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# Equivalent current dipole source localization of deceptive response during crime-relevant sentence processing*

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We investigated event-related potential generators in the P300-based guilty knowledge test using Korean sentences, which had an 'object-complement-verb' or a 'subject-object-verb' structure. Twenty-six participants were divided into a guilty group and an innocent group. Thirteen guilty participants performed a mock theft, and 13 innocent participants committed a crimeless act. During electroencephalogram recording, 3 kinds of stimuli were visually presented: target, probe, which included crime-relevant information, and irrelevant. The results of event-related potentials showed that the P300 amplitude for the probe sentence was larger than the irrelevant sentence in the guilty group; however, the innocent group did not show such difference. The equivalent current dipole analysis for the probe found a group difference of dipole location and power. In both groups, the sources of probe of verb element were determined to be located in the superior frontal gyrus. The guilty participants exhibited significant alterations in the hemispheric asymmetry of dipole power for the probe of verb element. This result seems to reflect that guilty participants have crime-relevant information and pay more attention to the probe compared to the innocent participants. This study also shows hemispheric asymmetry in the deceptive response using sentences.

**Keywords:** P300, guilty knowledge test, equivalent current dipole, hemispheric asymmetry, deception

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Deception can be defined as a deliberate attempt to mislead other people (DePaulo et al., 2003). Many cognitive functions are regarded to be involved in the deception process. For example, deception includes selective attention and understanding of question, memory retrieval, and planning for response, particularly, response inhibition. Mankind has paid attention in order to find out ways to know whether an individual is telling a lie; moreover, methods to detect deception have been improved with technological advance. Among deception detection methods, the P300 component of the event-related potentials (ERPs) has been widely studied (Andreassi, 2007). P300 is a positive-going component showing the largest amplitude around 300 ms post-stimulus. This component is known to be elicited in an oddball paradigm when a participant shows a rarely presented target among a series of frequently presented non-targets.

Farwell and Donchin (1991) suggested the P300-based guilty knowledge test (P300-based GKT), which is a kind of an oddball paradigm for examining a person's knowledge about a crime (Ben-Shakhar and Elaad, 2003;

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Lykken, 1974). Other researchers have also reported that P300 can discriminate people with crime-relevant information by using the P300-based GKT (Abootalebi et al., 2009; Rosenfeld et al., 1987, 1988). In the GKT, the stimuli consist of a target, a probe, and an irrelevant. The target, presented infrequently, is relevant to an experimental task and attracts participants' attention and elicits P300, yet, it is not relevant to a crime. It is because a subject is required to discriminate the target stimulus from other stimuli. The probe, presented infrequently as well, includes critical information of a crime, that is, guilty knowledge, and is exposed to only a few people involved in the crime, such as a criminal, a victim, or an investigator. The irrelevant, frequently presented, is not relevant to the crime or to the task. The participant is instructed to distinguish the target stimulus and make a target or non-target response during an experimental task. According to the basic premise of the test, the target would evoke the largest P300 in comparison to the probe and the irrelevant regardless of the participant's crime-relevance; however, the probe would show a different ERPs pattern, according to the participant's crime-relevant status. For a guilty participant who is crime-relevant, the probe would draw his attention more than the irrelevant, and the probe would elicit a larger P300. This occurs because the guilty participant knows the probe, the guilty knowledge. A guilty subject, who has the guilty knowledge, would pay more attention to probe stimulus, but not to irrelevant stimulus. However, the subject is required to respond only to target stimulus, and to make a non-target response to the probe stimulus, even knowing the probe stimulus. That's because the probe stimulus contain important information for the guilty subject and he should treat it as irrelevant stimulus to hide his knowledge about the crime and defeat the test. On the contrary, an innocent participant does not have information about the crime, and thus, he would attend equally to the probe and the irrelevant. Conversely, an innocent subject does not have any information about the crime and would be equally attentive to probe and irrelevant stimuli; therefore, the innocent subject would not respond incorrectly on purpose. Hence, compared to irrelevant stimulus, target and probe stimuli would elicit larger P300 amplitude in the guilty subjects, whereas probe stimulus would not elicit P300 amplitude larger than that elicited by irrelevant stimuli in the innocent subjects. Therefore, the P300-based GKT can detect a deceptive response when a guilty participant sees the probe stimulus and tries to process it as an irrelevant stimulus.

Several stimulus modalities have been applied to the GKT: pictures, words, phrases, or sentences (Boaz et al., 1991; Gamer, 2010; MacLaren and Taukulis, 2000). Among them, some studies used context phrases (e.g., in a jeweler's) and the following test words (e.g., a red ring) in order to detect a participant's guilty knowledge, and researchers implied that a test word, including guilty knowledge, is the key to detect a participant's guilt or innocence. These studies paid attention only to the responses to a critical test word due to the fact that deceptive decision was made after a participant saw the final word, that is, the critical information. The critical test words were usually nouns. Brain imaging studies on deception also measured brain activity for a test noun (Gamer et al., 2007; Ganis et al., 2003; Kozel et al., 2004; Lee et al., 2002). Regarding that many languages, including English, have a subject-verb-object sentence structure, it sounds plausible that there was no P300-based GKT study focused on verbs within whole phrases or sentences. In the P300-based GKT study using English sentences, a participant makes his decision of response when he recognizes the object, a final noun word. Korean, however, has a subject-object-verb sentence order and the participant decides how to respond when he sees the final word, the verb. In this sense, the participant's response can be changed according to the verb that depicts an action even when the object is the same. Therefore, in the P300-based GKT using Korean sentences, we need to focus not only on the object element but also on the verb element.

Meanwhile, many brain regions are related to deception, and each seems to play its role in deception mechanism. Up to the present, studies on deception often found frontal and parietal regions as neural sources of deceptive responses (Christ et al., 2009; Gamer et al., 2007; Ganis et al., 2003; Kozel et al., 2004; Lee et al., 2002). First of all, frontal, particularly the prefrontal regions are involved in working memory representation, judgment, and planning of response (Mohamed et al., 2006; Prabhakaran et al., 2000). Parietal cortex is known to be related to deception mechanism, such as making a calculated response or recalling an episodic memory (Lee et al., 2002; Wagner et al., 2005). Researchers also reported the anterior cingulate cortex as a neural generator in the deception process (Abe, 2011; Langleben et al., 2002); the anterior cingulate cortex is related to conflict monitoring (Van Veen and Carter, 2002).

Besides, it seemed that hemispheric difference exists in deceptive mechanism. Mohamed and colleagues (2006) found left hemisphere dominance in deception. In their functional magnetic resonance imaging (fMRI) study, participants made their responses to control (irrelevant) and relevant questions as to mock shooting. During the deception process, compared to the truth telling process, the frontal, temporal, and occipital regions in the left hemisphere were mainly activated. Also, Al-Hamouri (2012) reported that left hemisphere dominance was also present in deception. These studies implied that deception is a complex task, requires higher order cognitive functions, and involves the left hemisphere activation to a great extent. Some studies, on the other hand, suggested the involvement of the right hemisphere in deception in addition to the left hemisphere (Ganis et al., 2003; Kozel et al., 2004; Langleben et al., 2002). Kozel and colleagues (2004) showed the right prefrontal activation for lying minus truth-telling condition in their fMRI study. Langleben and colleagues (2002) also found the right superior frontal gyrus activation in addition to the left hemisphere activation during the lie condition. Until now, to our knowledge, the hemispheric laterality of the deception process does not seem to have been investigated.

In this context, deception detection technique, including the P300-based GKT, still requires more researches investigating the deception mechanism in detail for field use. One of possible researches may use source localization method. It can localize activated brain regions during cognitive processing from scalp voltage distribution, and this technique seems to be suitable for electroencephalogram (EEG) or ERPs (Wassenberg, 2008). This method would enable researchers to figure out the neural correlates of deception process and detect deception based on the cortical activity in a small region, and help investigators to discriminate a guilty suspect eventually. To our knowledge, there was only one study that investigated ERPs generator for deception using the source localization method. Jung et al. (2013) reported the frontoparietal activation during deceptive responses in the P300-based GKT. Up to now no prior study has directly examined hemispheric asymmetry of ERPs generator for deception.

This study is aimed at identifying the equivalent current dipoles related to ERPs of 3 stimuli (target, probe, and irrelevant sentences) and 2 within-sentence elements (complement/object and verb) in the P300-based GKT using Korean. For experimental manipulation, half of the participants committed a mock crime before EEG recording, whereas the other half did not. The two groups of participants' EEG were obtained from 64-channels and were analyzed. The equivalent current dipole model was applied with the template 3-dimensional MRI as a realistic head model of the boundary element method (Fuchs et al., 1998) for all participants. We expected that the 2 elements (complement/object and verb) within the probe sentence will show a distinct pattern in terms of ERPs and cortical source in the P300-based GKT; an element describing the object of a crime (usually a noun), and an element describing the act of a crime (usually a verb) will have their own role in the P300-based GKT. In this study, each sentence is a declarative sentence comprised of 3 elements: object-complement (adverb phrase)-predicate (verb) or subject-object (noun)-predicate (verb). Three kinds of sentences were used: target, probe, and irrelevant sentences. During EEG recording, a participant was required to discriminate target sentences from the other stimuli. The equivalent current dipole analysis was done with the ERPs for 2 elements (complement/object and verb) of target, probe, and irrelevant sentences. Then, a statistical analysis was conducted in order to compare dipole locations, powers, and hemispheric asymmetry of the probe stimulus between groups. This is a study focused on estimating the ERPs generator and finding dipoles on separate sentence elements in the P300-based GKT.

