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Detection of deception with P300

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Abstract. Because event-related potentials (ERPs) could reflect dynamic changes in brain function during cognitive processes in human subjects, and the changes are independent of the activities of autonomic nervous system, they have been used as indicators of lie detection.

Twenty subjects imagined they had committed burglary of an apartment. Guilty knowledge test (GKT) taking question-answers format was constructed according to the crime. For each of 18 questions, the corresponding five answers consisting of one relevant item (RI) and four irrelevant items (II) were presented serially after its presentation.

Significant differences in P300 amplitude were found between RIs and IIs at F3, Fz and F4, but not at N400. We also compared the differences in P300 amplitude between RI and II among F3, Fz and F4. Only the difference between F3 and F4 reached significant level.

These results suggested that we could utilize the P300 amplitude to distinguish guilt from innocence. Meanwhile, in the views of actual applications, if the visual stimuli eliciting P300 component were semantic to right-handed subjects, F3 was a better location to record ERPs for detecting deception than F4, Fz.

Keywords: ERPs, N400, P300, polygraph, voice-stress analyzer.

Introduction

Presently, the measures of autonomic arousal, such as polygraph and voice-stress analyzer, are widely used to assist in the determination of guilt. While some institutions and agencies have found them useful, the validity of these two methods to detect guilty knowledge have been repeatedly challenged [1]. The fundamental problem in these techniques is that the physiological processes available by activities of autonomic nervous system cannot reflect psychological ones correspondingly. They can yield unacceptably large numbers of false positives, that is, for indicating that people are guilty when they are in fact innocent [2]. An additional problem is that subjects can control autonomic arousal by using certain drugs, such as tranquilizers [3] or through physical acts, such as tensing muscles [4]. These methods can be used to escape detection.

ERPs are a good auxiliary measure in the detection of guilty knowledge for two reasons. First, ERPs have been shown to be sensitive to a variety of cognitive processes, including some unconscious processes which cannot be inhibited by subjects [5]. Second, because ERPs presumably reflect the activities of the central

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nervous system related to information processing rather than emotion-dependent activities of autonomic nervous system, the methods used to escape the detection of traditional techniques will be null [6]. Rosenfeld et al. used P300 as an indicator to detect guilty knowledge [7]. In their experiment, a larger P300 was elicited by an "oddball" stimulus – the item supposed to be stolen by the subjects. N400 component was firstly described by Kutas and Hillyard [8]. They compared ERPs produced in response to words which completed sentences in a semantically anomalous fashion with ERPs produced in response to completions that were semantically normal. For the semantically anomalous completions, a negative-going component in the ERPs, maximal in the central and parietal areas, was elicited approximately 400 ms after the onset of the final critical word. No such negative component was noted for the semantically normal completions. More important for its use in detection of guilty knowledge, the N400 effect has also been associated with the truth value of sentence read by a subject [9]. Boaz et al. [10] used the mismatch between context phrase-test word format (e.g., "A type of bird, Robin") to elicit N400 component to detect guilty knowledge. Such a mismatch can only be detected by people who had guilty knowledge of the crime. In this experiment, 10 clues (10 context phrases and correspondent test words) relating to the crime were provided to detect guilty knowledge but there was only one clue in Rosenfeld et al.'s experiment.

It is often such a case as described by Rosenfeld et al. that only a single clue (the murder weapon, the stolen item, etc.) can be utilized. This paradigm may be suited to field procedures for detecting guilty knowledge. However, one problem with this paradigm is that there is only a broad area showing positivity but not a clear P300 between 500 and 700 ms poststimulus in ERPs derived from some subjects. It will make judgment difficult. Habituation in subjects leads to such difficulties. Obviously, more clues of guilty knowledge can help us to elicit a clear P300 component to distinguish guilt from innocence. Moreover, more clues make it possible to utilize both N400 and P300 effects simultaneously by constructing context phrase-test word format to detect guilty knowledge.

In the present study, the combination of two indicators – P300 and N400 – to detect guilty knowledge was our purpose. At the same time, we compared the effects of lie detection at F3, Fz and F4. Dynamic time warping (DTW) as described by Roberts et al. [11] was used to obtain standard (template) representative pattern of ERPs for each subject. The time warping procedure attempted to match waveform A to waveform B best by shifting, expanding or contracting the time scale of waveform A in such a manner that it minimizes the "cost" of warping. DTW was used to adjust the latency of each component of ERPs in our study.

Method

Subject

Subjects (n = 20) were graduate students or young teachers of some universities.

Ages ranged from 21 to 35 years, and 11 of the subjects were men. All subjects were right-handed and reported having normal or corrected to normal vision. EEG data from two of these subjects were not included in the analysis because of excessive eye movement artifact.

