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Event-related potentials (ERP) employed in two studies (exp. 1, n = 20 females; exp. 2, n = 20 males) attempted to distinguish subjects who had participated in a mock crime (guilty group) from innocent subjects who did not perform in the crime scenario. A two-stimulus paradigm was used in which neutral and crime relevant questions were followed by either a yes or a no target stimulus. Subjects were instructed to indicate their agreement or disagreement that the yes or no target stimulus was consistent with the truth of the preceding question. Guilty subjects were told to deny the truth of the crime relevant items. In both experiments, P3 amplitude was smaller for the guilty subjects in the crime relevant condition than comparison conditions when the task demanded an agree response. In experiment 1, P3 amplitude to the target stimulus was smaller for guilty than innocent subjects in the crime relevant condition when an agree response was demanded. This effect was also apparent in the ERP waveforms for experiment 2, but it was not statistically significant.

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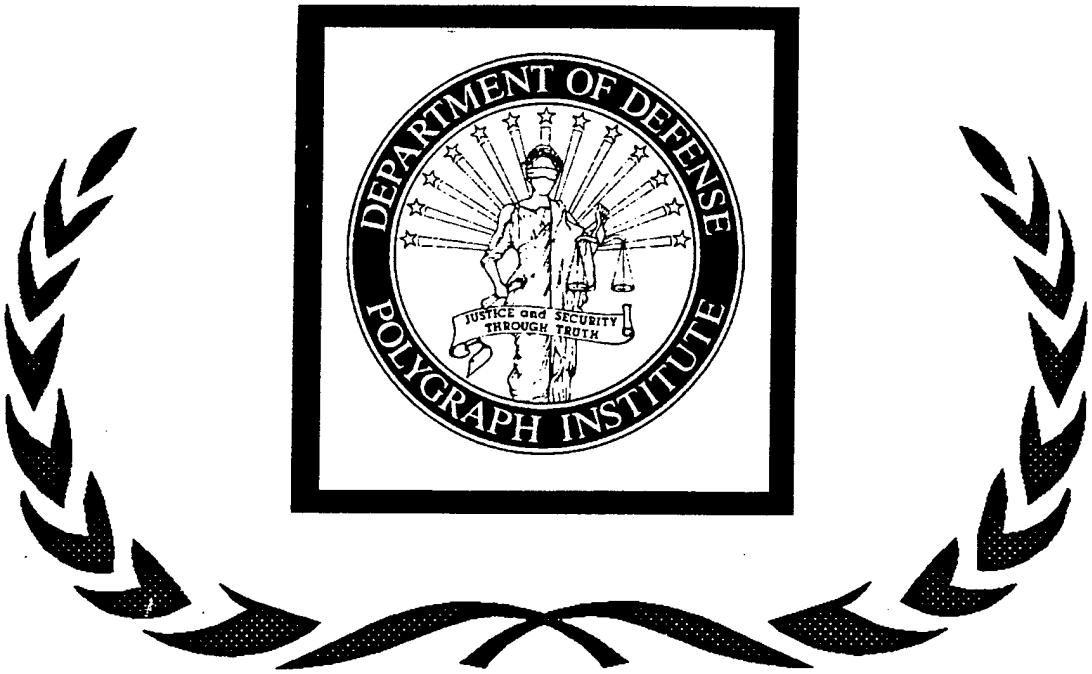

Event-Related Potentials and the Detection of Deception: A Two-Stimulus Paradigm

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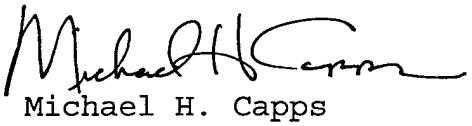
Director's Foreword

This report describes the use of event-related potentials (ERP), recorded from the scalp, during the psychophysiological detection of deception (PDD). Its most unique feature is that a two stimulus paradigm is used during the questioning procedure. The first stimulus is the question. The second stimulus is a Yes or No response to the question. The subject is then required to indicated agreement or disagreement with the second stimulus. The authors suggest that this procedure provides physical and semantic simplicity and repetitive constancy that is not characteristic of other questioning techniques. The promising results of this preliminary study suggest that the average P3 wave amplitude recorded during deception is smaller than that recorded during truthful responses. As with any preliminary study, replication will be required to confirm the results.

This study is one of several recent investigations concerning ERP during the PDD. These investigations represent the application of relatively new technology and procedures to the PDD, and each one provides additional information towards improving the PDD instrumentation and procedures. The Institute will continue to encourage and support these productive studies.



Michael H. Capps
Director

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This research was sponsored by the Department of Defense Polygraph Institute project DoDPI93-P-0008, under a grant administered by the Office of Naval Research, United States Department of the Navy (contract #N0001493-1-1002). The views expressed in this article are those of the author and do not reflect the official policy or position of the Department of Defense or the U.S. Government.

Abstract

STELMACK, R.M., HOULIHAN, M. and DOUCET, C. Event-related potentials and the detection of deception: A two-stimulus paradigm. November 1994, Report No. DoDPI93-R-0004. Department of Defense Polygraph Institute, Fort McClellan, AL 36205. Event-related potentials (ERP) employed in two studies (exp. 1, n = 20 females; exp. 2, n = 20 males) attempted to distinguish subjects who had participated in a mock crime (guilty group) from innocent subjects who did not perform in the crime scenario. A two-stimulus paradigm was used in which neutral and crime relevant questions were followed by either a yes or a no target stimulus. Subjects were instructed to indicate their agreement or disagreement that the yes or no target stimulus was consistent with the truth of the preceding question. Guilty subjects were told to deny the truth of the crime relevant items. In both experiments, P3 amplitude was smaller for the guilty subjects in the crime relevant condition than comparison conditions when the task demanded an agree response. In experiment 1, P3 amplitude to the target stimulus was smaller for guilty than innocent subjects in the crime relevant condition when an agree response was demanded. This effect was also apparent in the ERP waveforms for experiment 2, but it was not statistically significant.

Key-words: lie detection, P3, N2, N4, stimulus congruity, response compatibility

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Event-related potential (ERP) recording procedures were recently proposed as alternative and complementary to autonomic nervous system recording methods for the detection of deception (Bashore & Rapp, 1993). Several laboratories have reported research on the application of ERP methods to lie detection, though clearly this work is in the exploratory stage; neither field nor participatory crime simulations have been undertaken. In the present study, visual ERPs were employed in two studies that attempted to distinguish guilty subjects who had participated in a mock crime from innocent subjects who did not perform in the crime scenario. A two-stimulus paradigm was used to provide flexibility and range of questioning normally characteristic of field interrogations; but, that was also amenable to ERP recording.