## Methods

**Participants.** Twenty-six healthy male volunteers from an introductory psychology pool (age ranged from 18-26, mean=22.5 years) participated in this study. They had normal or corrected-to-normal vision and were all right-handed. All of them were free from a history of alcohol and drug abuse, psychiatric disorder, or neurological deficit. The participants were randomly assigned into a guilty group (*n*=13) and an innocent group (*n*=13). There was no significant group difference in the demographic data and in the following self-report scores: Beck Depression Inventory (Beck and Steer, 1987), Beck Anxiety Inventory (Beck et al., 1988), lie scale of the Minnesota Multiphasic Personality Inventory-2 (Butcher et al., 1989), Machiavellianism IV scale (Christie and Geis, 1970), and Self-Monitoring Scale (Snyder, 1974). Participants gave written informed consent after they fully understood the experimental process. All of them received a monetary reward for their participation.

**Stimuli.** Two sets of 12 Korean sentences were used in the experiment. One set of sentences were ‘object-complement (adverb phrase)-predicate (verb)’ structure (e.g., “Ji-gab-eul (the wallet) 10-beon-seo-rab-e (in the 10th drawer) gam-chwoss-da (hid);” in English, “I hid the wallet in the 10th drawer.”). The other set was a ‘subject-object (noun)-predicate (verb)’ structure (e.g., “Na-neun (I) 1-man-won-eul (₩10,000) hum-chyeoss-da (stole)”. This means, “I stole ₩10,000.”). Each of the 3 sentence elements was separately presented for 500 ms on a CRT monitor, subtended visual angles of 3.43° horizontally and 2.29° vertically. The stimuli were presented on a monitor screen with a monitor-to-head-distance of 80 cm, using the software Stim (Neuroscan, Charlotte, USA). The interstimulus interval was 1000 ms, and the interval between sentences was 3500 ms. A participant was instructed to respond at the end of a sentence when he saw 3 asterisks (***), a response cue. One set of stimuli had 1 target sentence, 1 probe sentence that included guilty knowledge, 4 irrelevant sentences, and 6 filler sentences. Only the adverb phrase of the first set and the noun of the second set were varied among the target, probe, and irrelevant sentences. To be specific, in the first set, 6 different adverbs were used: in the 10th (target), 1st (probe), and 5th, 6th, 7th, 8th (irrelevant) drawer. In the second set, 6 different nouns were used: ₩10,000 (target), ₩70,000 (probe), and ₩20,000, ₩40,000, ₩50,000, ₩60,000 (irrelevant). The object to hide (“the wallet”) and the person who performed the mock crime (“I”) were the same in the experimental task. Therefore, the object of the first set and the subject of the second set did not differ among the stimuli. Meanwhile, each target, probe, and irrelevant sentence has its filler sentence. It was because even when a participant saw a target object or a target complement, he had not to respond if the whole sentence was a filler sentence. The filler sentence had another verb: “neo-eoss-da” instead of “gam-chwoss-da” (“put” instead of “hid”) in the first set and “bo-ass-da” instead of “hum-chyeoss-da” (“saw” instead of “stole”) in the second set. Filler sentences were to help participants fully attend to the sentence by leading them to respond after they saw the whole sentence, and not analyzed.

**Procedure and tasks.** Two participants came to the laboratory at the same time and chose one of the 2 sealed envelopes. One envelope had a mock theft scenario; the participant who chose the envelope is assigned to the guilty group. Another envelope had a similar scenario without a crime; the participant who chose it is assumed to be the innocent participant. The guilty participant was requested to seek 2 introductory psychology textbooks, take ₩70,000 out of the wallet on the bookshelf, and hide the money in his pocket and hide the wallet in the 1st drawer. Meanwhile, an innocent participant was requested to seek 2 introductory psychology textbooks, and to type a short paragraph using a laptop computer in the laboratory. One of the 2 participants was a research assistant who feigned to be an actual participant; he was supposed to choose the other scenario that the real participant did not choose. When a participant and the research assistant fully understood the given scenario, they acted it out one by one. The duration of the mock crime session in the laboratory was controlled for approximately 10 minutes. After the mock crime session, the experimenter checked if the mock crime finished successfully, and told participants that money has been missing during the session and an EEG test is available to figure out who is charged of the crime. Participants were also required to do their best in order to prove their innocence, and were told that they can get a bonus if they passed the test. The experimenter did not know which scenario was performed by the real participant until the experiment finished.

EEG recording was conducted in a soundproofed, electrically shielded room. During the EEG recording, the participant went through 2 experimental tasks in a block-design. Each task included 3 blocks and each block lasted about 6 minutes. The first task (Task 1) was about the place where the wallet was hidden, and the second task (Task 2) was about the amount of the money stolen. The stimuli were sentences which had an ‘object-complement (adverb phrase)-predicate (verb)’ (Task 1) or a ‘subject-object (noun)-predicate (verb)’ (Task 2) structure. Each block comprised of 6 sentences (1 target sentence, 1 probe sentence, and 4 irrelevant sentences) repeated 15 times, and 6 filler sentences repeated twice. Stimuli were pseudorandomly presented, and target or probe sentence was not presented contiguously. The participant was instructed to press the left button on a respond pad to a target sentence, the right button to the probe and the irrelevant, and not to press any button to filler sentences. The participant was also demanded to respond rapidly and accurately immediately after the response cue. The response button and the task order were counterbalanced across participants. Before running experimental tasks, participants went through a training block. The entire EEG experiment lasted around an hour.

After the completion of the EEG experiment, the experimenter asked the participant a few questions and checked his memory of the experienced scenario. The experimenter also asked whether he tried to respond deceptively on purpose during the test and debriefed.

**EEG Recording.** EEG was recorded at 64 Ag/AgCl electrodes mounted on an elastic cap (Neuroscan, Charlotte, USA). The electrodes were positioned according to the international 10-20 system and referenced to the left and right mastoid processes. Horizontal electrooculograms (EOGs) monitored eye movements from the outer canthi of each eye, and vertical EOGs were recorded to monitor eye blinks from upper, lower side of left eye. All electrode impedances were maintained at 5 k$\Omega$ or less. EEG data were continuously obtained with a 0.05-100 Hz bandpass and sampled at 1000 Hz. The data were epoched with a 900 ms time window, including a 100 ms pre-stimulus baseline. Trials with artifacts were eliminated by automatic rejection process and manual investigation and any epoch whose amplitude exceeded ±100 $\mu$V at any channel were excluded. Trials with incorrect responses were also not included. Each participant’s EEG data with valid trials were then averaged for each target, probe, and irrelevant sentence element (complement (adverb phrase) and verb of Task 1, object (noun) and verb of Task 2), and 0.1-30 Hz bandpass filtered. The object word (“the wallet”) of Task 1 and the subject word (“I”) of Task 2 were the same in all sentences and did not analyzed.

**Source localization.** After the ERPs analysis, we used Curry V6.0 (Neuroscan, Charlotte, USA) for source localization. Equivalent current dipole model was applied to the ERPs data after matching the electrode locations with the template MRI in the Talairach atlas (Talairach and Tournoux, 1988). Nasion and bipolar preauricular points were used for anatomical coregistration. We conducted the independent component analysis (Hyvärinen and Oja, 1997; Onton and Makeig, 2006) based on 50 ms around the peak mean global field power of P300 and only component whose signal-to-noise ratio was more than 1 was used. The 3-compartment boundary element method model with about 4,000 triangle nodes was used for the volume conductor. Standard conductivities were 0.33, 0.0042, and 0.33 for the brain liquor, skull, and skin, respectively. Then, the equivalent current dipole analysis was conducted individually in order to gain the ideal dipoles for each stimulus condition (target, probe, and irrelevant) using the fixed multiple signal classification (MUSIC) algorithm (Mosher et al., 1992). The fixed MUSIC algorithm calculates independent dipole power with fixed dipole location and orientation as constraints; dipole location and orientation for an independent dipole do not change over time. The equivalent current dipole locations were restricted to the cortex with a minimal distance of 15 mm between dipoles in both hemispheres; and the distance from the seed was restricted to 20 mm. A pair of bilateral seed points minimizing the residual variance was applied to the algorithm. Particularly, the complement (adverb phrase) in Task 1 and the object (noun) element in Task 2 used parietal seed points, and verbs of both tasks used frontal seed points. These seed points were chosen in line with previous studies (Lee et al., 2002; Linden, 2005; Mohamed et al., 2006; Prabhakaran et al., 2000; Wagner et al., 2005). Two seeds in the bilateral inferior parietal lobule (Talairach coordinates −44/31/34, 52/−26/31, Brodmann area (BA) 40) and 2 seeds in the superior frontal gyrus (−29/54/−6, 24/57/−9, BA 10) were used. BA 40 is regarded as a part of Wernicke's area that is associated to language processing, and BA 10 is a part of the prefrontal association area that participates in judgment and planning. Residual variances were kept below 20 %.

