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Using Brain MERMER Testing to Detect Knowledge Despite Efforts to Conceal*

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ABSTRACT: This experiment examined the accuracy and reliability of the memory and encoding related multifaceted electroencephalographic response (MERMER) technique for detecting information related to events subjects have experienced, despite subjects' efforts to conceal that knowledge. Information obtained through interviews was used to develop stimulus sets consisting of words and phrases presented to subjects visually by computer. Sets were composed of three types of stimuli: life experience-related (Probes), stimuli the subject was asked to memorize and respond to (Targets), and irrelevant information (Irrelevants). Each set of stimuli was tested on two individuals: (1) one individual who had participated in the event in question—and thus had the relevant information stored in his/her brain, and (2) one who had not. Six subjects were tested. Electrical brain responses to the stimuli were recorded non-invasively from the scalp and analyzed. MERMERs, (memory and encoding related multifaceted electroencephalographic responses), of which the P300 is a sub-component, were used to determine whether the subject had the relevant information stored in his brain (information present) or not (information absent), thus indicating whether or not each subject had participated in the real-life event in question. Bootstrapping was used to analyze and compare the responses to the three types of stimuli. As predicted, MERMERs were elicited by Probe stimuli only in the subjects who had participated in the investigated event, by Target stimuli in all subjects, and in no case by Irrelevant stimuli. For each of the six subjects, brain MERMER testing correctly determined whether the subject had participated in and consequently knew about the event in question (information present) or had not participated (information absent). The statistical confidence for this determination was 99.9% in five cases and 90.0% in one case. The article concludes with a discussion of areas of future research and the potential for using this new technology as an investigative tool in criminal cases.

KEYWORDS: forensic science, multifaceted electroencephalographic response analysis, memory and encoding related multifaceted electroencephalographic response, psychophysiological detection of information, electroencephalograph, criminal investigation, brain waves

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The purpose of this paper is two-fold: (1) to report results of preliminary research on brain memory and encoding related multifaceted electroencephalographic response (MERMER) testing, a new technology that may be capable of linking evidence of a crime to information stored in the brain of the person who committed the crime, and (2) to encourage more research on this technology, which offers the promise of providing an accurate and scientific means of tying perpetrators to crimes and verifying the claims of those who were not involved. This technology evaluates the presence or absence of information/evidence in the one place where a comprehensive record of every crime is stored—the brain of the perpetrator.

Several major breakthroughs in criminal investigation precede brain MERMER testing. The development of a fingerprint classification system enables investigators to use the uniqueness of human fingerprints to place a suspect at a crime scene, as long as special procedures are applied to collect and preserve fingerprint evidence properly. Recent advances in DNA research allow investigators to connect biological evidence that is collected at the crime scene with evidence from the body of the criminal. Like fingerprinting, DNA can be successfully used only when investigators collect and preserve the specific kind of evidence demanded by the technique. Both DNA and fingerprinting have been highly successful in identifying offenders and in eliminating innocent suspects, but both are found only in a very small percentage of cases.

Investigators' need for other accurate, scientific means of linking perpetrators with crime scene evidence has inspired some scientists to ask, "What does the criminal always take with him from the crime scene that records his involvement in the crime?" The answer to this question, of course, is the brain. Physical evidence may or may not be present, but the brain of the criminal is always there, recording the events, in some ways like a video camera.

Until recently, there has been no way to detect this record stored in the brain. Might it be possible to utilize the brain as a source of information that would accurately reveal a suspect's presence at a crime scene? This paper reports the scientific progress, to date, in answering this question, and presents a test of the science of brain MERMER testing in detecting participation in real-life events.

Although brain MERMER testing is a new science, the evidence reported here, and in several other studies, suggests that recent advances in neuroscience allow scientists to detect information stored in the brain—information that potentially could scientifically, objectively, non-invasively, and accurately connect a criminal with a specific criminal act.

Recent research has shown that electrical brain responses can be a reliable indicator of information-processing activities in the brain. This may mean that measurements of such brain activity might tap information that could uniquely identify perpetrators and others, such as witnesses, involved in many types of crimes. This could conserve law enforcement personnel and financial resources, as well as provide a source of new leads. Conversely, the information from these measurements could steer investigators away from innocent individuals.

The invention of brain MERMER testing was based on recent progress in neuroscience, particularly in electroencephalography—a non-invasive measurement of electrical brain activity.

The recent history of electroencephalography can be compared to the old story of the blind men and the elephant. As the story goes, a group of blind men set out to investigate the nature of an elephant. One comes upon the trunk, another the tusk, another the leg, another the ear, another the side, another the foot, and still another the tail. When they compare notes, they each report accurately on what they have observed, yet they each have a different impression of what an elephant is like.

Brain waves, like elephants, have many different facets. The facet observed depends upon the method of observation and data analysis. The most obvious feature of brain waves is the multiple superimposed oscillations that the brain emits at different frequencies. These oscillations are ordinarily measured over a span of minutes or longer. Different frequencies of brain waves measured in this way have been named alpha waves, beta waves, etc. They can be used to distinguish gross states such as waking, sleeping, dreaming, and coma. They also can reveal certain information about the level of functioning and activation of the brain, as well as certain brain injuries.

In the last several decades, scientists have developed computerized methods of looking at changes in brain waves that take place over very short periods of time, e.g., on the order of one second (1). This short time scale is necessary in order to examine brain-wave phenomena that occur during information-processing brain activity, which often takes place quite quickly. Until recently, the fundamental method of examining information-processing brain activity has been signal averaging (2). A stimulus that is processed by the brain (e.g., a word or a picture flashed on a computer screen) is presented many times, and the brain-wave responses to the multiple presentations are averaged. The averaging process eliminates all activity that is not time-locked to the stimulus. This process reveals event-related brain potentials (ERPs)—specific, simple, positive and negative voltage changes that take place during the information processing of the particular stimulus. This provides a totally different picture than that provided by the frequency analysis yielding alpha and beta waves. This is like looking at an entirely different part of the elephant. Druckman and Lacy (3) have noted that, within appropriate research paradigms, ERP responses allow experimental psychologists to study processes that would be difficult to access by other means.