The approaches currently used in the application of ERP procedures to the detection of deception evolved from autonomic nervous system based polygraph techniques. Two of the studies used the control question method in combination with real life anti-social acts reportedly committed by their subjects (Rosenfeld, Angell, Johnson, & Qian, 1991; Bessinger, Rosenfeld, & Hays, 1991). A guilty knowledge method was also used with a computer generated espionage scenario (Farwell & Donchin, 1991). In all three of these studies, a single infrequently occurring stimulus item that was salient to the crime relevant scenario was used to elicit the P3 ERP component (Picton, 1992). In this work, the rationale for the increased P3 amplitude to the crime relevant item is similar to that used in autonomic nervous system recording procedures, that is, the guilty subject will respond more vigorously to the crime relevant items than to control items. The success in distinguishing guilty subjects in this early ERP work with the P3 component clearly demonstrates the feasibility of applying ERP methods to lie detection. Of course, at this stage of inquiry, there are some limitations that are inherent in the procedures that can be applied. The guilty knowledge design is not extensively used in applied settings because knowledge of the discrete elements of the crime may not be limited to the guilty subject. With the ERP averaging procedure, the use of single repetitive words is restrictive because even crime relevant words lose their salience with repetition. The use of sentences or phrases as target stimuli is also problematic because of variations in processing demands that attend phrases of different word length, meaning, or difficulty level.

In the present study, a two-stimulus paradigm is explored that attempts to obviate some of the limitations noted. The first stimulus is a question, neutral or crime relevant, that is followed by either a yes or no target stimulus. The subject is required to evaluate, i.e., to indicate agreement or disagreement, that the yes or no target stimulus is congruent with the truth of the preceding question e.g., are you reading this sentence? ...yes ...agree. Because the target stimuli are repeatedly the same and equiprobable, influences on the P3 waveform due to physical or semantic elements are minimized and the effects of stimulus probability or surprise is limited. At the same time, the content of the first stimulus can vary considerably to incorporate neutral or crime relevant material. The content of the question does not have a direct effect on the ERP, only indirect effects on the target stimulus through evaluation of the congruency of the yes or no stimulus with the truth of the question, and through the compatibility of the target stimulus with the truth of the response that is expressed.

The rationale for this paradigm is based on ERP research examining decision making on elementary cognitive tasks such as the Sternberg short term memory task, physical similarity, category matching tasks, and stimulus-response compatibility tasks (Bashore, 1990; McGarry-Roberts, Stelmack, & Campbell, 1992; Ragot, 1990). In the work with two-stimulus paradigms, it is clear that P3 latency to the target stimulus increases and P3 amplitude decreases with increasing task difficulty. With respect to lie detection, it can be assumed that lying is a more difficult task than telling the truth. In addition to assessing the congruity of the crime relevant question and target stimulus, and task of lying demands that the guilty subject produce a response that is incompatible with the true response. Thus, in general, it is expected that P3 latency will be longer and P3 amplitude will be smaller to the target stimuli for guilty than innocent subjects in the crime relevant than neutral or control conditions. It would be noted here that the control questions consist of items typically employed to assess social desirability responding. Like the neutral questions, they are intended to provide a truthful (but more personal) comparison condition for the processing of crime relevant items by the guilty group.

There has also been some interest in applying ERP methods to the detection of deception which were adapted from research on language and reading and that may be relevant to the paradigm employed here (Boaz, Perry, Raney, Fischler, & Shuman, 1991). A negative wave that develops between 300 and 500 ms (N4) has

been found to be especially sensitive to linguistic differences, notably violations of semantic congruity and expectancy (Kutas & Hillyard, 1980). In the serial presentation of words in a sentence, an N4 wave to the terminal word is elicited when it is semantically incongruous with the preceding context. Of particular relevance to the present study is work demonstrating the development of an N4 wave when the terminal word is not congruent with episodic (Fischler, Childers, Achariyapaopan, & Perry, 1985), personal, or self-referential knowledge (Fischler, Bloom, Childers, Arroyo, & Perry, 1984). The effects were also observed in the context of a lie detection study showing that the N4 component is elicited by words that complete sentences falsely (Boaz et al., 1991). It was evident from our preliminary work with the two-stimulus paradigm that the yes or no target stimulus following the question stem could be considered as a terminal word. An enhanced N4 wave could develop in conditions where the target stimulus (yes or no) was incongruent with the truth of the question that preceded it. Similarly, the N2 wave was examined because stimulus incongruity and response incompatibility influence the amplitude and latency of this wave (Bashore, 1990).

Methods--Experiment 1

Subjects

The subjects were 20 healthy female volunteers from the university community. They ranged in age from 18-33 years (M = 22.0). Ten subjects, designated as the guilty group, were selected at random to participated in a mock crime. The remaining subjects, designated the innocent group, were aware that a mock crime was performed by other students but they were not exposed to crime relevant elements of the scenario.

Procedure

When the subjects arrived at the laboratory, the general objectives of the study and the presentation and recording procedures were explained to them. They were asked to endorse informed consent forms that had been approved by the University of Ottawa Ethics Committee for this project.

Subjects in the guilty group were introduced to the mock crime scenario that involved removing a small object from a specific location in the women's locker room. The guilty subjects returned to the laboratory after completing this brief (5 min) task. Both innocent and guilty groups were shown the list of questions that were used in the experiment. They were asked to read them carefully to ensure that their meaning was clear and to

reduce the effects of novelty during the electroencephalograph (EEG) recording. Subjects in the innocent group were instructed that they should respond truthfully to all items. Subjects in the guilty group were told to deny their participation when items referred to the mock crime, but to respond truthfully to all other items. The subjects were then prepared for the EEG recording session. The subjects were advised that the experimenter who applied the electrodes and conducted the EEG recording did not know whether the subjects were from the innocent or guilty groups. The subjects were seated comfortably in a sound attenuated chamber. The stimulus items were presented on a video monitor 40 cm in front of the subject and responses were indicated by pressing buttons on a computer mouse.