**Statistical analysis.** To compare the behavioral data between groups, the repeated measures analyses of variance for reaction time and response accuracy were conducted with the stimulus condition (target, probe, irrelevant) as a within-subject factor, and the group as a between-subjects factor.

The P300 peak amplitude between 200 and 600 ms poststimulus and the P300 latency were analyzed by rmANOVA respectively, with the 12 electrode sites (Fp1, Fpz, Fp2, F3, Fz, F4, C3, Cz, C4, P3, Pz, P4) and the stimulus condition as within-subject factors, and the group as a between-subjects factor. The P300 time window (200-600ms) was determined by visually inspecting individual and grand-averaged waveforms.

For each repeated measures analysis of variance, the Greenhouse-Geisser correction (Greenhouse and Geisser, 1959) was applied. Further, independent $t$-tests of the P300 amplitude and latency at the midline electrode were performed as well: Pz for complement and object elements, Fz for verb elements.

With respect to the dipole analysis results, independent $t$-tests were conducted in order to compare anatomical location and moment of dipoles between the guilty and the innocent group. In order to estimate the hemispheric difference of dipoles, the asymmetry coefficient (AC) was calculated by the following equation: [(R − L)/0.5 x (R + L)], in which R and L represent the dipole moments on the right and left sides, respectively. Participants appeared to have leftward asymmetry ($AC < -0.05$), symmetry ($-0.05 \leq AC \leq 0.05$), or rightward asymmetry ($AC > 0.05$). Chi-square ($\chi^2$) tests were then conducted in order to compare dipole asymmetry between the 2 groups.

## Results

**Behavioral results.** There were no significant differences in reaction time and response accuracy between groups with respect to both tasks. However, an interaction effect between the stimulus condition and the group in Task 1 was found when it comes to the reaction time [$F(2,48)=7.55$, $p=.001$, $\eta_p^2=.239$]. In the guilty group, the target and the probe had longer reaction time than the irrelevant [target, mean=323 ms (standard deviation=71); probe, 326 ms (74); irrelevant. 316 ms (63)]. On the contrary, the irrelevant had the longest reaction time among the 3 stimuli in the innocent group [target, 340 ms (39); probe, 341 ms (38); irrelevant, 356 ms (42)]. Also, a main effect of the stimulus condition was significant in terms of response accuracy in task 2 [$F(2,48)=12.47$, $p=.001$, $\eta_p^2=.342$]. Response accuracy for the target was lower than the probe and irrelevant regardless of the group {[innocent group target, 92.8% (6.8); probe, 96.8% (3.7); irrelevant, 96.5% (2.9)], [guilty group target, 93.6% (6.1); probe, 97.0% (3.2); irrelevant, 96.3% (3.5)]}.

**Event-related potentials results.** The grand average ERPs waveforms evoked by 3 stimuli (target, probe, irrelevant) of complement element (adverb phrase) in Task 1 at 8 electrode sites (Fp1, Fp2, F3, F4, C3, C4, P3, P4) in the guilty and the innocent group were shown in Figure 1. The target exhibited the largest P300 amplitude in both groups. Also, the probe elicited a larger P300 amplitude than the irrelevant in the guilty group, particulalry in parietal sites. P300 appeared from around 300 ms and lasted for about 500 ms post-stimulus. However, the probe and the irrelevant induced a similar positivity in the innocent group regardless of site.

The statistical analysis of the P300 amplitude of complement element (adverb phrase) at 12 electrode sites (Fp1, Fpz, Fp2, F3, Fz, F4, C3, Cz, C4, P3, Pz, P4) found a main effect of the stimulus condition [$F(2,48)=13.24$, $p=.000$, $\eta_p^2=.356$]. This meant that P300 amplitude showed a different pattern according to the stimulus condition; the target had the largest P300 amplitude. There was also a main effect of electrode sites [$F(11,264)=20.22$, $p=.000$, $\eta_p^2=.457$], and it seemed to reflect that P300 amplitude was larger in the parietal region rather than in the frontal or central region in both groups. A stimulus condition x electrode sites interaction effect, was also significant [$F(22,528)=3.65$,

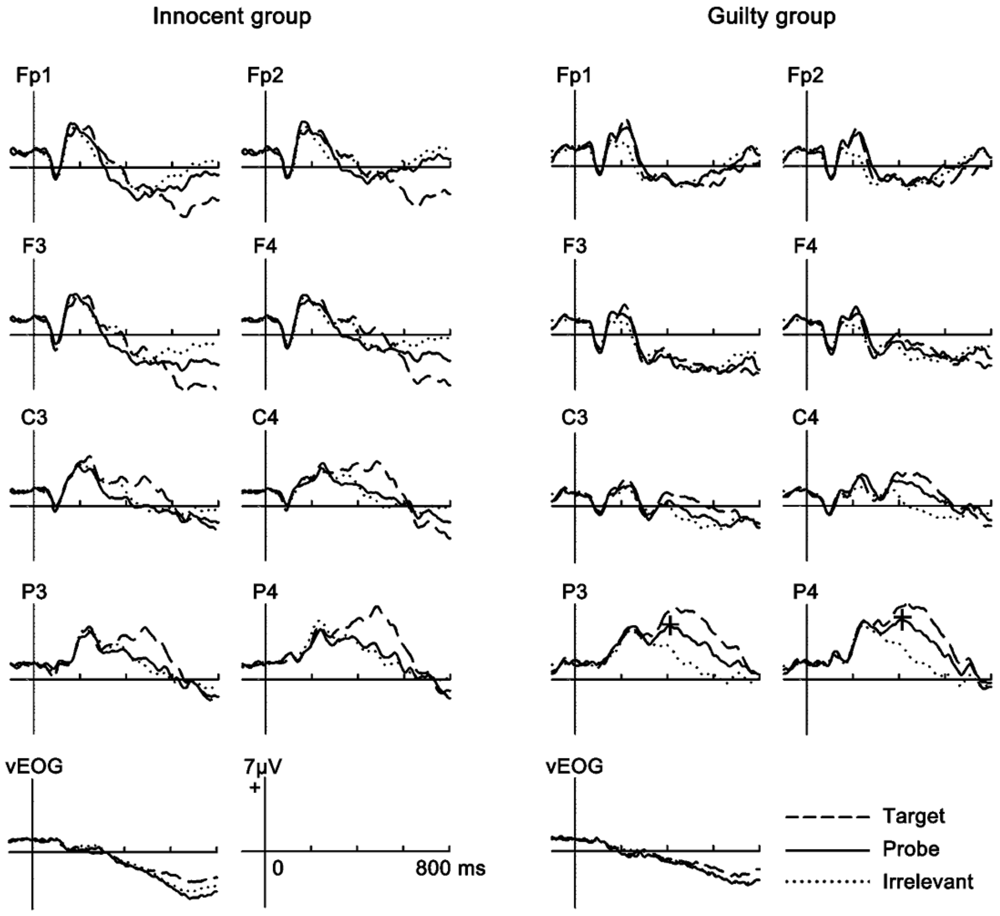


**Figure 1.** The grand average ERPs waveforms invoked by 3 types (target, probe, and irrelevant) of complement element (adverb phrase) at 8 electrode sites for Task 1 of the two groups. The P300 peak amplitudes of the probes at P3 and P4 sites were marked by the cross in the guilty group.