In the mid-1980s, researchers began to focus on the P300 as a specific ERP component that had the potential for detecting concealed information in the brain. (The P300 is also known as P3 or Late Positive Complex. Sometimes it is considered to be comprised of two separate components, P3a and P3b.) Farwell and Donchin (4,5) used event-related brain potentials in the detection of concealed information. "Farwell and Donchin's work has revealed [that this] neurocognitive link may be engaged automatically (i.e., out of the person's control), irrespective of either the person's covert. . . or overt. . . expression to the contrary. If so, this provides

a very powerful bridge to detecting the possession of critical information" (6).

Farwell and Donchin's (5) subjects completed an interactive computer briefing in which they learned the details of a mock espionage scenario. After this briefing, subjects actually performed the scenario. The subjects were tested the next day on their knowledge of the scenario in which they participated and one in which they did not participate.

Stimuli presented to test the subjects were classified into three categories: Targets, Probes, and Irrelevants (the same categories, described below, which were used in the research reported in this paper). Using a bootstrapping statistical analysis technique (5,7-9), Farwell and Donchin analyzed and classified the ERPs of the 40 subjects (20 knowledgeable and 20 not knowledgeable). There were no false negatives, no false positives, and 87.5% of the subjects were correctly classified as having or not having the relevant information. The remaining 12.5% were indeterminate.

Rosenfeld and his colleagues (10-13), and Allen and Iacono (14,15) achieved comparable results with similar procedures using ERPs.

Present-day brain MERMER testing, including the data reported here as well as in four other studies by Farwell and his colleagues (9,16-21), has achieved an even higher level of accuracy than that achieved in the ERP studies. In all five of these MERMER studies, accuracy has been 100% with no false negatives, no false positives, and no indeterminates. Three kinds of advances beyond the original ERP studies have increased accuracy: (1) the development of multifaceted electroencephalographic response analysis (MERA) and the discovery of the memory and encoding related multifaceted electroencephalographic response (MERMER), (2) advances in data acquisition procedures, and (3) advances in testing methods and procedures. All of these are described below and are described in more detail in Farwell (9,19,20).

The advances in information detection and data analysis leading to the development of MERA and to brain MERMER testing began with an analysis of the strengths and weaknesses of ERPs. Analyzing data through signal averaging to detect ERPs offers the advantage that this process isolates certain simple patterns of brain activity that take place while a specific stimulus is being processed. ERPs are simple patterns which often are not discernible in raw EEG data because these ERPs are overwhelmed by the complicated activity taking place simultaneously with them. The disadvantage of measuring ERPs is that the process of signal averaging eliminates all of the complicated patterns associated with information processing, leaving only the simple voltage changes over time. In other words, in the process of eliminating noise, a vast amount of meaningful signal is eliminated as well.

When the brain processes information, it does not produce only the simple voltage changes that constitute ERPs. There are many other complex changes that take place. These changes are eliminated by signal averaging because the resulting patterns of electrical activity are not phase-locked to the time of the stimulus, and thus they average out to zero when many signals are averaged to produce ERPs. Many features of the brain-wave responses are missed in ERP analysis either because they are eliminated by the signal averaging process or because they are not discernible through visual inspection of averaged responses.

Returning to our story of the blind men and the elephant, measuring ERPs is like walking the elephant through mud and collecting the footprints. It gives a very clear, solid picture of the feet, but loses all data about the rest of the elephant.

Recognition of the limitations inherent in ERP measurement and analysis led to the development of multifaceted electroencephalographic response analysis (MERA). MERA, like ERP analysis, analyzes specific, short-term segments of brain-wave data elicited by information-processing brain activity. Unlike ERP analysis, MERA is multifaceted in that it simultaneously examines multiple facets of the data. A specific multifaceted electroencephalographic response (MER) may contain: (1) one or several ERP components, (2) phasic changes in the frequency and dimensionality of the signal at a specific scalp location or at multiple locations, and (3) changes in the relationship between signals in different scalp locations measured by coherence, correlation, and covariance.

Using multifaceted electroencephalographic response analysis (MERA), Farwell and his colleagues (9,16–21) discovered that a specific multifaceted electroencephalographic response (MER), known as a memory and encoding related multifaceted electroencephalographic response (MERMER), is elicited when a person recognizes and processes a stimulus that is particularly noteworthy to him/her. The MERMER is the elephant of which the P300 is the foot. (Recall that the P300 is the ERP component used in the original brain-wave information detection studies.) The MERMER includes: (1) the P300, an electrically positive component maximal at the parietal scalp site, (2) another, longer latency, electrically negative subcomponent prominent at the frontal scalp site, and (3) phasic changes in the frequency and structure of the signal. (For a detailed discussion of the MERMER, see 9.)

Farwell and his colleagues have developed a system to use the MERMER to detect the presence or absence of specific information stored in the brain. Recall that the MERMER is elicited only by stimuli that are noteworthy or significant for the subject. Stimuli that are task-relevant (i.e., relevant to a task being performed) and stimuli that are relatively rare naturally tend to stand out. That is, they tend to be more noteworthy for the subject. The Farwell MERMER System utilizes this feature of the MERMER through the following procedure. A sequence of words, phrases, or pictures is presented on a video monitor under computer control. Each stimulus appears for a fraction of a second.

Three types of stimuli are presented: Targets, Irrelevants, and Probes. The Targets are made relevant and noteworthy to all subjects, i.e., the subject is given a list of the Target stimuli and instructed to press a particular button in response to Targets and another button in response to all other stimuli. Since the relatively rare Targets are singled out in the task being performed, the Targets are noteworthy for the subject, and each Target stimulus elicits a MERMER. Most of the non-Target stimuli are irrelevant, having no relation to the situation under investigation. These Irrelevants do not elicit a MERMER.

Some of the non-Target stimuli *are* relevant to the situation under investigation. These relevant stimuli are referred to as Probes. For a subject who has participated in the situation in question, the Probes are noteworthy due to the subject's knowledge of that situation, and, therefore, Probes elicit a MERMER when the subject is knowledgeable. Probes are indistinguishable from the Irrelevants for a subject who is not knowledgeable about the situation under investigation, and thus Probes do not elicit a MERMER if the subject is not knowledgeable.

