kept in the center of monitor. The face stimulus was presented in the center of the monitor for 500 ms. There was an interval of 1000 ms between the end of the face stimulus and onset of a cue. This cue, a cross, was presented for 500 ms in the center of the monitor. Subjects were instructed to respond once the cue appeared. 3000 ms after offset of the cue, a visual feedback signal in the form of either '+0.5' or '−2' lasting 500 ms was given, which indicated a reward or penalty, respectively. The monitor was black for a random period of 4–6 s during the inter-trial interval (I T I). Rest breaks, lasting 30 s, occurred after every 10th trial.

The feedback following the response to familiar face or strange one was decided by subjects' honest action, that was, '+0.5' for pressing the left button to familiar face and '−2' for pressing the right button to strange face. But the feedback for target face was fixed in advance. No matter how the subject reacted, the twenty-five target face stimuli were followed by '+0.5', and the others were followed by '−2'. Five feedback '−2's were interspersed in the 30 target face trials randomly. The object of this design was to increase subjects' mental burden because feedback '−2' meant the reduction in honorarium.

Before the beginning of formal experiment, subjects participated in practice session without EEG recording. Practice session consisted of 20 trials in which face pictures other than those used in formal experiment were presented. The object of these practice sessions was to make subjects familiar with the procedure of this experiment. The monitor was approximately 1 m in front of the subject. The cross (cue) covered 2×2 cm, the face picture 6×4 cm, the feedback signal 2×4 cm ('−2') or 2×6 cm ('+0.5').

2.4. EEG recording and processing

The presentation of stimuli and recording of EEG were conducted with Electrical Source Imaging-128 (Neuroscan, Inc.). Ag/AgCl electrodes were used in our experiment. Thirty channel EEG signals were recorded, including C3, C4, CP3, CP4, CPz, Cz, F3, F4, F7, F8, FC3, FC4, FCz, FP1, FP2, FT7, FT8, Fz, O1, O2, Oz, P3, P4, T5, T6, Pz, T3, T4, TP7 and TP8. Electrooculograms (EOG), was recorded bipolarly both horizontally, from electrodes at the outer canthi of the eyes and vertically, from a pair of electrodes above vs. below the left eye. The forehead was grounded and linked mastoids were used as reference. Elec-

Table 1
The mean difference of CNV amplitudes for three kinds of stimuli

Pair	Mean difference	S.D.	Pair	Mean difference	S.D.
C3_FA—C3_TA	1.5527*	1.7780	FT7_FA—FT7_TA	1.5566***	1.2805
C3_ST—C3_TA	3.7268***	0.6338	FT7_ST—FT7_TA	0.3887	2.2127
C4_FA—C4_TA	3.8044***	0.7215	FT8_FA—FT8_TA	1.7196**	1.4405
C4_ST—C4_TA	4.1051***	0.7980	FT8_ST—FT8_TA	2.6068***	1.0649
CP3_FA—CP3_TA	3.7207***	1.2103	FZ_FA—FZ_TA	3.6878***	1.1913
CP3_ST—CP3_TA	1.4180*	1.8974	FZ_ST—FZ_TA	3.9766***	1.0928
CP4_FA—CP4_TA	3.8054**	3.6318	O1_FA—O1_TA	4.6856***	1.8098
CP4_ST—CP4_TA	4.8002*	5.6465	O1_ST—O1_TA	4.3894***	1.3684
CPZ_FA—CPZ_TA	4.0177***	1.3239	O2_FA—O2_TA	3.2669***	0.9814
CPZ_ST—CPZ_TA	0.3575	2.1820	O2_ST—O2_TA	4.1339***	1.1250
CZ_FA—CZ_TA	3.8297***	1.0607	OZ_FA—OZ_TA	3.6444***	1.9489
CZ_ST—CZ_TA	3.3241***	1.0372	OZ_ST—OZ_TA	4.0926***	1.3938
F3_FA—F3_TA	2.8382***	1.3789	P3_FA—P3_TA	3.2633***	0.6630
F3_ST—F3_TA	5.0759***	1.7798	P3_ST—P3_TA	5.0285***	1.6654
F4_FA—F4_TA	2.3970***	0.9838	P4_FA—P4_TA	2.8740***	0.8767
F4_ST—F4_TA	2.6069***	0.7988	P4_ST—P4_TA	3.2381***	1.6565
F7_FA—F7_TA	1.3439***	0.7804	T5_FA—T5_TA	4.4426***	1.4524
F7_ST—F7_TA	−0.6576	2.2805	T5_ST—T5_TA	2.4476***	0.7026
F8_FA—F8_TA	0.8413	1.8820	T6_FA—T6_TA	2.4892***	0.8839
F8_ST—F8_TA	0.6620	1.8953	T6_ST—T6_TA	3.0276***	1.3044
FC3_FA—FC3_TA	3.0750***	2.0488	PZ_FA—PZ_TA	4.9859***	2.1882
FC3_ST—FC3_TA	3.4607***	0.9714	PZ_ST—PZ_TA	3.6706***	1.1260
FC4_FA—FC4_TA	1.7687***	0.8925	T3_FA—T3_TA	2.4485***	0.7175
FC4_ST—FC4_TA	3.4840***	0.9234	T3_ST—T3_TA	1.2398*	1.4373
FCZ_FA—FCZ_TA	3.3584***	1.0723	T4_FA—T4_TA	3.1259***	1.5017
FCZ_ST—FCZ_TA	1.5681*	2.4022	T4_ST—T4_TA	4.6654***	0.9967
FP1_FA—FP1_TA	1.7599***	0.7709	TP7_FA—TP7_TA	3.8507***	1.2372
FP1_ST—FP1_TA	0.81086	1.3573	TP7_ST—TP7_TA	2.6081***	1.2904
FP2_FA—FP2_TA	−0.2086	1.4902	TP8_FA—TP8_TA	4.1991***	1.1437
FP2_ST—FP2_TA	0.8593*	1.0420	TP8_ST—TP8_TA	6.1272***	1.9090