Stimulus presentation procedure

The stimulus presentation procedure was a paired-stimulus paradigm in which the first stimulus was a question and the second stimulus, termed the target stimulus, was either the word yes or no. The subject's task was to indicate by pressing a button whether they agreed or disagreed that the target stimulus, yes or no, was consistent with the truth of the question that had preceded it. Three categories of questions were composed, Neutral, Control, and Crime Relevant, with nine questions in each category. The questions were presented in a random order 18 times each during the EEG recording session, with the yes or no target stimulus following the question with equal probability. The neutral questions were simple items (e.g., Are you a student?) that were keyed so that an agree response affirmed that the yes stimulus was consistent with the truth of the question. A disagree response affirmed that a *No* stimulus was not consistent with the truth of the question. The control questions, which were keyed the same way, queried socially undesirable behaviors that most people have exhibited at sometime (e.g., Have you ever taken more than your share?). The crime relevant questions drew on specific elements from the mock crime and they were accusatory in nature (e.g., Did you take the brooch?). Subjects in the innocent group affirmed their innocence, and the guilty subjects denied their guilt, by pressing the agree response button when the question was followed by the *No* stimulus and by pressing the disagree response button when the question was followed by the *Yes* stimulus. The paired-stimulus presentation and response demands for the neutral, control and crime relevant question types are illustrated in Table 1.

Table 1
Question Type, Target Stimulus, and Response Demand for Experiment 1. The Congruity (Cong)/Incongruity (Incong) of the Target Stimulus with the Question and the Compatibility (Comp)/Incompatibility (Incomp) of the Response Demand with the Target Stimulus are Indicated in Brackets

Question Type	Target Stimulus	Response Demand
	Neutral	
"Are you a student?"	Yes (cong)	Agree (comp)
	No (incong)	Disagree (comp)
	Control	
"Have you ever cheated at a game?"	Yes (cong)	Agree (comp)
	No (incong)	Disagree (comp)
	Crime Relevant-Innocent group	
"Did you open locker D-54?"	Yes (incong)	Disagree (comp)
	No (cong)	Agree (comp)
	Crime Relevant-Guilty group	
"Did you open locker D-54?"	Yes (cong)	Disagree (incomp)
	No (incong)	Agree (incomp)

Subjects were administered 10 practice trials as many times as necessary for them to become accurate with their responding and comfortable with the procedure. The stimulus presentation series was paused after every 120 trials or when requested by the subject.

EEG recording

The EEG was recorded from Ag/AgCl electrodes placed at midline frontal (Fz), central (Cz), and parietal sites (Pz). The electro-oculogram (EOG) was monitored on a single channel from the infra-obital and supra-orbital ridges of the left eye.

The reference electrode was placed on the left mastoid and a ground electrode was placed on the forehead. Inter-electrode impedances were below 2 kOhms.

EEG and EOG signals were amplified using Nihon Kohden AB-621G polygraph amplifiers. The high filter was set at 30 Hz and the time constant was set at 2 seconds (s). A/D conversion was carried out at a 4.5 ms sampling rate. The sampling period was 4.5 s which included a 100 ms pre-stimulus period, a 2.5 s exposure duration for the first stimulus (question), a 500 ms delay (blank screen), a 500 ms exposure duration for the target stimulus (yes/no), and an additional 900 ms response recording epoch (blank screen). The inter-trial interval was 8 s, stimulus onset to subsequent stimulus onset.

The stimulus presentation, ERP averaging, and scoring were controlled by $InstEP_{TM}$ software. Single trials were stored for off-line analysis. Trials were rejected from the ERP average when the EEG or EOG exceeded ± 150 μV during the target stimulus presentation interval. Trials were also rejected if the response was omitted, was incorrect, or occurred before the onset of the target stimulus. A 100 ms period prior to the onset of the target stimulus was used as the baseline for determining the maximum peak amplitudes for the ERP waves.

Three waves in the ERP waveform to the target stimulus, designated N2, P3 and N4, were scored and subjected to statistical analysis. The N2 wave had a latency to maximum negative peak amplitude at about 260 ms at Fz. The P3 wave was a positive deflection having a latency to maximum peak amplitude at about 340 ms. In all conditions, the P3 amplitude was maximum at Pz. The N4 wave had a latency to maximum peak amplitude of about 490 ms at Fz.

Results

A four-way ANOVA, having a group factor (innocent, guilty) and three repeated measures factors, question type (neutral, control, crime relevant), response demand (agree, disagree), and electrode location (Fz, Cz, Pz), was applied to the ERP data, specifically the N2, P3, and N4 latency and amplitude values. In these analyses, the Greenhouse-Geisser ϵ correction was used for non-sphericity and corrected confidence levels are reported (Jennings & Wood, 1976). Planned pairwise comparisons were conducted to assess specific differences between innocent and guilty groups and between control and crime relevant conditions for guilty and innocent groups. Individual comparisons between means were assessed with the Scheffe test and referenced to the .05 level of confidence.

N2 Components

Overall, N2 amplitude was greater for the disagree than agree response demand [$F(1, 18) = 54.13$, $p < .01$]. There was a significant interaction between question type and electrode location [$F(4, 72) = 4.98$, $p < .01$, $\epsilon = .7961$] that was due to larger N2 amplitude in the crime relevant condition than neutral and control conditions at Pz, but not at Fz and Cz. There was also an interaction between question type, response demand and the group factor [$F(2, 36) = 7.44$, $p < .01$, $\epsilon = .7459$]. Analysis of this interaction indicated that the N2 amplitude effects were primarily due to the greater N2 amplitude for disagree than agree response demands in the neutral and control conditions but only for the guilty group. The N2 amplitude effects are illustrated in Table 2 with measures recorded at Fz.

Table 2
Mean (Standard Deviation) N2 Amplitude (in μV) at Fz to the Target Stimulus for Guilty and Innocent Groups Following the Neutral, Control, and Crime Relevant Questions Demanding an Agree or Disagree Response

		Question Type		
Response Demand	Group	Neutral	Control	Crime Relevant
Agree	Guilty	2.56 (5.38)	2.67 (5.97)	1.38 (4.97)
	Innocent	3.06 (4.77)	2.69 (3.60)	4.80 (3.73)
Disagree	Guilty	-1.92 (3.56)	-3.14 (4.01)	0.97 (5.67)
	Innocent	1.85 (3.09)	0.33 (3.08)	0.11 (2.45)

Note. Smaller positive values indicate larger negative amplitude.

The latency to maximum peak N2 amplitude was faster at Pz than at Fz and Cz [$F(2, 36) = 37.91$, $p < .01$, $\epsilon = .7655$], notably for the disagree response demand [$F(2, 36) = 6.87$, $p < .01$, $\epsilon = .8823$]. The mean N2 latency values at Fz are show in Table 3.