In analyzing the data, the Farwell MERMER System compares the responses to the three types of stimuli and computes a determination of whether the Probe responses contain a MERMER (i.e., are similar to the Target responses) or do not contain a MERMER (i.e., are similar to the Irrelevant responses). The system also com-

putes a statistical confidence for this determination. (For a detailed discussion, see 9,18–22.)

Using the MERMER, Farwell and Richardson (see 9,18) conducted a study in which Federal Bureau of Investigation (FBI) new agent trainees were presented Probes consisting of words, phrases, and acronyms which only FBI agents would know, along with Targets and Irrelevants. Non-FBI personnel were also tested. The Farwell MERMER System correctly classified all 17 of the FBI new agent trainees. The four control subjects were also correctly classified.

In 1992 and 1993, Farwell and his colleagues (21) conducted three experiments for the Central Intelligence Agency (CIA). All three experiments used brain responses to stimuli, consisting of Probes, Targets, and Irrelevants, to detect concealed information stored in the brain. The first experiment, using pictorial rather than verbal stimuli, explored whether or not brain waves could be used effectively to detect prior knowledge of information. The information detected was relevant to a mock espionage scenario enacted by some of the subjects, and the stimuli that elicited the brain responses were relevant pictures presented on a computer screen. In the second experiment, words, phrases, and acronyms were presented on a computer screen to subjects, some of whom were U.S. Navy officers who were experts in military medicine. The information detected was relevant to knowledge of military medicine. The purpose of this experiment was to determine whether this method could be useful in detecting members of a group or organization, or people with a particular expertise (i.e., intelligence agents). In the third experiment, which also used visually presented words, the information detected was relevant to real-life events, including two felony crimes. All 79 subjects in the three experiments were correctly classified as information present or information absent, i.e., as possessing or not possessing the critical information. There were no false positives, false negatives, or indeterminates.

The original data analysis in these experiments focused on the P300. Farwell has since analyzed these same data using the MERMER. All subjects remained in the correct categories; however, the confidence level improved.

The research described in this paper was conducted in 1993, and was, in part, a replication of the third experiment Farwell did for the CIA. This research differed from the CIA research in that, although the sample size was smaller, each set of stimuli was tested on both a knowledgeable subject and a subject who was not knowledgeable regarding the investigated event. This was done to determine if there was anything inherent in the nature of the stimuli selected for each set that would lend itself to a particular classification regardless of whether or not the subject was knowledgeable about the event in question.

Materials and Methods

Subjects

Three pairs of subjects, two females and four males, were tested. Participants ranged in age from their mid-20s to early 40s. Pairs were not randomly selected. Individuals in each pair were personally acquainted (i.e., pair one, subjects A and B knew each other). All subjects granted permission to have information about their life experiences provided to researchers in this experiment. Georgetown University's Review Board reviewed a description of this experiment and granted permission for these procedures to be used on human subjects.

Data from one subject were eliminated due to the subject's not understanding, and consequently not following, the directions. An-

other subject was substituted for this individual. (The authors chose to substitute another subject, rather than to re-explain the instructions and obtain additional data from the same subject, in order to maintain scientific control so that all subjects would undergo exactly the same procedure in this research study. In a field application, if a subject does not understand the instructions, those instructions can be reiterated or elaborated upon, and valid data can then be collected from the same subject.)

Materials

The Farwell MERMER System equipment consisted of a computer equipped with two monitors and the appropriate graphics and data acquisition/processing boards, a four-channel EEG amplifier system, a custom electrode headband, and the necessary custom software for data acquisition and analysis. (The Farwell MERMER System is also referred to as the Farwell MERA System; see 9,18.)

Method

One person in each pair (person A) was interviewed about details of the personal history and life experiences of the other (person B). Stimuli relevant to a particular real-life event were developed from interview material. Prior to beginning the interviews and testing, all individuals were advised of the procedures and reasons for this research, each signing waiver forms. All subjects knew the identity of the person who provided information about their life experiences, and each granted permission for the information to be provided. In each case, prior to the test, the knowledgeable subject did not discuss the information to be detected with the informer. On the day of the testing, all subjects were instructed to behave as if they knew nothing of the events investigated and to refrain from saying or doing anything that would reveal any relevant knowledge they might have to the researchers.

Nine Probe stimuli were developed that were relevant to each specific real-life event in question. For example, if the event was a birthday party celebration in a restaurant, the Probe stimuli might include the name of the restaurant ("Bosco's"), the name of another person present ("Jim Jones"), the nature of the celebration ("birthday party"), and an action that the subject engaged in ("lit candles").

For each Probe stimulus, similar Irrelevant stimuli were constructed that would be equally plausible for a person who had no knowledge of the event. For example, for the Probe "Bosco's," an Irrelevant could be "Henry's." For the Probe "Jim Jones," an Irrelevant could be "Bill Johnson." For the Probe "birthday party," an Irrelevant could be "anniversary celebration." For the Probe "lit candles," an Irrelevant could be "brought cake" (if the subject did not indeed bring the cake).

Each stimulus consisted of names, words, or phrases of up to 20 characters presented on a computer screen under computer control. Probes were stimuli relevant to the subject and to the event in question. Irrelevants were, as the name implies, irrelevant. For each Probe stimulus, there were four Irrelevant stimuli. The stimuli were structured such that the Probes and Irrelevants were indistinguishable for a subject who was not knowledgeable about the event in question.

In addition to the Probes and Irrelevants, one-sixth of the stimuli were Targets, one for each Probe. The task instructions made Targets recognizable and noteworthy for all subjects, whether or not they were knowledgeable about the event in question. Each subject was given a list of the Targets and told that he/she would need to recognize and identify them during the test. Subjects were in-

structed to press a special button each time one of the stimuli on the list of Targets appeared on the screen. Thus, the Targets were recognizable and noteworthy for all subjects. The Irrelevants were irrelevant for all subjects. The Probes, being relevant to the investigated event, were recognizable and noteworthy only for the subjects who had participated in the event.

Overall, there were nine Probes, nine Targets, and 36 Irrelevants for each event. These were divided into three subsets, each subset containing three Probes, three Targets, and 12 Irrelevants. Each subset, then, contained a total of 18 stimuli.