Materials

A piece of diary describing a burglary of an apartment in detail was read by the subjects. Guilty knowledge test (GKT) taking question-answers format was constructed according to the crime. Each of 18 questions comprised five answers including one relevant item (RI) and four irrelevant items (II). Each of the total 90 items was a word with 2–3 Chinese characters. It was relevant items, but not irrelevant items, that were semantically congruous with the question according to the crime.

Recording system

Stimulus presentation and EEG data collection were controlled separately by PC586 and PC486. Stimuli appeared centered on the screen placed directly in front of the subject. The distance between subject and screen was 1 m.

EEG was recorded from location F3, F4 and Fz according to the international 10-20 system and was referenced to linked ear lobes. The forehead grounded and eye movement were monitored by an electrode placed supraorbitally. An elastic cap with silver/silver chloride electrodes (Neuroscan Comp.) was used in all cases. Electrode impedances did not exceed 5 kΩ. The EEG signals were amplified and filtered with a band pass of 0.5–30 Hz by Neuropack-8 (Nihon Kohden, Japan). The signals were digitized at 250 Hz/location and stored on disk for later analysis.

Procedure

Upon the subject's arrival, a general description of the experimental procedure was given, and the subject's informed consent to participate was obtained. An electrode cap was put on and impedances of electrodes were verified less than 5 kΩ. The subject then sat in front of the screen of the computer in an electrically shielded room and the experimenter taught him/her how to operate the keyboard. All subjects were instructed to read the diary depicting a burglary of an apartment and to remember some details which had been labeled by the experimenter and were relevant to the questions. The subjects were given the following instructions: you should imagine that you had committed the theft as described in the diary and were accused of committing the crime. The police would let you go if you can pass a lie detector test. After a while, each of 18 questions on the theft will be presented on the screen followed by five items in a series. You ought to react to every item with "yes", "no" or "do not know" by pressing "g",

"j" or "h" on the keyboard. Try your best to appear innocent during this interrogation, even if you were the thief.

Every question was presented for 5,000 ms. Each of the five corresponding items was presented successfully for 300 ms, starting 1,000 ms after the offset of the question. There was an interval of 4,000 ms between the reaction of the subject and the presentation of another item. The collection of EEG data started 120 ms before the presentation of the item and ended 700 ms after the item disappeared. The total time of each item for collecting EEG data was 1,120 ms. After answering every six questions, the subject was instructed to have a break for 3 min. Subjects were asked to minimize head and body movements and eye blinks during the trials. After EEG data collection was completed, impedances were rechecked, and the electrodes were removed. The whole experiment took 1 h.

For every subject, EEG data were sorted by trial depending on whether a RI or an II was presented, then averaged coherently within each of two classes (RI — 18 times, II — 72 times). Data showing eye movements during recording epoch were discarded. To examine general trends in the data, we used dynamic time warping (DTW) to adjust the latency of components of ERPs for each subjects and calculated the grand average (across all subjects) for RI and II. Paired t test was used to test the amplitude difference of P300 and N400 between RIs and IIs.

Result

Upon visual inspection of averaged ERPs (Fig. 1), it was clear that two large positive peaks following the onset of the item, the first (P200) with a peak latency of about 210 ms and the second (P300) with a latency about 500 ms. A negative component (N400) occurred about 390 ms after the onset of the item and separated these two positive peaks. The mean and standard differences of amplitudes of P300 and N400 for each class (RI, II) and location (F3, F4, Fz) are listed in Table 1.

For each location, the difference in P300 amplitude between RI and II reached significant level using paired t test (at F3, $t = 5.35$, $p < 0.001$; at Fz, $t = 4.98$, $p < 0.001$; at F4, $t = 4.04$, $p < 0.001$). However, none of the differences of N400 amplitude between RI and II reached significant level (at F3, $t = 1.29$; at Fz, $t = 0.52$; at F4, $t = 0.68$). We also compared the differences in P300 amplitude between RI and II among F3, Fz and F4; only the difference between F3 and F4 reached significant level ($t = 2.19$, $p < 0.05$ s).

At F3, Fz and F4, 16, 16 and 15 of 18 subjects elicited, respectively, a larger P300 by RI than by II. Combining the data from F3, F4 and Fz, we detected that 15 of 18 subjects had guilty knowledge.

Discussion

In the present study, compared to irrelevant items, relevant items elicited a larger P300. However, irrelevant items did not elicit a larger N400 than relevant items.