**Table 1**. Means and standard deviations (in parentheses) of the P300 peak amplitudes and latencies at 2 parietal electrodes (adverb phrase) and 2 frontal electrodes (verb) of Task 1 in the innocent and guilty group.

| Word (Site) | | Innocent group ($n$=13) | | Guilty group ($n$ =13) | | | |
|---|---|---|---|---|---|---|---|
| Adverb phrase (Pz) | | P3 | P4 | P3 | | P4 | |
| | *Amplitude (μV)* | | | | | | |
| | Target | 4.9 (5.2) | 7.2 (4.4) | 8.2 (3.6) | | 8.5 (4.2) | |
| | Probe | 3.0 (3.3) | 4.7 (4.2) | 6.0 (2.4) | *** | 6.5 (3.3) | *** |
| | Irrelevant | 3.0 (2.8) | 4.2 (3.1) | 3.4 (3.1) | | 3.9 (3.4) | |
| | *Latency (ms)* | | | | | | |
| | Target | 387 (62) | 399 (67) | 422 (97) | | 416 (87) | |
| | Probe | 362 (56) | 389 (71) | 400 (102) | | 390 (85) | |
| | Irrelevant | 347 (65) | 362 (51) | 376 (100) | | 354 (78) | |
| Verb (Fz) | | F3 | F4 | F3 | | F4 | |
| | *Amplitude (μV)* | | | | | | |
| | Target | 11.8 (7.5) | 12.0 (7.3) | 9.4 (6.6) | | 11.4 (5.9) | |
| | Probe | 5.7 (5.7) | 6.6 (5.1) | 8.3 (6.3) | ** | 9.1 (6.4) | * |
| | Irrelevant | 4.7 (4.8) | 5.5 (4.3) | 5.2 (5.3) | | 6.4 (5.1) | |
| | *Latency (ms)* | | | | | | |
| | Target | 315 (40) | 317 (38) | 361 (80) | | 356 (80) | |
| | Probe | 343 (46) | 343 (46) | 364 (96) | | 364 (104) | |
| | Irrelevant | 321 (56) | 335 (64) | 363 (105) | | 361 (104) | |

* $p < .05$; ** $p < .01$; *** $p < .001$

$p$=.011, $\eta_p^2$=.132]. In terms of probe and irrelevant P300, amplitudes were similar in frontal, central, occipital regions in both groups, but showed a difference in the parietal region. Also, in the parietal region, the probe showed a larger P300 than the irrelevant in the guilty group; yet, those 2 stimuli looked similar in the innocent group. However, no group effect was found. Table 1 describes the P300 amplitude and latency at the P3 and P4 sites for the complement element (adverb phrase) of Task 1 in the 2 groups. Paired $t$-tests found that there were significant amplitude difference between the probe and the irrelevant stimuli only in the guilty group [P3, $t$(12)=5.17, $p$=.000; P4, $t$(12)=5.82, $p$=.000]. The amplitudes of the probe stimuli were significantly higher than the irrelevant stimuli in the guilty group. In short, only the guilty group showed distinct probe ERPs and further, it seemed that the probe attracted attention and elicited P300 for the guilty participants.

On the other hand, Figure 2 illustrates the grand average ERPs waveforms elicited by the verb element at 8 electrode sites. The probe evoked a larger P300 than the irrelevant at the frontal electrodes in the guilty group. The waveform at the central site also showed a difference in amplitude between the probe and the irrelevant in the guilty group. P300 occurred around 200 ms and lasted for about 450 ms post-stimulus. In the innocent group, however, the probe and the irrelevant did not show an amplitude difference at any site.

The main effects of the stimulus condition [$F$(2,48)=38.57, $p$=.000, $\eta_p^2$=.616] and electrode sites [$F$(11,264)=21.50, $p$=.000, $\eta_p^2$=.473] were found in the statistical analysis of the P300 amplitude elicited by the verb (Task 1) at 12 electrode sites. Group effect did not reach the statistical significance. The main effect of the stimulus condition showed that the target had the largest P300 amplitude regardless of group. The main effect of

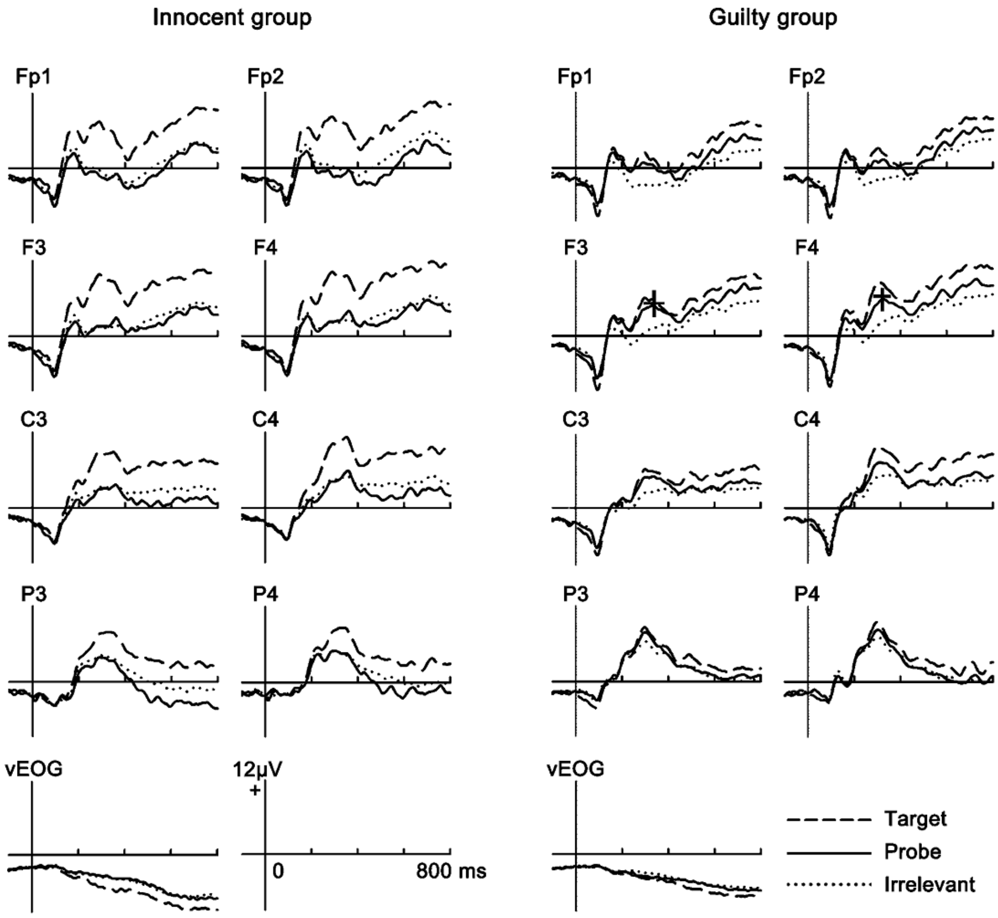


**Figure 2**. The grand average ERPs waveforms invoked by 3 types (target, probe, and irrelevant) of verb element at 8 electrode sites for Task 1 of the two groups. The P300 peak amplitudes of the probes at F3 and F4 sites were marked by the cross in the guilty group.

electrode sites seemed to reflect larger P300 amplitude in the frontal and central regions than any other regions. Meanwhile, an interaction effect between the group and stimulus condition [$F(2,48)=5.39$, $p=.01$, $\eta_p^2=.183$] was found, and it suggested that there was statistically a significant group difference according to the stimulus condition. The probe had larger P300 amplitude than the irrelevant in the guilty group, but not in the innocent group. Also, a stimulus condition x electrode sites interaction [$F(22,528)=6.62$, $p=.000$, $\eta_p^2=.216$] was significant. The target elicited larger P300 amplitude in the frontal and central sites than any other regions, but the P300 amplitude of the probe and the irrelevant was not dissimilar for all sites. Table 1 describes the P300 amplitude and latency at the F3 and F4 sites for the verb element of Task 1 in the 2 groups. Paired *t*-tests found that there were significant amplitude difference between the probe and the irrelevant stimuli only in the guilty group [F3, $t(12)=3.26$, $p=.007$; F4, $t(12)=2.68$, $p=.020$]. The amplitudes of the probe stimuli were significantly higher than the irrelevant stimuli in the guilty group during the processing of verb stimuli.

The grand average waveforms induced by an object element (noun) in Task 2 looked similar to the waveforms of the complement element (adverb phrase) (Task 1). Likewise the above results, the target induced the largest P300 amplitude in the guilty and the innocent groups. Also, the probe P300 and the irrelevant P300 showed a clearly distinct pattern in parietal region in the guilty group. Main effects of the stimulus condition [$F(2,48)=15.37$, $p=.000$, $\eta_p^2=.390$] and electrode sites [$F(11,264)=10.32$, $p=.000$, $\eta_p^2=.301$] were present with respect to P300 amplitude at 12 electrode sites. Each of these effects indicated that the target had the largest P300

**Table 2.** Means and standard deviations (in parentheses) of the P300 peak amplitudes and latencies at 2 parietal electrodes (object) and 2 frontal electrodes (verb) of Task 2 in the innocent and guilty group.

| Word (Site) | | Innocent group ($n$=13) | | Guilty group ($n$ =13) | | | |
|---|---|---|---|---|---|---|---|
| | | P3 | P4 | P3 | | P4 | |
| Object (Pz) | *Amplitude* ($\mu V$) | | | | | | |
| | Target | 4.5 (4.0) | 6.1 (3.2) | 8.4 (3.8) | | 8.7 (3.8) | |
| | Probe | 4.5 (4.4) | 5.4 (4.0) | 5.8 (2.6) | ** | 6.7 (2.8) | ** |
| | Irrelevant | 4.0 (3.8) | 4.7 (3.9) | 4.6 (2.6) | | 5.7 (2.8) | |
| | *Latency (ms)* | | | | | | |
| | Target | 320 (46) | 328 (43) | 390 (93) | | 374 (87) | |
| | Probe | 323 (43) | 326 (44) | 375 (86) | | 345 (81) | |
| | Irrelevant | 327 (44) | 320 (45) | 369 (87) | | 333 (75) | |
| | | F3 | F4 | F3 | | F4 | |
| Verb (Fz) | *Amplitude* ($\mu V$) | | | | | | |
| | Target | 12.2 (6.0) | 12.6 (6.9) | 13.6 (8.2) | | 15.6 (7.8) | |
| | Probe | 5.0 (6.5) | 6.1 (6.1) | 8.9 (6.3) | * | 9.9 (6.9) | * |
| | Irrelevant | 5.0 (5.7) | 6.0 (6.3) | 6.0 (6.0) | | 7.0 (6.2) | |
| | *Latency (ms)* | | | | | | |
| | Target | 322 (89) | 324 (67) | 359 (100) | | 365 (99) | |
| | Probe | 349 (89) | 357 (83) | 371 (100) | | 387 (107) | |
| | Irrelevant | 335 (100) | 337 (95) | 363 (117) | | 371 (114) | |