MERMER testing consists of a series of stimulus presentations or "trials," each lasting three seconds. In each trial, one stimulus is flashed on the screen, and the electrical brain response to that stimulus is recorded. The trials are presented in blocks, each block consisting of 72 trials. That is, the subject views and responds to a series of 72 stimuli, then pauses for a time, and then another series of 72 stimuli is presented, and so on. Each block lasts about three and one-half minutes.

In each block, only one of the three subsets of 18 stimuli is used. Each of these stimuli is presented four times to reach the total of 72 trials for the block. Each subject participated in nine blocks of trials, three blocks using each of the three stimulus subsets.

Trials with data contaminated by artifacts generated by eye movements or other muscle-generated noise were rejected on-line, and additional trials were presented so that the required number of 72 artifact-free trials was obtained. The order of stimulus presentation was randomized within each block.

Prior to the test, each subject was asked to study a list of the Targets, and was instructed that he/she would need to recognize and identify these stimuli during the test.

Before each test began, the researcher read descriptions of the Probes and Targets to be presented, for example, "Some of the items you will see are relevant to a particular person and a particular event. One of the items is the name of the restaurant where the event took place." As these items were described, the experimenter asked the subject to repeat the descriptions.

Once this process was completed, the experimenter read the list of all stimulus items (the actual Probes, Targets, and Irrelevants) that were presented. This list of items was not presented again until the test was over.

Descriptions of the Target and Probe stimuli specific to each block (but *not* the actual stimuli) were repeated for the subject at the beginning of each of the nine blocks to enhance the significance of the stimuli by establishing the context in which they were presented. For example, "In this block one of the stimuli you see will be the name of a person who was present at the investigated event."

Subjects were given a mouse for the purpose of responding with a button press to each stimulus. Subjects were instructed to press the left-hand button whenever a stimulus appeared that was on the list of Target stimuli they had studied before the test. For all other stimuli, subjects were instructed to press the right-hand button. Thus, subjects pressed the right-hand button for both Probes and Irrelevants, whether they recognized the Probes or not. In terms of overt behavior then, subjects concealed their knowledge of the Probes. The only indication of their knowledge of the Probes was provided by their brain responses.

By selecting an arbitrary set of stimuli which subjects must discriminate (Targets), a task was created that focused the subjects' attention in a manner that ensured the elicitation of the MERMER in response to these Target stimuli. The designation of arbitrary Targets made it possible to hide the items relevant to the investigation (Probes) among the more frequently occurring stimuli (Irrele-

vants), while assigning a task that ensured that the subjects had to notice, process, and categorize all stimuli. For the subjects who were not knowledgeable, these Probe items were indistinguishable from the Irrelevants, because nothing in the procedure drew the subjects' attention to these items. For the knowledgeable subjects, the Probe items were noteworthy, because they were associated with the information the subject possessed regarding the event under investigation.

The predictions were as follows: (a) the Probes would elicit a MERMER for the knowledgeable subjects, who in each case had participated in the event under investigation; and (b) the Probes would not elicit a MERMER for the subjects who were not knowledgeable because they had not participated in the event.

Subject B from each pair was tested on the stimulus set constructed from interview material relevant to Subject B's life. Subjects were presented with visual stimuli with a duration of 300 msec at an inter-stimulus interval of three seconds. In addition to Subject B in each pair being tested on stimuli pertinent to him/her, Subject A from another pair was tested on the same stimuli. Thus, pair 1 Subject B was tested on information about him/herself gathered from pair 1 Subject A. In addition, pair 2 Subject A was tested on the same stimuli. Therefore, each set of stimuli was tested on (1) a subject for whom the Probe stimuli were relevant, and (2) a subject for whom the Probe stimuli were not relevant.

All subjects were instructed not to indicate knowledge of relevant information to the experimenter in any way, including their button presses. This essentially instructed knowledgeable subjects to conceal their knowledge during the test.

Brain responses were recorded from the midline frontal, central, and parietal scalp locations, (Fz, Cz, and Pz, respectively) referenced to linked mastoids (behind the ear), and from a location on the forehead to track eye movements. Scalp recording was done with disposable EEG electrodes, similar to those used in standard EEG recording. The electrodes were embedded in a special headband designed and constructed by Dr. Farwell's Human Brain Research Laboratory (see 18,19).

Data were digitally filtered using a 49-point optimal digital filter with a passband cutoff frequency of four Hz and a stopband cutoff frequency of six Hz (22).

At the end of each test, subjects were given a written list of all stimulus items and asked to mark each item as noteworthy, somewhat noteworthy, or irrelevant. If, for some reason, any of the intended Irrelevant stimuli were, in fact, relevant for a subject for reasons unknown to the experimenter, they could be eliminated from the data analysis. This happened in two cases, yet the MERMER System was sufficiently robust that both subjects were correctly classified, one with 99.9% confidence and the other with 90.0%, even with these spurious Irrelevant stimuli. One reason for this could be that the average Irrelevant responses included 35 stimuli that were truly irrelevant and only one that was not. Thus, the Irrelevant brain-response pattern dominated for the Irrelevant stimuli in data analysis.

In the present study, the experimental procedure and data acquisition methodology were essentially the same as those used in the previous four MERMER studies conducted by Farwell and his colleagues (see 9, 16–21). In addition to the MERA technique and the MERMER brain response, these four studies introduced several innovations that may have contributed to the higher level of accuracy achieved in these studies than in the original Farwell and Donchin (5) study and the other ERP studies.

In data acquisition, the inter-stimulus interval was extended beyond the approximately 1.5 s typical of previous studies to 3 s, and

the data analysis epoch was extended to 2.2 s post-stimulus. This allowed the data analysis to consider a previously unobserved, frontally prominent, electrically negative subcomponent with a latency of up to 2 s post-stimulus (a markedly longer latency than the P300 used in previous studies). This component, in addition to the P300, was a major feature contributing to the signal analysis and statistical computation resulting in the accurate determinations of information presence or absence. In order to improve the accuracy of data analysis and the detection of complex patterns in the waveform, the digitizing rate was increased to 333 samples per second (100 samples per second was typical for previous studies).