Table 3
Mean (Standard Deviation) N2 Latency (in ms) at Fz to the Target Stimulus for Guilty and Innocent Groups Following the Neutral, Control, and Crime Relevant Questions Demanding an Agree or Disagree Response

Response Demand	Group	Question Type		
		Neutral	Control	Crime Relevant
Agree	Guilty	272.80 (49.16)	268.85 (57.64)	333.01 (42.80)
	Innocent	255.66 (51.26)	246.88 (70.84)	253.91 (65.96)
Disagree	Guilty	282.47 (16.96)	262.26 (48.25)	254.35 (51.63)
	Innocent	253.47 (33.34)	239.84 (30.34)	253.03 (24.41)

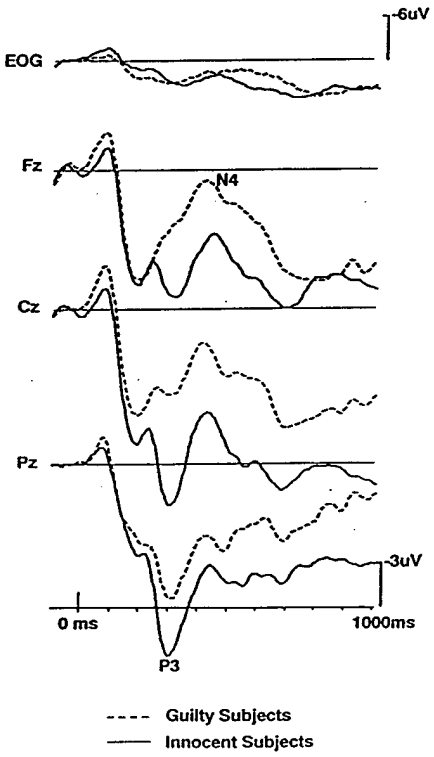

Figure 1. Grand average ERP waves recorded at Fz, Cz, and Pz. When subjects were required to agree to a no target stimulus following a crime relevant question, the guilty group exhibited smaller P3 amplitude than the innocent group.

P3 Components

P3 amplitude was greater at centro-parietal than frontal electrode sites [$F(2, 26) = 10.39$, $p < .01$, $\epsilon = .8648$], and greater for agree than disagree response demands [$F(2, 26) = 11.52$, $p < .01$, $\epsilon = .6418$]. There was a significant interaction between groups and response demand [$F(1, 13) = 7.49$, $p < .02$]. For the innocent group, P3 amplitude for the agree response demand, was greater than for the disagree response demand and than for the agree and disagree response demand of the guilty group. Planned comparisons assessed the interaction of group and question type for the agree response demand [$F(2, 30) = 3.49$, $p < .05$, $\epsilon = .8862$]. As shown in Figure 1, P3 amplitude was smaller for the guilty than innocent group for the agree response demand, notably in the crime relevant condition. Further, for the agree response demand, P3 amplitude for the guilty subjects was smaller in the crime relevant condition than in the neutral and control conditions, notably at Cz and Pz (Figure 2); whereas, the P3 amplitude of innocent subjects was equal or greater in the crime relevant condition compared to the neutral and control conditions (Figure 3).

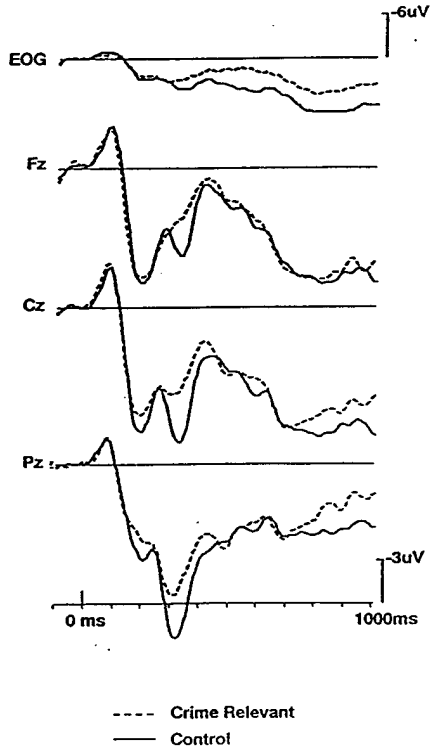

Figure 2. Grand average ERP waves recorded at Fz, Cz, and Pz. When guilty subjects were required to make an agree response, P3 amplitude to the target stimulus was smaller in the crime relevant condition than in the control condition.

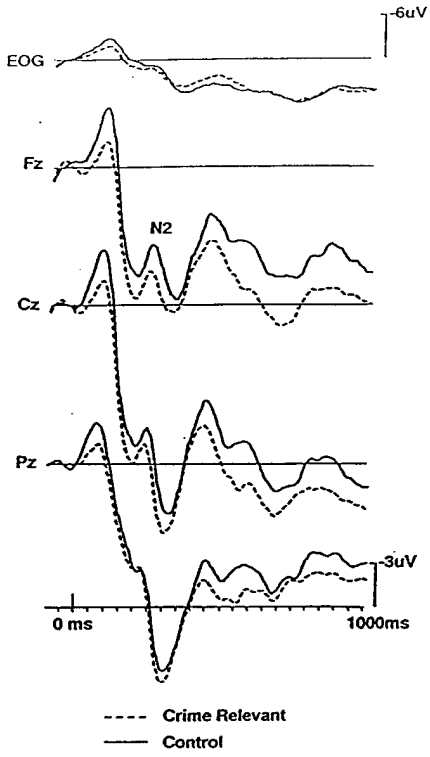

Figure 3. Grand average ERP waves recorded at Fz, Cz, and Pz when innocent subjects were required to agree to the target stimulus following crime relevant and control questions. The difference in the P3 amplitude which was apparent for guilty subjects is absent for innocent subjects.

The mean P3 amplitude of guilty and innocent groups for neutral, control, and crime relevant question conditions for agree and disagree response demands are presented in Table 4.

Table 4
Mean (Standard Deviation) P3 Amplitude (in μV) at Pz to the Target Stimulus for Guilty and Innocent Groups Following the Neutral, Control, and Crime Relevant Questions Demanding an Agree or Disagree Response

		Question Type		
Response Demand	Group	Neutral	Control	Crime Relevant
Agree	Guilty	14.13 (5.66)	14.34 (5.48)	11.33 (6.75)
	Innocent	14.53 (4.43)	14.37 (5.03)	15.05 (4.13)
Disagree	Guilty	12.52 (5.44)	11.12 (5.30)	9.80 (5.72)
	Innocent	13.58 (3.66)	10.95 (2.78)	9.68 (3.64)

For P3 latency, a significant main effect of group was evident, with the guilty group exhibiting longer mean latency than the innocent group [$F(1, 13) = 9.06$, $p < .01$]. P3 latency was also longer for the disagree than the agree response demand [$F(1, 13) = 17.23$, $p < .01$]. Analysis of the interaction of group, response demand and question type [$F(2, 26) = 4.51$, $p < .01$, $\epsilon = .9389$], indicated that the guilty group exhibited longer latency than the innocent group in the control condition for the agree response demand and in the neutral condition for the disagree response demand. There were no significant main effects or interactions for electrode location. These P3 latency effects are presented in Table 5.