*$P<0.05$, **$P<0.01$, ***$P<0.001$ by paired *t*-test, FA-familiar face, ST-strange face, TA-target face.

trode impedances did not exceed 5 kΩ. EEG and EOG signals were filtered with a band pass of 0.05 to 30 Hz and digitized at 250 Hz/location and stored on disk for later analysis. The eye activity correction was conducted by the software SCAN in ESI-128. Its algorithm was proposed by Semlitsch et al. (1986) and trials still containing artifacts (mainly movement artifacts and drifts in a single channel) which have voltages in excess of ±75 μV were discarded. ERPs were extracted by averaging EEG separately for subjects, the three types of face stimuli and recording channels. Then a phase-true filter with a band pass of 0.05–10 Hz was applied to the ERPs. The average voltage amplitude of the 200 ms pre face stimulus interval was used as baseline for all further ERP amplitude measures.

Since the CNV was the focus of this experiment, only average voltage amplitudes from 1000 to 1500 ms (0 ms is the onset of face stimulus) were computed. These average voltage amplitudes for each subject, electrode and type of face picture were used for further analyses with ANOVA and paired *t*-test. To properly evaluate interactions of electrode with face type, the data were transformed according to the second correction procedure outlined by McCarthy and Woods (1985). That is, CNV amplitudes from thirty channels were treated as a 30-dimension vector. This vector was normalized to unit length separately for each subject and