In Farwell and Donchin (4,5) and other previous studies, the Targets were irrelevant to the investigated event and were made relevant to the subject only by the task instructions. In the present study and the other four recent MERMER studies conducted by Farwell and his colleagues (9,16–21), the Targets were relevant not only to the task instructions, but also to the investigated event. This made the Target stimuli more similar to the Probe stimuli for a knowledgeable subject, and may have, therefore, increased the similarity of the Target and Probe responses, and improved the discrimination of the data analysis for these subjects. (For a subject who was not knowledgeable, this change made no difference since such a subject does not recognize the event-relevant information.)

As in previous research by Farwell and his colleagues (9,16–21) the statistical technique of bootstrapping was employed to compare the brain responses to the different types of stimuli. This allowed a determination of information present or information absent and provided a statistical confidence for this determination for each individual case.

Bootstrapping is a statistical method of analysis that assesses, for each subject, the similarity between the Probe brain response and those brain responses elicited by the Targets and the Irrelevants respectively. This technique provides an estimate of the sampling distribution of a parameter when a limited number of samples are available. This is done by obtaining many random subsamples from the available data and recomputing the parameter for each subsample.

The essential question regarding each subject is, "Does the subject recognize the Probe stimuli as significant?" In terms of brain responses, the question is "Does the subject's brain response to the Probes contain a MERMER?" For each subject, the bootstrapping technique provides a level of statistical confidence that the Probe brain responses are more similar to the Target brain responses (which contain a MERMER) than to the Irrelevant brain responses (which do not contain a MERMER), or, alternatively, that the Probe brain responses are more similar to the Irrelevant brain responses than to the Target brain responses. If the Probe responses are more similar to the Targets (i.e., Probes, like Targets, elicit a MERMER), then this indicates that Probe stimuli, like Targets, are recognized as significant by the subject. In this case, the determination is information present, i.e., the subject has information relevant to the investigated situation stored in his brain. If the Probe responses are more similar to the Irrelevant responses (i.e., Probes, like Irrelevants, do not elicit a MERMER), then the determination is information absent, i.e., the subject does not have the relevant information stored in his/her brain.

The determinations made by the MERMER System and presented here are binary, i.e., either information present or information absent, and the statistical confidence levels presented here are stated as a percent, e.g., 99.9%.

Thus, if the MERMER System produces a determination of information present with a statistical confidence of 99.9%, then

mathematically there is a 99.9% probability that the Probe brain response is more similar to the Target response than to the Irrelevant response for this specific subject.

The Farwell MERMER System applies this data analysis algorithm automatically to produce for each subject a determination of information present or information absent and a statistical confidence for this determination. (For a detailed discussion, see 8,9,16,19.) This is a mathematical process and does not depend on any subjective judgments or interpretation of the data.

Results

The MERMER System data analysis algorithm correctly classified all six subjects. All three subjects who were tested on their own biographical data were correctly classified as information present, and thus as having participated in the investigated event, with a confidence level of 99.9% in each case. All three subjects who were not knowledgeable were also correctly classified as information absent in the brain, two with a confidence level of 99.9% and one with 90.0% confidence.

There were no false negatives, no false positives, and no indeterminate outcomes.

There are many different ways to present MERMER brain response data visually. Different methods illustrate different features of the data. No one method can adequately capture all of the information incorporated in the data in a visually recognizable form. One method that is often effective in providing a visual representation of the differences in brain responses involves plotting average responses to Probe, Target, and Irrelevant stimuli as voltage over time at a specific scalp location.

Figures 1 and 2 present the average brain responses to Probe, Target, and Irrelevant stimuli for two of the subjects. Figure 1 presents data for a subject who is knowledgeable regarding the investigated event. Figure 2 presents data for a subject who is not knowledgeable regarding the investigated event.

These figures present plots of voltage over time at the parietal (Pz) scalp location. In these figures, the MERMER appears as a

positive voltage peak at approximately 500 msec followed by a negative voltage deflection maximal at approximately 1200–1500 msec. (The latency of these deflections varies according to the speed of the individual subjects' brain processing.)

The brain responses of two subjects whose data are presented here are typical of their respective groups, knowledgeable and not knowledgeable. As can be clearly seen in the figures, for the knowledgeable subjects (Fig. 1) the MERMER is elicited in response to both Targets and Probes. For the subjects who were not knowledgeable (Fig. 2), the MERMER is elicited only in response to Targets.

Although there are recognizable common features, there are also individual differences among subjects in the pattern of brain responses. These individual differences are accounted for in the bootstrapping data analysis algorithm, which makes individual within-subject comparisons of brain responses to the three types of stimuli. The statistical analysis yielded a correct determination with a high level of statistical confidence in every case. This is an important feature of the MERMER System—it does not depend on subjective evaluation, interpretation, or scoring of the data.

Discussion

Three pairs of subjects were tested to determine if brain MERMER testing implemented by the Farwell MERMER System could detect concealed information regarding real-life events stored in the brain. In each pair, Subject A was interviewed about a salient event in Subject B's life and the people, places, things, and actions involved in the event. Stimuli were developed from interview material, and Irrelevant stimuli were added that would be equally plausible to someone who had not participated in the event in question and did not know the details about it.

For subjects who were not knowledgeable, this was a simple and ordinary classification task. These subjects recognized only two types of stimuli: (a) Targets, which were noteworthy due to task instructions and also relatively rare, and (b) irrelevant stimuli (con-