* $p$ < .05; ** $p$ < .01

amplitude and the amplitude was the largest in the parietal region. An interaction among group, stimulus condition, and electrode sites was close to being significant [$F$(22,528)=2.40, $p$=.073, $\eta_p^2$=.091]. It seemed to demonstrate that the probe and the irrelevant had a different impact on ERPs in the parietal sites in the guilty group, but not in the innocent group. Table 2 describes the P300 amplitude and latency at the P3 and P4 sites for the object element of Task 2 in the 2 groups. Paired $t$-tests found that there were significant amplitude difference between the probe and the irrelevant stimuli only in the guilty group [P3, $t$(12)=3.30, $p$=.006; P4, $t$(12)=4.55, $p$=.001]. The amplitudes of the probe stimuli were significantly higher than the irrelevant stimuli in the guilty group. The difference between the probe and the irrelevant stimuli induced by an object element (noun) in Task 2 looked similar to the difference of the complement element (adverb phrase) (Task 1).

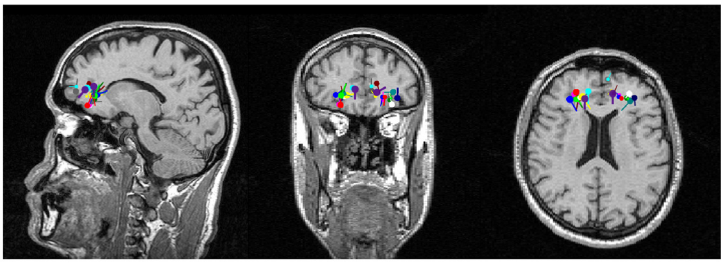
The grand average waveforms induced by the verb element (Task 2) showed the similar pattern to the waveforms of the verb element of Task 1. The target evoked larger P300 amplitude than the probe and the irrelevant regardless of the group. In the guilty group, the probe elicited larger amplitude than the irrelevant in the bilateral frontal, central, and parietal regions. On the contrary, amplitudes of the probe and the irrelevant were almost equal in the innocent group. The statistical analysis of P300 amplitude of the verb element at 12 electrode sites found main effects of the stimulus condition [$F$(2,48)=49.81, $p$=.000, $\eta_p^2$=.675] and electrode sites [$F$(11,264)=17.24, $p$=.000, $\eta_p^2$=.418], and a stimulus condition x electrode sites interaction [$F$(22,528)=9.86, $p$=.000, $\eta_p^2$=.291]. In both groups, the target elicited a significantly larger amplitude than the probe or the irrelevant stimulus. Besides, in the guilty group, the probe elicited larger P300 than the irrelevant, particularly in the frontal region. Unfortunately, a group effect did not reach the statistical significance. These results were comparable with the results of the verb in Task 1. From these results, we could conclude that although the verb was the same in whatever stimulus it was presented, the verb after the probe engendered P300 in the guilty group. Table 2 describes the P300 amplitude and latency at the F3 and F4 sites for the verb element of Task 2 in the 2 groups. Paired $t$-tests found that there were significant amplitude difference between the probe and the irrelevant stimuli only in the guilty [F3, $t(12)=2.82$, $p=.016$; F4, $t(12)=2.50$, $p=.028$]. The amplitudes of the probe stimuli were significantly higher than the irrelevant stimuli in the guilty group.

In the statistical analyses of the P300 latency of complement (adverb phrase), the object (noun) and verb elements at 12 electrode sites did not find a significant group effect. However, for the adverb phrase and the verb (Task 1), the main effects of the stimulus condition were found [adverb phrase, $F(2,48)=3.64$, $p=.037$, $\eta_p^2=.132$; verb, $F(2,48)=3.67$, $p=.034$, $\eta_p^2=.133$].

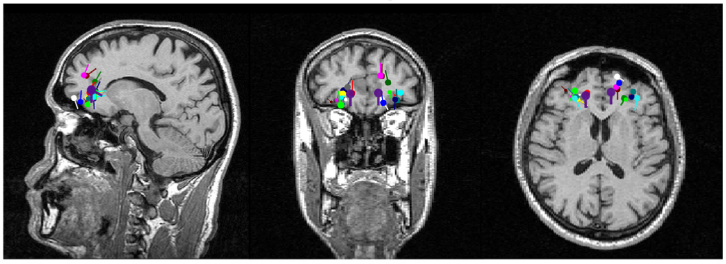
**Source analysis results** The equivalent current dipole analysis was conducted at 50 ms interval around the peak mean global field power of P300 for each stimulus. We used bilateral seed points in order to estimate 2 equivalent current dipoles using the fixed MUSIC algorithm embedded in Curry V6.0. Bilateral inferior parietal seeds were applied for the adverb phrase and object element, and superior frontal seeds were used for verbs. Among these results, Table 3 shows the mean location and power of dipoles of ERPs from a complement element (adverb phrase) of Task 1 in the guilty and innocent groups. There was no meaningful difference between the groups in terms of dipole locations and power of the target and the probe. In terms of dipole asymmetry, the guilty groups had a relatively leftward asymmetry in comparison to the innocent group. The number of leftward dipoles was larger than the rightward or symmetric dipoles in both groups.

**Table 3**. Mean location (mm) and equivalent current dipole power (μAmm) of ERPs elicited by target, probe, and irrelevant of complement element (adverb phrase) of Task 1 in the guilty and innocent group. The numbers of X, Y, and Z were the distance from the anterior commissure

| | | Innocent group ($n$ =13) | | Guilty group ($n$ =13) | | Analysis | |
|---|---|---|---|---|---|---|---|
| | | Left (S.D.) | Right (S.D.) | Left (S.D.) | Right (S.D.) | Left | Right |
| | | | | | | $t$ ($p$) | $t$ ($p$) |
| *Target* | | | | | | | |
| | X | −31.1 (4.4) | 39.1 (3.3) | −28.6 (2.6) | 43.4 (8.2) | 1.78 (0.09) | 1.77 (0.10) |
| | Y | −28.4 (9.3) | −31.4 (8.7) | −31.6 (5.5) | −29.8 (11.5) | −1.08 (0.29) | 0.4 (0.69) |
| | Z | 25.3 (4.6) | 24.2 (6.7) | 26.5 (6.6) | 22.6 (4.8) | 0.54 (0.59) | −0.7 (0.49) |
| | Power | 65.9 (51.0) | 44.3 (43.2) | 90.3 (41.4) | 30.7 (43.1) | 1.34 (0.19) | −0.8 (0.43) |
| *Probe* | | | | | | | |
| | X | −31.2 (6.0) | 42.3 (5.8) | −29.0 (4.4) | 38.7 (5.7) | 1.08 (0.29) | −1.61 (0.12) |
| | Y | −30.8 (9.7) | −27.3 (7.7) | −28.9 (8.6) | −30.6 (9.6) | 0.52 (0.61) | −0.97 (0.34) |
| | Z | 26.2 (5.2) | 21.7 (9.5) | 28.3 (4.9) | 25.5 (5.0) | 1.07 (0.29) | 1.31 (0.2) |
| | Power | 45.0 (29.0) | 41.3 (30.8) | 65.3 (46.1) | 32.2 (21.8) | 1.34 (0.19) | −0.87 (0.39) |
| *Irrelevant* | | | | | | | |
| | X | −31.2 (4.8) | 43.7 (8.9) | −29.5 (2.5) | 45.6 (10.9) | 1.1 (0.29) | 0.48 (0.64) |
| | Y | −29.0 (9.8) | −34.1 (7.8) | −31.1 (7.1) | −25.0 (7.9) | −0.64 (0.53) | 2.96 (0.01) |
| | Z | 25.5 (4.4) | 23.0 (5.3) | 24.3 (3.7) | 22.7 (7.6) | −0.72 (0.48) | −0.1 (0.92) |
| | Power | 51.5 (26.4) | 23.1 (18.5) | 50.5 (21.1) | 37.6 (35.2) | −0.11 (0.91) | 1.31 (0.2) |



Innocent group



Guilty group

**Figure 3.** Dipole distribution of the probe of the verb element in Task 1 in the innocent and guilty groups. A–anterior; P–posterior; L–left; R–right; L/A–left anterior; R/P–right posterior. The innocent participants had more and larger dipoles in the left hemisphere in comparison to the right hemisphere, and the guilty participants had relatively an even dipole distribution in both hemispheres

Chi-square test revealed no statistically significant difference between groups.