Table 5
Mean (Standard Deviation) P3 Latency (in ms) at Pz to the Target Stimulus for Guilty and Innocent Groups Following the Neutral, Control,2 and Crime Relevant Questions Demanding an Agree or Disagree Response

Response Demand	Group	Question Type: Neutral	Control	Crime Relevant
Agree	Guilty	329.93 (23.09)	322.03 (19.98)	325.10 (26.46)
	Innocent	335.13 (20.69)	304.45 (20.20)	306.20 (20.24)
Disagree	Guilty	365.97 (33.01)	365.09 (41.01)	343.12 (27.74)
	Innocent	320.27 (33.34)	336.97 (30.34)	332.62 (24.41)

N4 Components

N4 amplitude was greater at frontal than centro-parietal electrode sites [$F(2, 36) = 7.76$, $p < .01$, $\epsilon = .9589$], an effect that was pronounced in the neutral condition [$F(4, 72) = 8.12$, $p < .01$, $\epsilon = .6298$]. Analysis of the interaction between response demand, group, and question type [$F(2, 36) = 6.10$, $p < .01$, $\epsilon = .9044$], indicated that for the agree response demand, N4 amplitude was greater for the guilty than innocent group in the crime relevant condition. This N4 amplitude effect is illustrated in Figure 1.

Overall, N4 latency was longer at Pz than Cz [$F(2, 36) = 8.97$, $p < .01$, $\epsilon = .7972$], and longer for disagree than agree response demands [$F(1, 18) = 12.44$, $p < .01$]. Analysis of the

interaction between electrode site, question type, and response demand [$F(4, 72) = 4.68$, $p < .01$, $\epsilon = .7972$], indicated a departure from this pattern in which N4 latency was longer at Fz than Cz and Pz in the crime relevant condition. There were no significant main effects or interactions for groups in this analysis.

Summary and Discussion

The guilty group was distinguished from the innocent group by smaller P3 amplitude centro-parietally and by greater negative amplitude fronto-centrally with the N4 wave in the crime relevant condition with the agree response demand. A potentially important effect for detecting deception is that the guilty group exhibited smaller P3 amplitude centro-parietally for the crime relevant than control and neutral conditions with the agree response demand. For the innocent group, this effect was absent. It can be noted that in the crime relevant condition, the no stimulus is congruent with the truth of the question for the innocent group but not the guilty group. In the crime relevant condition, the no target stimulus is also compatible with the truth of the response demand (agree) for the innocent group and/but is incompatible with the response demand of the guilty group (in truth they would disagree). The guilty group also displayed longer P3 latency than the innocent group overall, but P3 latency did not distinguish between crime relevant and control conditions for the guilty group.

In the present study, the questions posed required an agree response to a yes target stimulus in the neutral and control conditions, but the crime relevant questions required an agree response to a no target stimulus. Although the ERP waveforms tended to be more negative (and less positive) for disagree than agree response demands, there were no differences in ERP components between question conditions for the innocent group. Nevertheless, the conjunction of target stimulus and response demands were investigated in a second experiment that attempted to replicate the effects observed here using a sample of male subjects in a different mock crime scenario. Neutral conditions were introduced such that yes and no target stimuli required both agree and disagree responses.

Methods--Experiment 2

Subjects

The subjects were male volunteers from the university community who ranged in age form 18 to 27 ($M = 21$). As in experiment 1, they were randomly assigned to either the guilty group ($n = 10$) that participated in a mock crime or to the innocent group ($n = 10$) that did not.

Procedure

The instructions, preparation of the subject, and recording environment were essentially the same as for the first experiment. The same two-stimulus paradigm, with a question followed by the yes or no target stimulus, and the same response requirement to agree or disagree with the conjunction of the question and target stimulus, was employed. In this case, the mock crime involved removing a $20 bill from a purse. Three categories of questions, with 15 items in each category, were composed: (a) Neutral affirmative questions that required an agree response following the yes target stimulus, (b) Neutral negative questions that required an agree response following the no target stimulus, (c) Crime relevant questions that required an agree response following the no target stimulus. The questions were presented in random sequence 10 times each in three blocks of 150 trials with the yes or no target stimulus equiprobable within each question category. The paired-stimulus presentation and response demands for the neutral affirmative, neutral negative and crime relevant question types are presented in Table 6.

Table 6
Question Type, Target Stimulus, and Response Demand for Experiment 2. The Congruity (Cong)/Incongruity (Incong) of the Target Stimulus with the Question and the Compatibility (Comp)/Incompatibility (Incomp) of the Response Demand with the Target Stimulus are Indicated in Brackets

Question Type	Target Stimulus	Response Demand
	Neutral Affirmative	
"Are you a student?"	Yes (cong)	Agree (comp)
	No (incong)	Disagree (comp)
	Neutral negative	
"Is today Sunday?"	Yes (incong)	Disagree (comp)
	No (incong)	Agree (comp)
	Crime Relevant-Innocent	
"Did you open the blue wallet?"	Yes (incong)	Disagree (comp)
	No (cong)	Agree (comp)
	Crime Relevant-Guilty	
"Did you open the blue wallet?"	Yes (cong)	Disagree (incomp)
	No (incong)	Agree (incomp)

The electrode placement and EEG recording parameters were the same as in experiment 1. However, the EEG sampling period was 4.096 s, including a 0.096 s pre-stimulus period, a 2.0 s exposure duration for the first stimulus (question), a 1.0 s interval (blank screen) between the question and the target stimulus, and a 1.0 s exposure duration for the target stimulus (yes/no). The inter-trial interval was 5.5 s, stimulus onset to subsequent stimulus onset. The scoring and statistical analysis of the ERP data were the same as for experiment 1.

Results

N2 Components

An interaction between response demand and question type was observed in which N2 amplitude to the target stimulus was greater for the disagree than agree response demand in the neutral affirmative condition but not the neutral negative and crime relevant conditions [$F(2, 24) = 12.53$, $p < .01$, $\epsilon = .7745$]. This effect influenced the overall greater N2 amplitude for disagree than agree response demands [$F(1, 12) = 5.17$, $p < .05$]. The means and standard deviations for the N2 amplitude analysis are shown in Table 7.