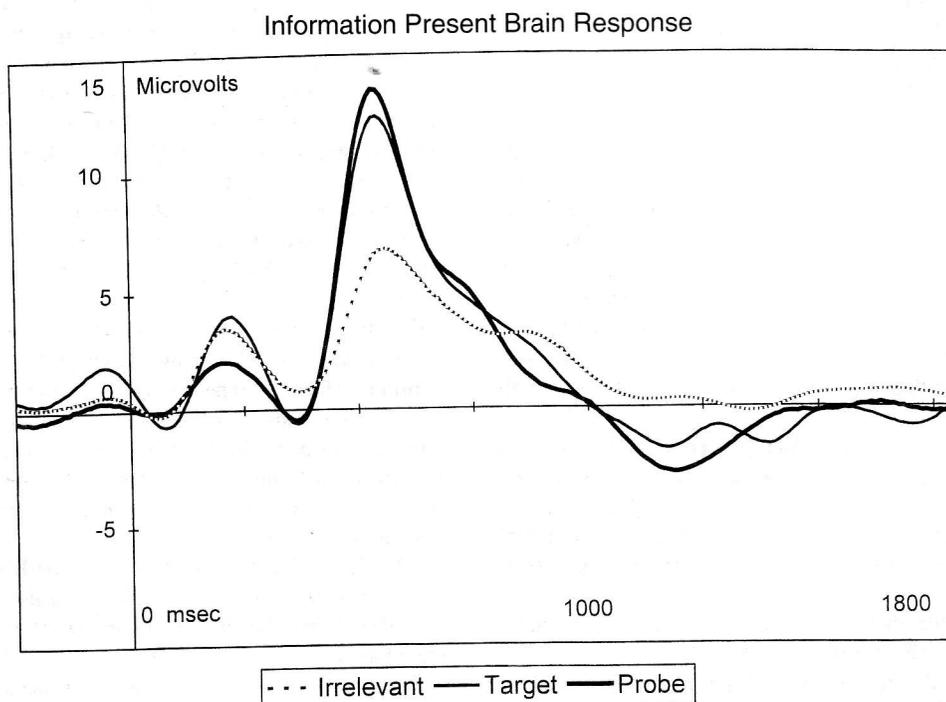


FIG. 1—Average brain response of Subject 1 at Pz (parietal) scalp site in response to Target, Probe, and Irrelevant stimuli.

Information Absent Brain Response

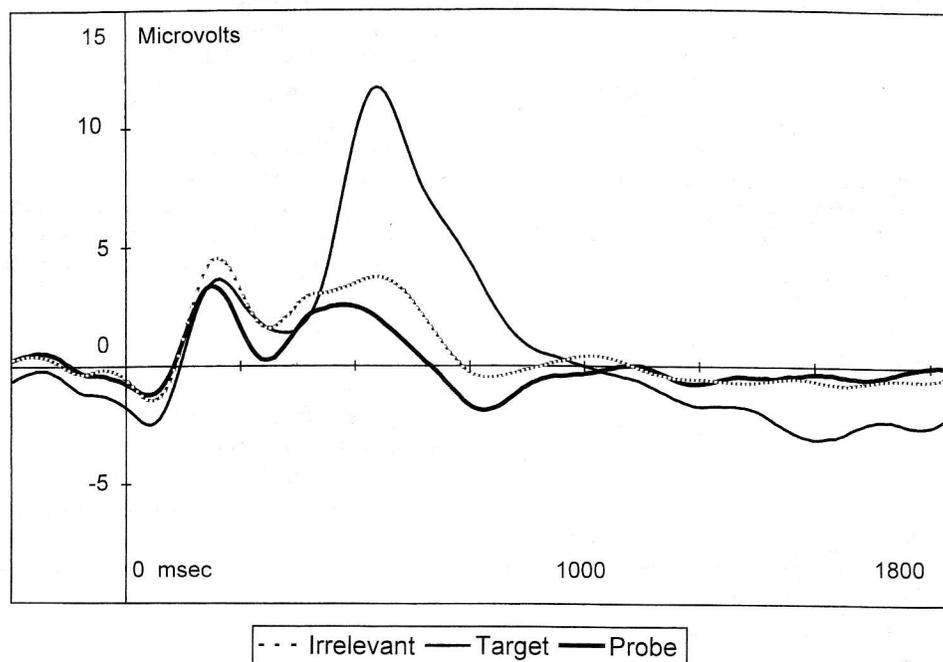


FIG. 2—Average brain response of Subject 6 at Pz (parietal) scalp site in response to Target, Probe, and Irrelevant stimuli.

sisting in fact of true Irrelevants, plus Probes—which they did not distinguish as being different from the Irrelevants). Previous research (9,16–21) has shown that processing by the brain of noteworthy events results in the elicitation of a MERMER in the brain response. Thus, the Targets elicited a MERMER and the Irrelevants did not. For subjects who were not knowledgeable, the (unrecognized) Probes also did not elicit a MERMER.

Knowledgeable subjects, however, recognized a second noteworthy and relatively rare type of stimuli, namely the Probes, which were relevant to them. Thus, for knowledgeable subjects the Probes, too, elicited a MERMER.

The present study's experimental design served to create a two-category series for an individual who was not knowledgeable, and a three-category series (with the same stimuli) for an individual who was knowledgeable. For a subject who was not knowledgeable, one category (Targets) was noteworthy. For a knowledgeable subject, two categories (Targets and Probes) were noteworthy. The Targets provided a template for a response to the stimuli known to be noteworthy—MERMER-producing stimuli. The Irrelevants provided a template for a response to stimuli that are not noteworthy—non-MERMER-producing stimuli.

The determination of information present or information absent in the brain consisted of comparing the Probe responses to (a) the Target responses, which contained a MERMER, and (b) the Irrelevant responses, which did not contain a MERMER. Probe responses similar to Target responses, i.e., containing a MERMER, indicated that the subject recognized the Probes and, therefore, the determination was information present, i.e., the subject was knowledgeable. Brain responses to the Probes which were similar to those of the Irrelevants, i.e., lacking a MERMER, indicated that the subject did not recognize the Probes and, therefore, the determination was information absent, i.e., the subject was not knowledgeable.

Note that knowledgeable and not knowledgeable refer to the true state of the subject, and information present and information absent refer to the determinations by the Farwell MERMER System. (In-

formation present and information absent are also referred to respectively as “match” and “no match,” indicating whether or not there is a match between information from the crime scene and information stored in the brain.) In this experiment, as in all previous ones using this system, the determinations matched the true subject state in every case. That is, brain MERMER testing was 100% accurate.

Future Perspectives

The brain is centrally involved in every human action and records everything that human beings do, including criminal acts. Perhaps the only reason that the brain has not yet become central to criminal investigations is that in the past there has been no scientific, objective way to connect the record stored in the brain with evidence from the crime. While some crimes may not have sufficient physical evidence, the brain is always there, storing a record of the actions and even the thoughts involved in the crime. This paper reports some of the first practical steps of progress towards utilizing the brain as a source of evidence in criminal investigations.