Figure 3 demonstrates the dipole distribution of the probe of verb element (Task 1) in the 2 groups. There was no statistical difference regarding the dipole locations and power between groups (Table 4). However, we noted a significant difference between the guilty participants and innocent participants with regard to the pattern of

**Table 4.** Mean location (mm) and equivalent current dipole power (µAmm) of ERPs elicited by target, probe, and irrelevant of the verb element (Task 1) in the guilty and innocent groups. The numbers of X, Y, and Z were the distance from the anterior commissure

| | | Innocent group (*n* =13) | | Guilty group (*n* =13) | | Analysis | |
|---|---|---|---|---|---|---|---|
| | | Left (S.D.) | Right (S.D.) | Left (S.D.) | Right (S.D.) | Left<br>*t* (*p*) | Right<br>*t* (*p*) |
| *Target* | | | | | | | |
| | X | −22.0 (5.2) | 22.6 (6.4) | −23.1 (5.4) | 18.8 (5.1) | −0.5 (0.62) | −1.64 (0.11) |
| | Y | 36.3 (5.0) | 40.5 (6.1) | 36.0 (3.7) | 40.1 (7.1) | −0.17 (0.87) | −0.16 (0.87) |
| | Z | −9.1 (7.5) | −12.2 (13.6) | −7.4 (8.2) | −10.7 (11.2) | 0.54 (0.59) | 0.3 (0.77) |
| | Power | 124.4 (88.3) | 71.1 (72.8) | 177.4 (264.8) | 69.3 (69.2) | 0.69 (0.5) | −0.06 (0.95) |
| *Probe* | | | | | | | |
| | X | −22.2 (4.5) | 19.1 (9.6) | −22.9 (5.8) | 19.0 (8.0) | −0.36 (0.73) | −0.03 (0.98) |
| | Y | 35.5 (3.1) | 41.3 (7.5) | 35.9 (2.5) | 43.8 (7.3) | 0.41 (0.68) | 0.86 (0.4) |
| | Z | −9.0 (8.0) | −10.7 (7.5) | −10.9 (8.1) | −9.8 (12.6) | −0.6 (0.55) | 0.22 (0.82) |
| | Power | 93.6 (55.8) | 42.2 (17.8) | 63.8 (61.3) | 66.8 (59.2) | −1.29 (0.21) | 1.44 (0.17) |
| *Irrelevant* | | | | | | | |
| | X | −21.4 (4.0) | 20.0 (7.6) | −19.5 (4.0) | 18.4 (6.5) | 1.24 (0.23) | −0.57 (0.57) |
| | Y | 36.0 (2.4) | 41.9 (7.2) | 38.1 (4.5) | 41.6 (7.4) | 1.47 (0.15) | −0.1 (0.92) |
| | Z | −8.8 (9.1) | −14.4 (12.8) | −6.6 (8.8) | −7.2 (11.7) | 0.61 (0.55) | 1.5 (0.15) |
| | Power | 98.9 (43.9) | 28.6 (16.5) | 129.2 (171.3) | 45.8 (34.9) | 0.62 (0.54) | 1.6 (0.13) |

**Table 5**. Asymmetry coefficient (AC) of equivalent current dipole power in ERPs evoked by target, probe, and irrelevant word of the verb element (Task 1) in the guilty (n =13) and the innocent groups (n =13). AC was calculated using the formula [(R – L)/0.5 x (R + L)], where R and L are the dipole powers on the right and left sides, respectively.

| | Asymmetry coefficient (AC) | No. (%) | | |
|---|---|---|---|---|
| | Mean (S.D.) | Leftward | Symmetric | Rightward |
| | | AC 〈 −0.05 | −.0.05 ≤ AC ≤ 0.05 | AC 〉 0.05 |
| *Target* | | | | |
| Innocent group | −0.59 (1.21) | 7 (53.8) | 0 | 6 (46.2) |
| Guilty group | −0.27 (1.64) | 9 (69.2) | 0 | 4 (30.8) |
| *Probe** | | | | |
| Innocent group | −0.33 (1.54) | 11 (84.6) | 0 | 2 (15.4) |
| Guilty group | 0.04 (1.70) | 6 (46.2) | 0 | 7 (53.8) |
| *Irrelevant* | | | | |
| Innocent group | −1.01 (0.65) | 12 (92.3) | 0 | 1 (7.7) |
| Guilty group | −0.55 (1.41) | 9 (69.2) | 1 (7.7) | 3 (23.1) |

* *p* 〈. 05

hemispheric distribution in the dipole power of the ERPs generators elicited by the verb element of probe (Table 5). When the participants were classified in terms of leftward asymmetry, symmetry, and rightward asymmetry, there was a significant difference between groups in the distribution of AC for the verb element of probe ($\chi^2$=4.25, *p*〈.05). The innocent group evidenced a higher degree of leftward asymmetry than did the guilty group in terms of the dipole powers of the ERPs generators elicited by the verb element of probe. Whereas, seven guilty participants showed rightward asymmetry and 6 guilty participants exhibited leftward asymmetry in the dipole powers of the ERPs generators elicited by the verb element of probe. That is, the guilty group had a significant rightward asymmetry of dipole distribution for the probe in comparison to the innocent group. This result is interesting regarding that the AC distribution for the probe of complement element (adverb phrase) showed leftward asymmetry. Figure 4 shows difference between groups in the distribution of AC for probe of the verb element. From these results, we could assume that the bilateral superior frontal area may reflect deceptive decision making for the guilty participants after they saw probe of verb element.

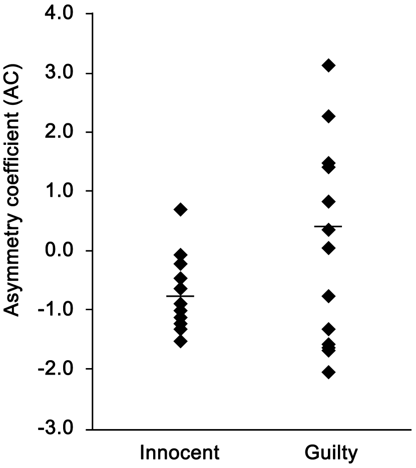


**Figure 4**. Asymmetry coefficient (AC) distribution of the probe of the verb element in Task 1 in the two groups. The horizontal lines in the graph indicate the mean value of asymmetry coefficients in the innocent and the guilty groups, respectively. One outlier from the innocent group was dropped. It showed an opposite pattern with respect to the complement element in the same task. The guilty group had rightward asymmetry of AC distribution in comparison to the innocent group

With regards to the object element (noun) of Task 2, the z-coordinates of the probe in the right hemisphere were significantly different between groups [$t(24)=-2.12$, $p=.046$]. Also, the dipole for the target in the left hemisphere was larger in the guilty group than in the innocent group. However, a significant group difference, in terms of AC distribution and difference in dipole power of probe, was not found. The statistical analysis of the verb element of Task 2 did not found any significant results.

## Discussion

In this study, the equivalent current dipoles of P300 were estimated using the P300-based GKT with Korean sentences. Overall, this study implies that people who have guilty knowledge seem to differ from people without the knowledge in ERPs and equivalent current dipoles. The ERPs data suggested that the probe caused a higher P300 than the irrelevant in bilateral frontal and parietal regions in the guilty group. However, the probe and the irrelevant seemed to be processed similarly in the innocent group. The equivalent current dipole analysis also found hemispheric lateralization of dipole distribution for the probe of verb element in the guilty group compared to the innocent group.

With regards to ERPs results, a larger P300 amplitude for the probe stimulus than the irrelevant in the guilty group suggests that guilty participants paid more attention to a crime-relevant item. The P300 amplitude for the probe of the complement and object elements (adverb phrase and noun, respectively) was the largest at the parietal site; for the probe of verb elements, it was the largest at the frontal site. Parietal lobe is known to function as allocating attentional resources to a specific task whereas frontal lobe is known as the core of executive functions, such as working memory process, organization of behavior, or motor control (Banich, 2004; Gamer et al., 2007; Ganis et al., 2003; Kozel et al., 2004; Lee et al., 2002; Mohamed et al., 2006; Prabhakaran et al., 2000). The frontal source of P300 also seemed to reflect the response inhibition process (Bekker et al., 2005; Dimoska et al., 2006; Kok et al., 2004; Ramautar et al., 2004).

The sources of probe of complement element (adverb phrase) in Task 1 were determined to be located in the inferior parietal lobule. In terms of the probe of complement element (adverb phrase) in Task 1, the guilty and the innocent groups had relatively leftward asymmetry. Although there was no group difference, previous works primarily suggested left hemispheric activity during deception process, in particular, during selective attention process (Al-Hamouri, 2012; Spence et al., 2001). The experimental task is a cognitive demanding task for a guilty participant who tries to defeat the test, in comparison to an innocent participant who does not need to make a deceptive response. When the guilty participant sees an adverb phrase and a noun illustrating a crime, he has to figure out the meaning of the word, store the information in working memory, and determine whether the word is important to him. In this context, the left parietal involvement would be larger for him when he selectively processes the probe stimulus and allocates more cognitive resources to pass the test successfully.