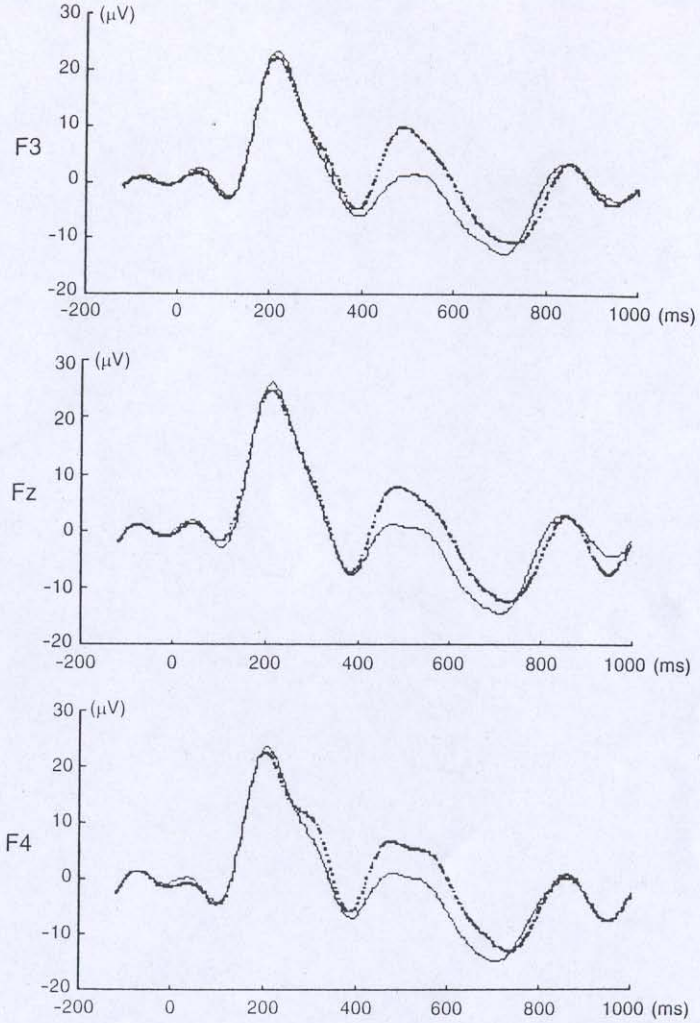

Fig. 1. Grand averaged ERPs elicited by RI (solid line) and II (dashed line) at F3, Fz and F4 (n = 18).

The P300 has been hypothesized to reflect updating of memory or surprise. Its amplitude is determined by subjects' attention and small probability of significant stimuli to subjects. All subjects learned new information in the laboratory and GKT on that information was constructed. Among the five items (including one relevant item and four irrelevant items) following a question, only relevant items were semantically congruous with the question, so it was significant to subjects. Meanwhile, its probability was 20%.

Table 1. Amplitudes of the ERP peaks.

	F3	Fz	F4
P300			
RI	9.31 (7.52)[a]	7.59 (6.31)[a]	5.94 (6.80)[a]
II	1.66 (4.40)	1.49 (5.76)	1.46 (5.66)
N400			
RI	−5.09 (6.54)	−7.51 (5.33)	−6.60 (5.66)
II	−6.79 (3.97)	−8.02 (4.34)	−7.26 (4.04)

Note: mean (SD) (μV) peak-to-baseline amplitudes of P300 and N400 elicited by RI and II at F3, Fz and F4 (n = 18). [a]$p < 0.001$ (paired t test between RIs and IIs).

N400 reflects semantic processing of words in context. N400 component was also observed for false sentences pertaining to episodic information learned by subjects in the laboratory (e.g., "Diane is a lawyer") in which the sentence endings are not incongruous in any way [12]. In our experiment, irrelevant items were semantically incongruous with the question according to the information learned by subjects. According to Boaz et al.'s hypothesis, N400s ought to be elicited in suspect by the irrelevant items (II) and P300s, by the relevant items, but neither component could be elicited in innocence [10]. The combination of two indicators — P300 and N400, to detect guilty knowledge was our purpose in the present experiment. It will be more effective than using only one indicator. The result of our experiment could not confirm this point. There was a difference in the design of the experiment between Boaz et al.'s study and ours. In our study, first, question-answers format, rather than strict context phrase-test word format or sentence completion format was used. Secondly, the question followed by five answers was presented only once, rather than before every answer.

In the views of application, the larger the difference in P300 amplitudes between relevant items and irrelevant items, the easier it is to detect deception. The difference in P300 amplitude at F3 was the largest and that at F4 was the smallest. Moreover, the difference in P300 amplitude between F3 and F4 reached a significant level. These results suggested that if the visual stimuli evoking P300 component are semantic to right-handed subjects, F3 was a better location to record ERPs for detecting guilty knowledge than F4 and Fz. Because multiple clues were utilized in this experiment, a clear positive peak with a latency of 500 ms was elicited, rather than a broad area showing positivity between 500 and 700 ms poststimulus in ERPs elicited by the repeated presentation of a single clue as described by Rosenfeld et al. [7]. Although they were both defined as P300, our design could avoid subjects' habituation to stimuli and made lie detection easy.

In the present study, the presence of guilty knowledge was detected with ERPs at a rate significantly better than chance. The ERP method described in this study reflects the automatic cognitive processes for decision making and countermeasures were avoided. Moreover, it minimizes the effects of potentially con-

founding variables and examiner bias. Thus ERPs show promise as a method for detecting the presence of guilty knowledge.

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