If future research supports the viability of using brain MERMER testing as an investigative aid, it will have some features in common with fingerprinting and DNA. All three are scientific techniques which could be used to link evidence associated with a crime to the perpetrator of the crime. Because of this, brain MERMER testing is sometimes referred to as “Brain Fingerprinting.”

There are, however, differences between MERMER and these other technologies. One difference is in the type of evidence. Fingerprinting matches prints left at the crime scene with the patterns on the fingers; DNA connects biological samples from the crime scene with the DNA of the perpetrator; and brain MERMER testing could link crime-related information with information stored in the brain of the perpetrator.

Another difference between brain MERMER testing on the one hand, and DNA and fingerprints on the other, is that DNA and fin-

gerprints detect something that is unique to the individual, and MERMER detects information that may be possessed by more than one individual (for example, when there are several perpetrators of a crime).

If brain MERMER testing does become widely available and successful in the field, what will be the implications for criminal investigative procedures and training? Certainly, the brain MERMER testing procedure itself must be performed by a properly trained expert. In addition, like fingerprinting, DNA, and all other breakthroughs in investigation, the advent of brain MERMER testing will necessitate changes in the way crimes are investigated and will require investigators to learn new skills. Investigators who apply the MERMER technique will need to collect and preserve the specific kind of evidence demanded by the technique. This means that investigations must include, from the beginning, an expert trained to recognize and collect information from crime scenes specifically suited to identifying the perpetrator through brain MERMERs. This is probably the greatest challenge to the success of brain MERMER testing in the field.

When and if MERMER testing becomes a widely practiced technique, it could have significant implications for how, when, and whether cases are solved, and for the treatment of suspects. The goal of forensic science is not only to identify perpetrators correctly, but also to exonerate innocent suspects accurately, and to do so as quickly as possible and with a minimum of trauma and invasive procedures. From a human rights perspective, minimizing the time and trauma of investigative procedures is important in every case, and particularly important in the case of innocent individuals.

How does MERMER testing address these concerns? What MERMER testing may contribute in the case of an innocent suspect is an opportunity to prove his/her innocence early in the investigative process, thereby minimizing trauma and expense and avoiding possible negative outcomes such as invasive procedures, false conviction, and punishment. For an innocent suspect, the MERMER test consists of simply viewing words or pictures on a screen and pushing buttons in accord with the task instructions. The innocent suspect does not even know which items are relevant to the crime. The suspect does not answer any questions, make any statements, offer any testimony, hear any accusations, or submit to any invasive procedures.

In the case of a guilty suspect, what MERMER testing may contribute is an efficient means to correctly identify the perpetrator early in the investigative process, even when there is little or no physical or testimonial evidence. The fact that the technique is non-invasive and non-testimonial serves to increase its potential applicability for any suspect, whether guilty or innocent.

Brain MERMER testing is not an alternative to or substitute for fingerprinting, DNA, or other traditional investigative processes. It has almost nothing in common with "lie detection" or polygraphy. Polygraphy is a technique of interrogation and detection of deception. The interrogator asks questions and uses the polygraphy in an attempt to determine whether or not the suspect is lying, and to elicit a confession during the interrogation.

In contrast, MERMER testing is not a technique for interrogation or for the detection of deception. Brain MERMER testing does not require any questions of or any answers from the suspect. The subject neither lies nor tells the truth during the procedure, and in fact the results of MERMER testing are exactly the same whether the subject lies or tells the truth at any time. MERMER testing determines objectively whether or not certain information is stored in the brain, regardless of any false or truthful statements the subject may or may not make about it.

Like other scientific investigative techniques, brain MERMER testing is compatible with and complementary to all other viable technologies for solving crimes. Information and evidence obtained through several different technologies often provide a more complete and accurate picture than any one technology alone can provide.

MERMER testing has some physical requirements. During the testing itself, subjects must sit and view the screen in order for the data to be collected. Artifacts caused by occasional or minor movements can be eliminated in data analysis, but the subject must sit and refrain from major movements of the body for data collection to be possible.

Will brain MERMER testing potentially solve every case? No. Fingerprinting and DNA can determine scientifically whether or not a person was present at the crime scene in the small number of cases where fingerprints or DNA are available. Brain MERMER testing offers the promise of the same capability, even in cases where no physical evidence is available. As with every forensic science technology, however, there are limitations to the MERMER technology and cases where it is not applicable.

MERMER detects the presence or absence of information, not guilt or innocence *per se*. In some cases, a person may possess virtually all of the available information about a crime even though he/she is not a perpetrator. For example, in the course of interrogation investigators may make the mistake of revealing to a suspect information that they know about a crime before the MERMER test has been applied. In such cases, possessing crime-relevant information does not identify an individual as the perpetrator and, therefore, MERMER cannot be applied to solving the case. In this context, it is important that investigators take effective precautions to protect insofar as possible against revealing to the suspect the known details of a case before the MERMER test is run. Investigators may want to keep accurate records (e.g., tape recordings) of interactions with the suspect where relevant information may be exchanged.

MERMER would not be applicable in a case in which two suspects in an investigation were both present at a crime, but one was a witness and one was a perpetrator. MERMER can only detect information that places both at the scene of the crime; it cannot determine what their roles were there. (This is like a situation in which there are two sets of fingerprints at a crime scene.) The technique can narrow the field of suspects to two, but cannot definitively identify one of these as the perpetrator and exonerate the other. Note, however, that this would not result in a false positive outcome for the test, i.e., a correct information present determination would be compatible with a suspect's story that he was a witness. Crime-relevant information possessed by the subject for legitimate reasons is a limitation on the applicability, not on the accuracy, of the technique.

MERMER would not be definitive in a case in which investigators do not know sufficient information about a crime to be able to test a suspect for crime-relevant information stored in the brain. For example, authorities may suspect that someone has been stealing cash from a retail outlet, but may not know how much was taken, when, where, or how the crime took place. How often such cases will occur in the field is an empirical question that can only be answered by applying MERMER extensively in the field using properly trained personnel and investigative procedures designed to facilitate this new technique.