Table 7
Mean (Standard Deviation) N2 Amplitude (in μV) at Fz to the Target Stimulus for Guilty and Innocent Groups Following the Neutral Affirmative, Neutral Negative, and Crime Relevant Questions Demanding an Agree or Disagree Response

Response Demand	Group	Question Type: Neutral Affirmative	Neutral Negative	Crime Relevant
Agree	Guilty	5.84 (3.76)	2.32 (3.87)	3.00 (4.18)
	Innocent	4.69 (4.81)	4.07 (4.05)	4.33 (4.88)
Disagree	Guilty	1.41 (3.87)	3.61 (3.81)	3.16 (2.90)
	Innocent	1.68 (3.93)	3.95 (5.81)	4.14 (5.53)

Note. Smaller positive values indicate greater negative amplitude.

The latency of the N2 component was longer at Fz than Pz [$F(2, 24) = 6.69$, $p < .01$, $\epsilon = .7593$]. Overall, N2 latency was longer for disagree than agree response demands [$F(1, 12) = 27.4$, $p < .001$], an effect that was somewhat more pronounced for guilty than innocent subjects [$F(1, 12) = 5.90$, $p < .05$]. Analysis of the interaction of electrode placement and response demand indicated the greater N2 latency for the disagree than agree response demand at Cz and Pz but not at Fz [$F(2, 24) = 4.60$, $p < .05$. $\epsilon = .6473$]. An interaction of electrode location, question type and group indicated the longer N2 latency at Fz than Pz in the neutral affirmative and crime relevant conditions for the guilty group [$F(4, 48) = 4.93$, $p < .01$, $\epsilon = .6473$]. An interaction of question type, response demand and group indicated the longer N2 latency for the disagree than agree response demand in the neutral negative condition for the guilty group [$F(2, 24) = 5.485$, $p < .05$, $\epsilon = .7286$]. The mean N2 latency values are presented in Table 8.

Table 8
Mean (Standard Deviation) N2 Latency (in ms) at Fz to the Target Stimulus for Guilty and Innocent Groups Following the Neutral Affirmative, Neutral Negative, and Crime Relevant Questions Demanding an Agree or Disagree Response

Response Demand	Group	Question Type: Neutral Affirmative	Neutral Negative	Crime Relevant
Agree	Guilty	262.00 (35.20)	248.50 (54.82)	282.80 (33.52)
	Innocent	261.50 (32.70)	268.80 (46.45)	259.56 (37.55)
Disagree	Guilty	288.00 (22.18)	274.00 (37.72)	275.20 (39.00)
	Innocent	276.40 (22.82)	262.80 (41.95)	271.20 (47.36)

P3 Components

P3 amplitude to the target stimulus was smaller in the crime relevant condition than in the neutral conditions [$F(2, 30) = 12.45$, $p < .01$, $\epsilon = .9803$] and smaller at Fz and Cz than at the Pz electrode site [$F(2, 30) = 13.79$, $p < .01$, $\epsilon = .5565$]. For the agree response demand, P3 amplitude at Fz was also smaller than at Cz [$F(2, 30) = 4.06$, $p < .05$, $\epsilon = .7180$]. A priori contrasts indicated that for the agree response demand, the guilty group displayed smaller P3 amplitude in the crime relevant than neutral negative and affirmative conditions at parietal sites [$F(1, 9) = 12.62$, $p < .01$]. No comparable differences were observed for the innocent group. The ERP waveforms for the agree response demand contrasting neutral negative and crime relevant conditions are illustrated in Figure 4 for the guilty group and in Figure 5 for the innocent group.

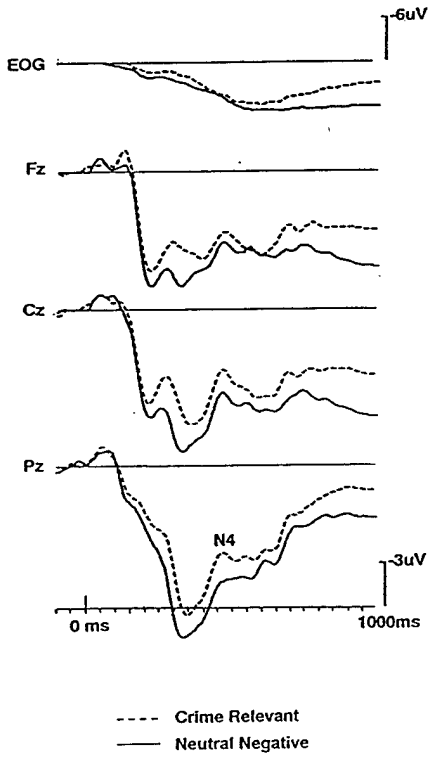

Figure 4. Grand average ERP waves recorded at Fz, Cz, and Pz. When guilty subjects were required to make an agree response to the no target stimulus, P3 amplitude was smaller in the crime relevant condition than in the neutral negative condition.

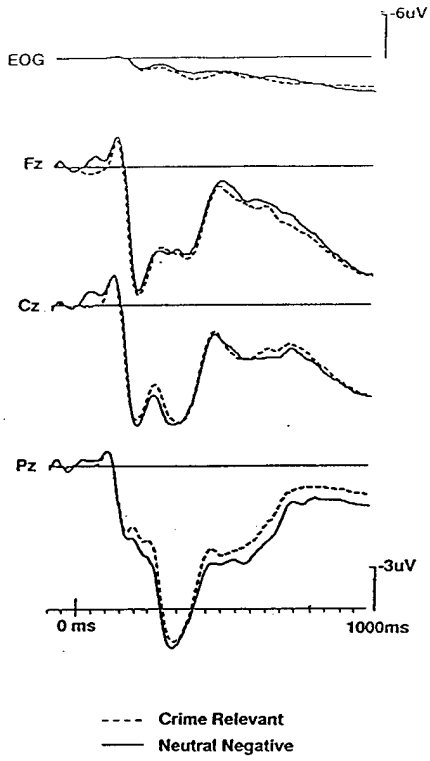

Figure 5. Grand average ERP waves recorded at Fz, Cz, and Pz when innocent subjects were required to agree to a no target stimulus following crime relevant and neutral negative questions. The difference in the P3 amplitude which was apparent for guilty subjects is absent for innocent subjects.