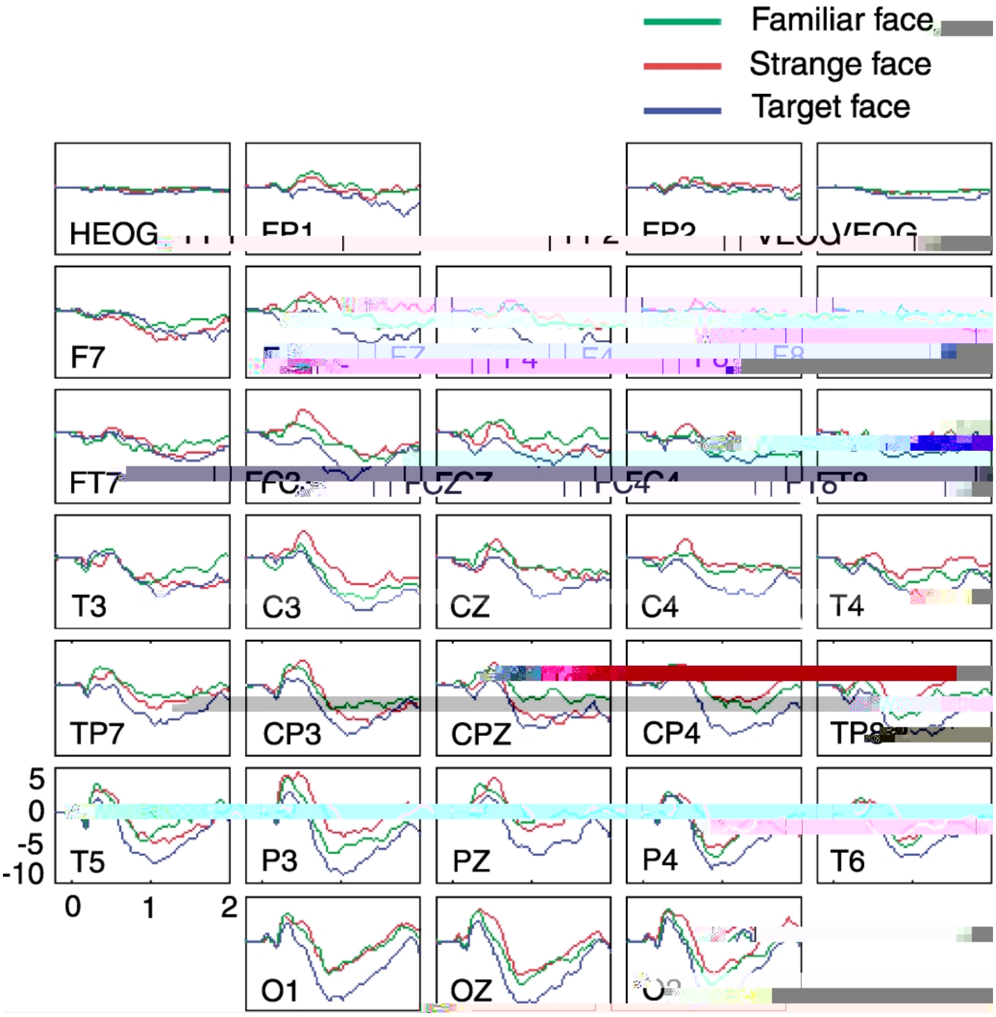

Fig. 1. Grand average ERPs $(N=12)$ for three types of face pictures at each electrode. The units of ordinate and abscissa are microvoltage and second, respectively.

condition before being applied with ANOVA for examining its topography.

Because the ANOVA F statistics may become overly large when repeated-measurement factors have more than two levels (i.e. the case here with electrode position in the topographical analysis), the *P* values of all effects resulting from these factors were corrected towards conservative interpretation by reducing their degree of freedom. This was done by multiplying the original degrees of freedom with Huynh–Feldt epsilon and truncating the product to an integer. The uncorrected degrees of freedom along with the Huynh–Feldt epsilons are reported in the result section.

3. Results

3.1. Behavioral data

99.9 percent of responses made by subjects followed experimenter's instruction, that is, mak-