On the other hand, the probe of verb element (Task 1) showed a group difference in dipole distribution; the guilty group had almost an even distribution in both hemispheres, somewhat rightward, whereas the innocent group had leftward asymmetry. The sources of probe of verb element were determined to be located in the superior frontal gyrus. The innocent group showed leftward asymmetry in the irrelevant of verb element as well as the probe of verb element. On the other hand, the guilty group showed leftward asymmetry only in the irrelevant of verb element. These results may reflect that the innocent participants may experience similar processes with regard to the irrelevant and probe stimuli of verb element. On the other hand, these results raise the possibility that the irrelevant and probe stimuli of verb element may exhibit different processes in the guilty group. Half of the guilty group showed rightward asymmetry and the other half exhibited leftward asymmetry in the dipole powers of the ERPs generators elicited by the verb element of probe. Some prior researches reported the right hemisphere involvement in deception, in addition to the left hemisphere (Ganis et al., 2003; Kozel et al., 2004; Langleben et al., 2002). The right hemisphere is regarded as important in holding the overall attention (Cohen et al., 1988). The right hemisphere seems to activate when a participant sustains his attention until a whole sentence is finished. A guilty participant is keen on controlling his response after the probe of complement and object elements because he should inhibit his truthful response if the following verb is non-filler. Therefore, a guilty participant has to make his response based on 2 decisions: truthful or lying, filler or non-filler. This occurs because he does not need to respond deceptively to filler verbs, even though the verbs are presented after the probe stimulus. On the contrary, an innocent participant is not as much attentive to the probe as the guilty participant, and thus, there is only one decision that he would make: filler or non-filler. In this process, the right hemisphere seems to be more associated with arousal and sustaining attention in the guilty group compared to the innocent group.

Considering ERPs and the dipole results, several different cognitive stages are probably involved in deception and it seems to be the hemispheric difference between the 2 elements in the probe sentence illustrating a crime act. A complement/object element may be associated with selective attention to the relevant item and also associated with the left hemisphere, whereas a verb element seems to reflect a sort of post-processing after a participant sees a critical, crime-relevant adverb phrase or a noun, and thus, is probably associated with the right hemisphere. This difference between 2 sentence elements is probably due to the characteristic of Korean sentences. When a participant reads a Korean sentence, he first processes the critical detail, and sequentially a word related to the action of a crime; in this context, a verb takes part in processing a whole sentence. However, in a sentence in other languages, a participant already knows the action of a crime before he sees the detail. For instance, when he reads 'Did you steal the blue diamond?', he knows that something is stolen at the same time he reads the verb 'steal', even though he does not know the detail of 'the blue diamond'. In that case, the order of sentence processing is opposite to the Korean sentence, and therefore, we would not find the difference of a verb element among target, probe, and irrelevant sentences. We can conclude that sentence order largely attributes to hemispheric difference between within-sentence elements, and further, a study might deal with hemispheric lateralization according to the sentence order.

Particularly, on the other hand, verb processing may be related to the right hemispheric function, such as response inhibition. The right prefrontal area has been known to be related to response inhibition (Abe et al., 2006; Lee et al., 2002; Spence et al., 2001). Gamer and colleagues (2007) also reported that activation of the right inferior frontal area was controlled by stimulus conflicts in their GKT study. Although some previous studies suggested that the left hemisphere, particularly the left frontal cortex is more involved in verb processing than the right hemisphere (Cappelletti et al., 2008; Damasio and Tranel, 1993; Sereno, 1999), it seemed that right hemisphere might have an effect to sentence processing in this study. The above researches mainly focused on verb production and verb retrieval, rather than on the response according to the verb. When it comes to the experimental tasks in this study, on the other hand, participants had to choose between target and non-target responses after the verb presentation, not to generate their own response. Therefore, the right hemisphere seems to be activated when a participant processes a verb as a cue to response, in particular, a false response.

One limitation of the present study is that experimental manipulation would never be the same as a real-world setting. The risk for the crime act and emotional state are hard to control (Ford, 2006). To be specific, the experimenter motivated participants with a monetary reward in order to deal with the test seriously, and such manipulation controlled an incentive, not a loss. A guilty participant would not lose anything when the test proved his guilt; he would receive the appointed amount of money for his participation, even though he would not be earning a bonus. Therefore, manipulating a punishment or a loss would draw more reliable results in future research. Also, a future study might investigate other deception detection paradigms in order to figure out the neurological mechanism of deception. In this study, the guilty participants' deceptive response was forced by the experimenter, and the forced deception would show a smaller activation compared to the planned or self-determined deception; this process was also suggested by Wu and colleagues (2009), who reported larger P300 amplitude for self-determined deception than forced deception. A real crime suspect would lie by himself, and he will get punished if he fails to deceive. In this sense, further research would deal with whether a significant difference in cortical activation between deceptions with and without the intention to deceive exits. Meanwhile, regarding that we used only one algorithm, fixed MUSIC with predetermined seeds, in order to investigate equivalent the current dipole in the P300-based GKT, more elaborate and proper algorithms may by attempted for each data when calculating the equivalent current dipoles.

In summary, the present study investigated equivalent current dipoles of ERPs in the P300-based GKT. To our knowledge, this is the first study to find equivalent current dipoles in the P300-based GKT using sentences. Guilty participants showed larger P300 amplitude for the probe stimulus than innocent participants, and the amplitude was the largest at the parietal site for a complement or an object element, and at the frontal site for a verb element. Dipole source localization of the probe stimulus was done for 2 different sentence elements and found hemispheric lateralization in verb element of Task 1. With regards to the AC data, an adverb phrase or a noun, which presents the crime detail, had leftward asymmetry, whereas a verb, which describes the act of a crime, showed rightward asymmetry as well as leftward asymmetry. Our results indicate that guilty participants require more cognitive resources. Further, they use a planned strategy compared to innocent participants in crime-relevant sentence processing. In this process, complement/object and verb element seems to be associated with the discrete course of the deception process; the former may reflect selective attention, and the latter may show participants' sustained attention and response inhibition.

## References

Abe, N. (2011). How the brain shapes deception: An intergrated review of the literature. *Neuroscientist, 17,* 560-574.

Abe, N., Suzuki, M., Tsukiura, T., Mori, E., Yamaguchi, K., Itoh, M., & Fujii, T. (2006). Dissociable roles of prefrontal and anterior cingulate cortices in deception. *Cerebral Cortex, 16,* 192-199.

Abootalebi V, Moradi MH, Khalilzadeh MA (2009) A new approach for EEG feature extraction in P300-based lie detection. *Computer Methods and Programs in Biomedicine, 94,* 48-57.

Al-Hamouri, F. A. (2012). Hemispheric dominance for deception: A dual-task performance study. *International Journal of Humanities and Social Science, 2,* 168-171.

Andreassi, J. L. (2007). *Psychophysiology: human behavior and physiological response.* (5th ed.). New York: Psychology Press.

Banich, M. T. (2004). *Cognitive neuroscience and neuropsychology.* (2nd ed.). Boston: Houghton Mifflin Company.

Beck, A. T., Epstein, N., Brown, G., & Steer, R. A. (1988). An inventory for measuring clinical anxiety: Psychometric properties. *Journal of Consulting and Clinical Psychology, 56,* 893-897.

Beck, A. T., & Steer, R. A. (1987). *Manual for the Revised Beck Depression Inventory.* San Antonio: Psychological Corporation.

Bekker, E. M., Kenemans, J. L., Hoeksma, M. R., Talsma, D., & Verbaten, M. N. (2005). The pure electrophysiology of stopping. *International Journal of Psychophysiology, 55,* 191-198.

Ben-Shakhar, G., & Elaad, E. (2003). The validity of psychophysiological detection of information with the guilty knowledge test: A meta-analytic review. *Journal of Applied Psychology, 88,* 131-151.

Boaz, T. L., Perry, Jr. N. W., Raney, G., Fischler, I. S., & Shuman, D. (1991). Detection of guilty knowledge with event-related potentials. *Journal of Applied Psychology,* 76, 788-795.

Butcher, J., Dahlstrom, W., Graham, J., Tellegen, A., & Kaemmer,

B. (1989). *Manual for the restandardized minnesota multiphasic personality inventory: MMPI-2.* Minneapolis: University of Minnesota Press.

Cappelletti, M., Fregni, F., Shapiro, K., Pascual-Leone, A., & Caramazza, A. (2008). Processing nouns and verbs in the left frontal cortex: A transcranial magnetic stimulation study. *Journal of Cognitive Neuroscience, 20,* 707-720.