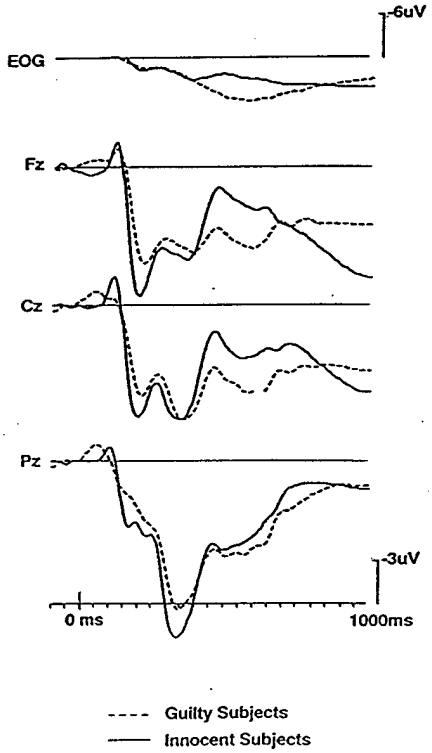

Figure 6. Grand average ERP waves at Fz, Cz, and Pz recorded when subjects were required to agree to a no target stimulus following a crime relevant question. The guilty group tended to display smaller P3 amplitude than the innocent group, but the effect was not statistically significant.

As seen in Figure 6, P3 amplitude tended to be smaller for the guilty than innocent group in the crime relevant condition for the agree response demand, but this difference was not significant at the .05 level of confidence. The mean P3 amplitude at Pz of guilty and innocent groups for the neutral and crime relevant question conditions for agree and disagree response demands are presented in Table 9.

Table 9
Mean (Standard Deviation) P3 Amplitude (in μV) at Pz to the Target Stimulus for Guilty and Innocent Groups Following the Neutral Affirmative, Neutral Negative, and Crime Relevant Questions Demanding an Agree or Disagree Response

		Question Type		
Response Demand	Group	Neutral Affirmative	Neutral Negative	Crime Relevant
Agree	Guilty	13.52 (5.53)	12.07 (4.19)	9.86 (3.66)
	Innocent	13.93 (5.79)	12.09 (5.35)	11.81 (5.29)
Disagree	Guilty	12.42 (5.20)	11.73 (4.77)	10.81 (4.49)
	Innocent	11.95 (3.66)	12.73 (6.78)	11.20 (6.40)

P3 latency was longer for the disagree than agree response demand [$F(1, 15) = 20.65$, $p < .01$], an effect that was mainly due to the longer latency of disagree than agree response demands in the neutral affirmative and neutral negative question conditions [$F(2, 30) = 4.31$, $p < .05$, $\epsilon = .9467$]. Analysis of the interaction of response demand, question type and electrode location [$F(4, 60) = 2.88$, $p < .05$, $\epsilon = .7681$], indicated that this effect was especially marked for the neutral conditions at the frontal electrode location. The mean P3 latency at Pz for all conditions are shown in Table 10.

Table 10
Mean (Standard Deviation) P3 Latency (in ms) at Pz to the Target Stimulus for Guilty and Innocent Groups Following the Neutral Affirmative, Neutral Negative, and Crime Relevant Questions Demanding an Agree or Disagree Response

Response Demand	Group	Question Type: Neutral Affirmative	Neutral Negative	Crime Relevant
Agree	Guilty	344.40 (25.47)	346.00 (41.19)	350.00 (30.65)
	Innocent	332.80 (27.44)	334.00 (29.83)	339.60 (28.81)
Disagree	Guilty	408.00 (30.70)	387.60 (53.05)	378.80 (55.81)
	Innocent	356.40 (31.24)	356.00 (31.89)	340.00 (39.19)

N4 Components

N4 amplitude to the target stimulus was greater for fronto-central than parietal electrode sites [$F(2, 28) = 12.41$, $p < .01$, $\epsilon = .7401$], and for crime relevant than neutral negative questions [$F(2, 28) = 4.14$, $p < .03$, $\epsilon = .9729$].

The latency of the N4 wave was longer for the guilty than innocent group but only for the disagree response demand [$F(1, 14) = 5.09$, $p < .05$].

Summary of experiment 2

As in experiment 1, the salient effect in experiment 2 that distinguishes the guilty from innocent groups is the smaller P3 amplitude for the guilty group in the crime relevant than neutral conditions with the agree response demand. This effect was absent for the innocent group. The greater negative amplitude of the N4 component that differentiated the guilty from innocent groups in the crime relevant condition in experiment 1 did not emerge in experiment 2.

Discussion

This research was specifically designed to assess a two-stimulus paradigm for the purpose of detecting deception using ERP methods. The paradigm follows an interrogation procedure where neutral and crime relevant questions are posed. The subject

is required to evaluate the truth of the question that is asked. In an interrogation, a plausible sequence has the interrogator say "Did you steal the money? You did, didn't you" and the subject responds "No, I disagree, that is not true." In adapting the interrogation to permit the recording of ERPs, the flexibility of an interrogation is maintained by permitting a wide variety of questions as the first stimulus in the trial sequence. A single word *Yes* or *No* was introduced following the question as the target for evaluating the question and for determining the response. The *Yes* or *No* target has a number of features that are advantageous to ERP averaging, including physical and semantic simplicity and repetitive constancy. Several ERP paradigms are helpful in assessing the waveforms that develop when the target stimulus is processed, but the differences between these paradigms and the present one tend to be greater than the similarities. Because the yes and no target stimuli occur with equal probability, the P3 wave that develops is comparable to match/mismatch paradigms (Pritchard, 1981) rather than oddball paradigms (Fabiani, Gratton, Karis, & Donchin, 1987). In the present case, the equal probability of occurrence of the target stimuli has the advantage of limiting the effects of surprise or novelty on the ERP wave. Because the stimulus elements in the task are semantic, the paradigm is comparable in some respects to semantic incongruity paradigms that examine variation in N2 and N4 waves (Pritchard, Shappell, & Brandt, 1991). Only stimulus-response compatibility paradigms, however, feature conditions that invoke the subject to respond opposite to the signal given in the target stimulus as required of the guilty subjects (Bashore, 1990). In stimulus-response compatibility paradigms, the congruity of the stimuli that are employed are typically evaluated on the basis of physical or lexical characteristics rather than semantics and the items are presented as single stimuli rather than sequential stimulus pairs as in the paradigm employed here. From this perspective, and given the difficulty in separating and classifying overlapping positive and negative waves (Pritchard, et al., 1991; Ritter, et al., 1984), it is expedient to discuss the effects observed in the context of the paradigm employed here and in terms of their consistency across the two studies.

In both experiments, the salient effect that distinguished the guilty from innocent group was the smaller P3 amplitude of the guilty group to the target stimulus in the crime relevant than comparison control conditions for the agree response demand. That is, P3 amplitude was smaller, for guilty subjects, when the crime relevant question (Did you take the brooch?) was followed by a *No* target that required them to lie by executing an agree response. These effects can best be understood in terms of the congruity (truth) of the target stimulus with the question and of the compatibility (truth) of the target stimulus with the response expressed.