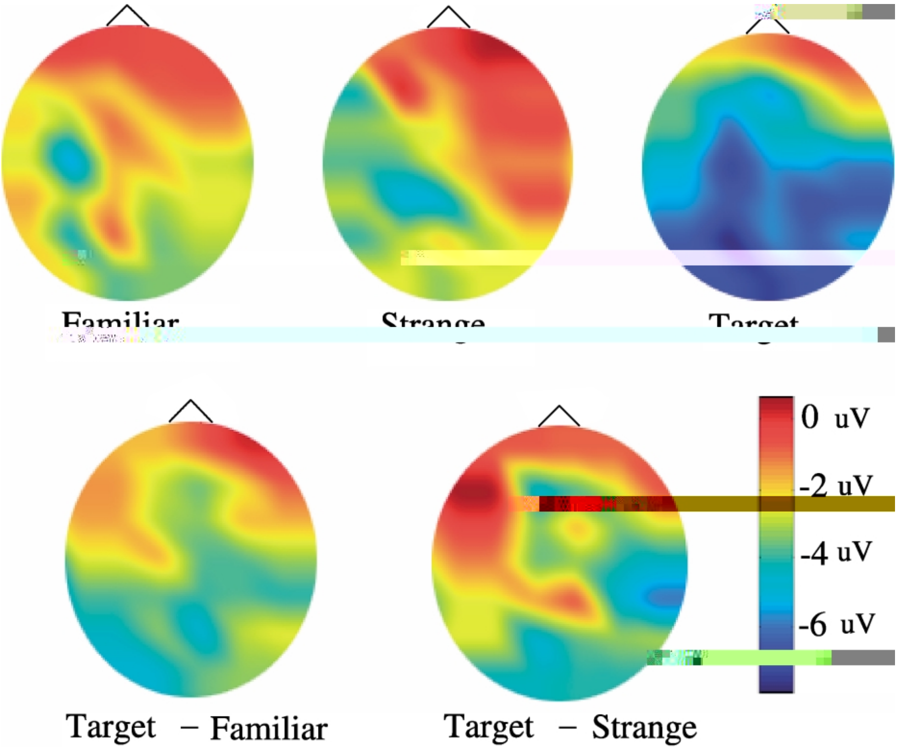

Fig. 2. Topographies of CNVs elicited by three types of faces and their difference ($n = 12$).

ing deceptive response to target face and honest response to familiar and strange face.

3.2. ERP data

Grand average ERPs for three types of face stimuli at each electrode were shown in Fig. 1. Topographies of CNVs elicited by three types of faces and their difference were shown in Fig. 2. It is very obvious that the CNV elicited by target face is more negative than those by familiar and strange faces at most of the electrode positions, especially at the central, parietal and occipital areas.

Two ANOVAs were run to compare the topographies of different types of pictures. The topography elicited by target face is significantly different from those by familiar face ($F(29, 319) = 6.216$, $P < 0.001$, $\varepsilon = 0.209$) and strange face ($F(29, 319) = 9.909$, $P < 0.001$, $\varepsilon = 0.16$). Other Three ANOVAs were run to see the main effect of type (Familiar vs. Strange, Strange vs. Target, Familiar vs. Target). They revealed the CNV elicited by target face was significantly more negative than those by familiar ($F(1, 11) = 1553.9$, $P < 0.001$, $\varepsilon = 1$) and strange faces ($F(1, 11) = 905.5$, $P < 0.001$, $\varepsilon = 1$), but there were no significant difference between familiar and strange faces ($F(1, 11) = 0.091$, $P = 0.762$, $\varepsilon = 1$). For the purpose of application it was important to determine which electrode can provide the most reliable information to distinguish target and non-target face (familiar and strange faces). So we applied paired *t*-test at each electrode position. It was found that, at almost all electrode positions as in Table 1, the values of slow waves elicited by target face are significantly lower than those by non-target faces ($P < 0.05$). Especially, in Fig. 3, if the significant level reach 0.001 at some electrode, that electrode position was marked as gray. These electrodes are F3, Fz, F4, FC3, FC4, Cz, C4, T4, TP7, TP8, T5, P3, Pz, P4, T6, O1, Oz and O2.

Also, since the CNV elicited by target face is more negative than those by familiar and strange at most of electrode positions, it would be nice to find a global indicator (consider the values at all electrode positions) to distinguish target and non-target faces. Here, we calculated the length of 30-dimension vector, which consists of CNV values from thirty electrode sites. Each site corresponds to a dimension of this vector. The result was shown in Fig. 4. The vector length from target face is very significantly higher than non-target faces ($P < 0.0001$, t-value is 21.82 for familiar and target face, 20.79 for strange and target face). For the t-test at the individual site, the t-value is no more than 13.07. That is to say, in this experiment, the global indicator-vector length was more suitable for distinguishing target and non-target faces than individual indicators at individual sites.

4. Discussion

Our study shows that, with an experimental paradigm of delayed response, target faces can elicit enhanced CNV. The CNV elicited by target face is significantly more negative than those by non-target face at most of electrode positions. At some electrode positions statistical significance was very high. These results strongly support the feasibility of using CNV as a new indicator for lie detection.