Christ, S. E., Van Essen, D. C., Watson, J. M., Brubaker, L. E., & McDermott, K. B. (2009). The contributions of prefrontal cortex and executive control to deception: Evidence from activation likelihood estimate meta-analyses. *Cerebral cortex, 19,* 1557-1566.

Christie, R., & Geis, F. L. (1970). *Studies in Machiavellianism.* New York: Academic Press.

Cohen, R. M., Semple, W. E., Gross, M., Holcomb, H. J., Dowling, S. M., & Nordahl, T. E. (1988). Functional localization of sustained attention. *Neuropsychiatry, Neuropsychology, and Behavioral Neurology, 1,* 3-20.

Damasio, A. R., & Tranel, D. (1993). Nouns and verbs are retrieved with differently distributed neural systems. *Proceedings of the National Academy of Sciences, 90,* 4957-4960.

DePaulo, B. M., Lindsay, J. J., Malone, B. E., Muhlenbruck, L., Charlton, K., & Cooper, H. (2003). Cues to deception. *Psychological Bulletin, 129,* 74-118.

Dimoska, A., Johnstone, S. J., & Barry, R. J. (2006). The auditory-evoked N2 and P3 components in the stop-signal task: Indices of inhibition, response-conflict or error-detection? *Brain and Cognition, 62,* 98-112.

Farwell, L. A., & Donchin, E. (1991). The truth will out: Interrogative polygraphy (“Lie detection”) with Event-Related brain potentials. *Psychophysiolgy, 28,* 531-547.

Ford, E. B. (2006). Lie detection: Historical, neuropsychiatric and legal dimensions. *International Journal of Law and Psychiatry, 29,* 159-177.

Fuchs, M., Drenckhahn, R., Wischmann, H., & Wagner, M. (1998). An improved boundary element method for realistic volume-conductor modeling. *IEEE Transactions on Biomedical Engineering, 45,* 980-997.

Gamer, M. (2010). Does the guilty actions test allow for differentiating guilty participants from informed innocents? A re-examination. *International Journal of Psychophysiology, 76,* 19-24.

Gamer, M., Bauermann, T., Stoeter, P., & Vossel, G. (2007). Covariations among fMRI, skin conductance, and behavioral data during processing of concealed information. *Human Brain Mapping, 28,* 1287-1301.

Ganis, G., Kosslyn, S., Stose, S., Thompson, W., & Yurgelun-Todd, D. (2003). Neural correlates of different types of deception: An fMRI investigation. *Cerebral Cortex, 13,* 830-836.

Greenhouse, S. W., & Geisser, S. (1959). On methods in the analysis of profile data. *Psychometrika, 24,* 95-112.

Hyvärinen, A., & Oja, E. (1997). A fast fixed-point algorithm for independent component analysis. *Neural Computation, 9,* 1483-1492.

Jung, E. K., Kang, K., & Kim, Y. Y. (2013). Frontoparietal activity during deceptive responses in the P300-based guilty knowledge test: An sLORETA study. *NeuroImage, 78,* 305-315.

Kok, A., Ramautar, J. R., De Ruiter, M. B., Band, G. P. H., & Ridderinkhof, K. R. (2004). ERP components associated with successful and unsuccessful stopping in a stop-signal task. *Psychophysiology, 41,* 9-20.

Kozel, F. A., Padgett, T. M., & George, M. S. (2004). A replication study of the neural correlates of deception. *Behavioral Neuroscience, 118,* 852-856.

Langleben, D. D., Schroeder, L., Maldjian, J. A., Gur, R. C., McDonald, S., Ragland, J. D., O’Brien, C. P., & Childress, A. R. (2002). Brain activity during simulated deception: An event-related functional magnetic resonance study. *NeuroImage, 15,* 727-732.

Lee, T., Liu, H. L., Tan, L. H., Chan, C. C. H., Mahankali, S., Feng, C. M., Hou, J., For, P. T., Gao, J. H. (2002). Lie detection by functional magnetic resonance imaging. *Human Brain Mapping, 15,* 157-164.

Linden, D. E. J. (2005). The P300: Where in the brain is it produced and what does it tell us? *Neuroscientist, 11,* 563-576.

Lykken, D. T. (1974). Psychology and the lie detector industry. *American Psychologist, 27,* 725-739.

MacLaren, V., & Taukulis, H. (2000). Forensic identification with event related potentials. *Polygraph, 29,* 330-343.

Mohamed, F. B., Faro, S. H., Gordon, N. J., Platek, S. M., Ahmad, H., & Williams, J. M. (2006). Brain mapping of deception and truth telling about an ecologically valid situation: Functional MR imaging and polygraph Investigation—Initial Experience1. *Radiology, 238,* 679-688.

Mosher, J. C., Lewis, P. S., & Leahy, R. M. (1992). Multiple dipole modeling from spatio-temporal MEG data. *IEEE Transactions on Biomedical Engineering*, 39, 541-557.

Onton, J., & Makeig, S. (2006). Information-based modeling of event-related brain dynamics. *Progress in Brain Research, 159,* 99-120.

Prabhakaran, V., Narayanan, K., Zhao, Z., & Gabrieli, J. D. (2000). Integration of diverse information in working memory within the frontal lobe. *Nature Neuroscience, 3,* 85-90.

Ramautar, J. R., Kok, A., & Ridderinkhof, K. R. (2004). Effects of stop-signal probability in the stop-signal paradigm: The N2/P3 complex further validated. *Brain and Cognition, 56,* 234-252.

Rosenfeld, J. P., Cantwell, B., Nasman, V. T., Wojdac, V., Ivanov, S., & Mazzeri, L. (1988). A modified, event-related potential-based guilty knowledge test. *International Journal of Neuroscience, 42,* 157-161.

Rosenfeld, J. P., Nasman, V. T., Whalen, R., Cantwell, B., & Mazzeri, L. (1987). Late vertex positivity in event-related potentials as a guilty knowledge indicator: A new method of lie detection. *International Journal of Neuroscience, 34,* 125-129.

Sereno, J. A. (1999). Hemispheric differences in grammatical class. *Brain and Language, 70,* 13-28.

Snyder, M. (1974). Self-monitoring of expressive behavior. *Journal of Personality and Social Psychology, 30,* 526-537.

Spence, S. A., Farrow, T. F. D., Herford, A. E., Wilkinson, I. D., Zheng, Y., & Woodruff, P. W. (2001). Behavioural and functional anatomical correlates of deception in humans. *Neuroreport, 12,* 2849–2853.

Talairach, J., & Tournoux, P. (1988). *Co-planar stereotaxic atlas of the human brain: 3-dimensional proportional system: An approach to cerebral imaging.* Stuttgart: Thieme.

Van Veen, V., & Carter, C. S. (2002). The anterior cingulate as a conflict monitor: FMRI and ERP studies. *Physiology & Behavior, 77,* 477-482.

Wagner, A. D., Shannon, B. J., Kahn, I., & Buckner, R. L. (2005). Parietal lobe contributions to episodic memory retrieval. *Trends in Cognitive Sciences, 9,* 445-453.

Wassenberg, W. J. G. (2008). *Multichannel EEG: Towards applications in clinical neurology.* Groningen: University of Groningen.

Wu, H., Hu, X., & Fu, G. (2009). Does willingness affect the N2-P3 effect of deceptive and honest responses? *Neuroscience Letter, 467,* 63-66.

# 범죄관련 문장처리동안 속임반응의 등가 전류 쌍극자 뇌 국소화 분석

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본 연구는 ‘목적어-보어-서술어(동사)’ 또는 ‘주어-목적어-서술어(동사)’ 구조의 문장을 이용하여 P300-기반 유죄지식검사에서 사건관련전위의 뇌 국소화 분석을 수행하였다. 26명의 실험참가자들은 유죄집단과 무죄집단으로 나뉘어졌다. 13명의 유죄집단은 모의범죄를 저지르고 13명의 무죄집단은 이러한 범죄를 저지르지 않았다. 뇌파를 측정하는 동안 세 가지 자극 유형(목표자극, 탐침자극, 무관련자극)의 문장이 시각적으로 제시되었다. 유죄집단에서 서술어 탐침자극의 P300 진폭이 무관련자극의 P300 진폭보다 크게 나타난 데 반해 무죄집단에서는 이러한 차이가 나타나지 않았다. 탐침자극의 등가 전류 쌍극자 분석은 쌍극자의 위치와 쌍극자의 파워에서 집단 간 차이를 나타냈다. 두 집단 모두 서술어 탐침자극의 뇌 국소화 분석 위치가 상 전두 이랑으로 나타났다. 유죄집단은 서술어 탐침자극의 쌍극자 파워에서 반구 비대칭에 유의미한 변화가 나타났다. 이러한 결과는 유죄집단이 범죄관련 정보를 가지고 있고 무죄집단에 비해 탐침에 주의를 더 기울이는 것을 반영한다. 본 연구는 또한 속임 반응 동안 반구 비대칭을 제시하였다.

**주제어:** P300, 유죄지식검사, 등가 전류 쌍극자, 반구 비대칭, 속임