Overall, P3 amplitude was smaller, for both groups, in the comparison conditions where the target stimulus was incongruent with the question i.e., where subjects were required to execute a disagree response. The pattern is present in all comparison conditions except in the neutral negative condition (yes-disagree) where there is no significant difference. The smaller P3 for disagree than agree response demands is an effect that is consistent with several studies demonstrating smaller P3 amplitude to mismatch or incongruous target items in two-stimulus paradigms (Bashore, 1990; Houlihan, Campbell, & Stelmack, 1994) and with the effects of feedback that disconfirmed the expectations of guilty subjects in the study reported by Bessinger, et al., 1991. This pattern of smaller P3 amplitude to incongruous target items was evident in the crime relevant condition for both guilty and innocent subjects in the first experiment and for innocent subjects in the second experiment. There is a caveat here because in the crime relevant condition the target stimulus *Yes* was congruous with the question for the guilty subjects. In this case, smaller P3 amplitude for the disagree response demand develops because the target stimulus *Yes* is incompatible with the response executed (disagree) for the guilty subjects. This effect is consistent with studies demonstrating smaller P3 amplitude for incompatible than compatible response requirements (Bashore, 1990; Ragot, 1984).

In both experiments, there is good consistency across conditions in which the target stimulus was congruent with the question i.e., where subjects were required to execute an agree response. In the neutral negative condition of experiment 2, an agree response was required following a *No* target stimulus that was congruent with a false question (Is today Sunday?) i.e., the negation was congruent with the false question. This neutral negative condition provided an appropriate comparison for the crime relevant condition for the innocent group for whom the crime relevant question was also false. In the neutral negative condition, P3 amplitude was slightly, but not significantly reduced, from the neutral affirmative condition for both groups and was equivalent to the crime relevant condition for the innocent group. In the crime relevant condition, for the guilty group, the target stimulus *No* was incongruent with the question (which was true for this group) and was incompatible with the response selected, factors which compounded to reduce P3 amplitude in this crime relevant condition.

If lying is a more difficult task than telling the truth, then P3 latency, which increases with increases in task difficulty (McGarry-Roberts, et al., 1992), would be longer for the guilty group in the crime relevant condition than for truthful conditions than for the innocent group. In experiment 1, guilty subjects did display longer P3 latency than innocent subjects overall, but the effect was not statistically significant in the crime relevant condition. Moreover, there

were no significant differences in P3 latency between conditions for the guilty group. Similarly in experiment 2, the pattern of longer latencies for guilty than innocent subjects was maintained across all conditions but the effect was not statistically significant. It is interesting to note, however, that P3 latency tended to be longer in those conditions where the target stimulus is incongruous with the question. This effect prevailed in all truthful conditions except in the neutral condition of experiment 1 for the innocent group, where the effect was not significant. The longer P3 latency for incongruous than congruous stimuli is consistent with stimulus evaluation effects commonly reported (e.g., Magliero, Bashore, Coles, & Donchin, 1984). A departure from this pattern was apparent for the guilty subjects in the crime relevant condition of both experiments. The pattern was, in fact, reversed with longer latencies for congruous than incongruous stimuli. Response incompatibility does not account for the differences because the response demand for the guilty subjects was incompatible for both the congruous and incongruous stimuli.

There is some evidence that both N2 latency and amplitude are increased when an incompatible response is required but are unchanged when incongruent stimuli are presented (Bashore, 1990). In the present studies, both stimulus incongruity and response incompatibility have an effect on the N2 wave. In experiment 1, N2 amplitude was greater for disagree than agree response demands overall. More importantly, however, N2 amplitude was greater, across all electrode sites and for both groups, when the target stimulus was incongruous than congruous with the question. The only exception to this stimulus incongruity effect was for the guilty group in the crime relevant condition (Did you take the brooch? Yes/disagree) where smaller N2 amplitude may be attributable to response incompatibility but not stimulus incongruity. In experiment 2, N2 amplitude was again greater for disagree than agree response demands overall but the effect was only significant in the neutral affirmative condition.

In both studies, N2 latency tended to be longer fronto-centrally for disagree than agree response demands, effects that appear attributable to stimulus incongruity. Again, response compatibility is a confounding factor in this analysis although this was not expressed in the interaction effects between groups. Nevertheless, it is worthwhile to note that in both studies, the longest mean N2 latency was observed at Fz for the guilty group in the crime relevant condition for the agree response demand, that is, the condition in which both stimulus incongruity and response incompatibility are extant.

In experiment 1, N4 amplitude was greater for disagree than agree response demands. Moreover, N4 amplitude was greater for the guilty than innocent group in the crime relevant condition for the agree response demand. In general, these effects parallel

those observed for the N2 wave, with greater N4 amplitude for both groups when the target stimulus was incongruous than congruous with the question. This wave did not distinguish between neutral and crime relevant conditions for the guilty group. Moreover, the effect was not evident in experiment 2.

In general, the effects in experiment 1 tend to be somewhat more clear-cut, with reduced P3 amplitude for the guilty subjects differentiating between both groups and conditions in experiment 1, but only between conditions in experiment 2. There were some differences between the two experiments that merit discussion. Subjects in experiment 1 were female, whereas, the subjects in experiment 2 were male. The sex differences are evident in the larger P3 amplitude and faster latency for females than males. The female experimenters who collected the data in these two studies facetiously opined that perhaps the males were better liars than the females. From the data, however, it would appear that the males were not as effective in telling the truth. The principal difference between the two studies is that P3 amplitude for the agree response in the crime relevant condition is somewhat smaller for the innocent males than females. This suggests that the crime relevant questions posed for the crime scenario in the second experiment may have been flawed, that is, not sufficiently crime relevant (e.g., Did you open the desk drawer?) to clearly differentiate the innocent from the guilty subjects.

In conclusion, the two-stimulus paradigm employed here holds some promise as a new method for detecting deception. The compound effects of stimulus incongruity and response incompatibility on the ERP wave, notably P3 amplitude, to simple target stimuli reliably distinguishes guilty subjects. Because the matter of overlapping waves is an issue that cannot be adequately addressed with the present data, it is premature, and may be misleading, to generate detection rates from individual records. Clearly, the dynamics of this process must be confirmed before attempting to assert the efficacy of this approach.

Moreover, in order to obviate the criticisms addressed to the control question technique employed with autonomic response measures, it is important to rigorously examine comparison control conditions. In this regard, it will be useful to examine crime relevant control questions that are false (Did you take the necklace?) in comparison to crime relevant questions that are true for the guilty subjects (Did you take the brooch?). It will also be worthwhile to accommodate the paradigm to a guilty knowledge format by limiting the questions to guilty knowledge items.

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