We should also note that the amplitude of CNV depended only on the property of subjects' response (honest or dishonest) and not on the stimulus properties. That is the key difference between P300 method and our CNV method; in the P300 method, a high amplitude P300 was evoked by a guilty knowledge-related stimulus, regardless of subjects' response. Additionally, other researchers did not focus on the cognitive processes immediately preceding subjects' response. Given our findings, we believe that P300 and CNV are complementary methods in lie detection. For example, since the P300 amplitude is sensitive to the face familiarity (Neville et al., 1982), the experimenter has to design a control question test to avoid a high false alarm rate, which occurs when a simple guilty knowledge test is used (Rosenfeld, 2002). However, with the CNV method, this simple guilty knowledge test should work as shown in our experiment. Because the CNV and P300 components reflect the cognitive processes in different time interval, it would be very interesting and feasible, to combine these two lie detection methods. In an oddball paradigm with delayed response, we can predict that the guilty knowledge-related stimulus will evoke enhanced P300 and CNV. The amplitudes of P300 and CNV constitute a two dimensional vector. This vector, as an indicator of lie detection, could be more reliable and sensitive than either of P300 and CNV.

As mentioned previously, many studies have tried to separate CNV into subcomponents (Rosler and Heil, 1991; van Boxtel and Brunia, 1994; Verleger et al., 2000). The object of our experiment was not to find the functional equivalence of CNV or to distinguish independent functional components, but to find the best indicators at the best sites of the scalp that would have the greatest validity and reliability. Since the topographies of CNV are rather complex explaining them thoroughly was quite difficult given the stated goals of our study. In our experiment, enhanced CNV was found in the frontal, central, parietal, occipital and temporal areas. Because of the short interval between the face stimulus and the imperative stimulus, early and late CNV components showed considerable overlap. There were a number of factors that could contribute to the enhanced CNV, including further processing face stimulus, the assembling and maintaining of stimulus-response links, motivation and uncertainty about passing the test. Additionally, the topographical analysis showed that the particular topography elicited by target face is significantly different from those by familiar and strange faces. This result indicates that their electrical sources are different. That is to say, both the position of electrical sources and their activity levels may contribute to the enhanced CNV.

Most of lie detection research has focused on finding an electrode site which can provide the most reliable information for valid judgment. In our experiment, we found that most individual sites can provide reliable information. We also found that the vector length can be used as a

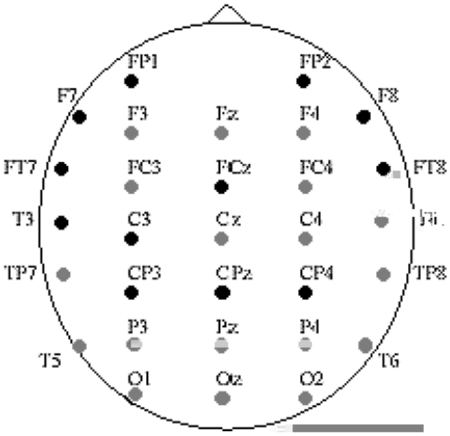

Fig. 3. Highly significant difference ($P < 0.001$) between target face and strange, familiar face was indicated by gray mark ($n = 12$).

global indicator for lie detection and is even better than the CNV amplitude at individual sites.

Based on the discussion above we conclude that CNV is a reliable indicator for lie detection within the experimental paradigm of delayed response and that both local and global data can offer the information necessary to reliably detect deception.

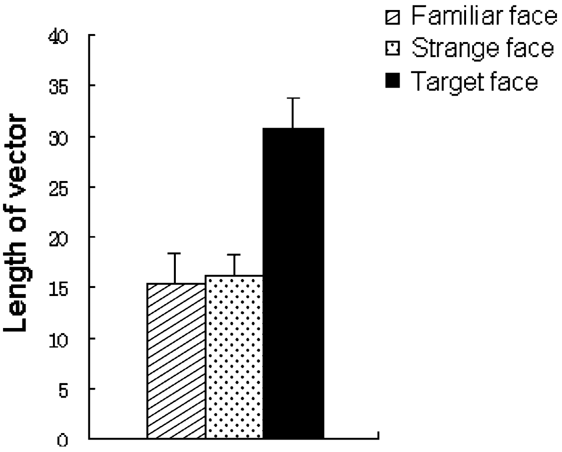

Fig. 4. Length of vectors for three kinds of faces ($n = 12$). Vertical bars denote 1 S.D.

Acknowledgments

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