How many cases brain MERMER testing can solve overall and what will be the range of application of the technique in solving crimes remains, at this point, empirical questions that can only

be answered by widespread application of the technique in the field.

The opportunity to access the vast potential of the human brain as a storehouse of evidence; the promise that brain MERMER testing may be able to solve a wide variety of cases that now remain unsolved; the potential to solve cases more quickly, accurately, and effectively; and the opportunity to provide innocent suspects with a non-invasive, non-stressful, and reliable means to exonerate themselves call for extensive future research, both in the laboratory and in the field.

Conclusion

It would be inappropriate to generalize the results of the present research because of the small sample of subjects. The 100% accuracy and high confidence level of the results, however, provide further support for results from previous research using brain MERMER testing. The research reported here adds to the body of knowledge by accurately determining both the presence and absence of specific information relevant to real-life events in the lives of subjects, despite subjects' efforts to conceal that knowledge.

The usefulness of brain MERMER testing for law enforcement in detecting concealed knowledge should be explored further. One possibility for future studies would be to use as subjects incarcerated criminals who have exhausted their appeals and/or have confessed. In these cases there is an actual crime, and ground truth is known with a high level of certainty. With appropriate permission and observing all legal and ethical considerations, case files of these inmates could be reviewed to determine pertinent crime details that were available during the investigation. Stimulus sets of Targets, Probes, and Irrelevants could then be constructed and brain MERMER testing administered to determine whether or not the subject's brain responses indicate knowledge of known pertinent crime information. The same stimulus sets could be tested on subjects who have no knowledge of the specific crime. This would provide a test of the ability of brain MERMER testing to identify the perpetrator of an actual crime, using information actually available in the investigation of the crime.

Additional studies could explore the reliability of using auditory and pictorial as well as visual linguistic material as Probe, Target, and Irrelevant stimuli. Further studies using brain MERMER testing to detect real-life events under varying circumstances would also be valuable.

Determining responsibility for criminal acts is often a difficult challenge for investigators. Today's sophisticated crime scene analysis techniques can sometimes place the perpetrator at the scene of the crime; however, physical evidence is not always present. Without other aids, such as eyewitness testimony or a confession, investigators may develop a suspect, but have no way to confirm their suspicions.

Knowledge of numerous details of the crime, such as the murder weapon, the specific position of the body, the amount of money stolen—any information not available to the public—may reveal that a particular individual is associated with the crime. Additional research is required to determine if brain MERMER testing is a technique that could tell an investigator that a particular person possesses this detailed knowledge. Additionally, if research determines that brain MERMER testing is reliable enough that it could be introduced as evidence in court, it may be the criminal investigative tool of the future.

References

1. Gaillard AKW, Ritter W. Tutorials in event-related potential research: endogenous components. Amsterdam: North-Holland, 1983.
2. Picton TW. Handbook of electroencephalography and clinical neurophysiology: human event-related potentials. Amsterdam: Elsevier, Vol. 3, 1988.
3. Druckman D, Lacey JI. Brain and cognition: some new technologies. Washington, D.C.: National Academy Press, 1989.
4. Farwell LA, Donchin E. The brain detector: P300 in the detection of deception. *Psychophysiology* 1986;24:434.
5. Farwell LA, Donchin E. The truth will out: interrogative polygraphy ("lie detection") with event-related brain potentials. *Psychophysiology* 1991;28:531-41.
6. Bashore T, Rapp P. Are there alternatives to traditional polygraph procedures? *Psych Bull* 1993;113:3-22.
7. Farwell LA, Donchin E. The truth will out: interrogative polygraphy with event-related brain potentials. *Psychophysiology* 1988;25:445.
8. Wasserman S, Bockenholt U. Bootstrapping: applications to psychophysiology. *Psychophysiology* 1989;26:208-21.
9. Farwell LA, inventor. Method and apparatus for multifaceted electroencephalographic response analysis (MERA). US patent 5,363,858. 1994 Nov 15.
10. Rosenfeld JP, Nasman VT, Whalen I, Cantwell B, Mazzeri L. Late vertex positivity in event-related potentials as a guilty knowledge indicator: a new method of lie detection. *Int J Neurosci* 1987;34:125-9.
11. Rosenfeld JP, Cantwell B, Nasman VT, Wojdak V, Ivanov S, Mazzeri L. A modified, event-related potential based guilty knowledge test. *Int J Neurosci* 1988;42:156-61.
12. Rosenfeld JP, Angell A, Johnson M, Quan J. An ERP-based, control-question lie detector analog: algorithms for discriminating effects within individual's average waveforms. *Psychophysiology* 1991;28(3): 319-35.
13. Johnson MM, Rosenfeld JP. Oddball-evoked P300-based method of deception detection in the laboratory II: utilization of non-selective activation of relevant knowledge. *Int J Psychophysiol* 1992;12:289-306.
14. Allen JJB, Iacono WG. A comparison of methods for the analysis of event-related potentials in deception detection. *Psychophysiology* 1997; 34:234-40.
15. Allen JJB, Iacono WG, Danielson KD. The identification of concealed memories using the event-related potential and implicit behavioral measures: a methodology for prediction in the face of individual differences. *Psychophysiology* 1992;29:504-22.
16. Farwell LA. The brain-wave information detection (BID) system: a new paradigm for psychophysiological detection of information [unpublished doctoral dissertation]. Urbana-Champaign (IL): University of Illinois, 1992.
17. Farwell LA. Two new twists on the truth detector: brain-wave detection of occupational information. *Psychophysiology* 1992;29(4A):S3.
18. Farwell LA. Brain MERMERs: detection of FBI Agents and crime-relevant information with the Farwell MERA system. Proceedings of the International Security Systems Symposium; 1993; Washington, D.C.
19. Farwell LA, inventor. Method and apparatus for truth detection. US patent 5,406,956. 1995 Apr 18.
20. Farwell LA, inventor. Method for electroencephalographic information detection. US patent 5,467,777. 1995 Nov 21.
21. Farwell LA, Hernandez R. Brain-wave detection of concealed information. Office of Research and Development of the Central Intelligence Agency (CIA); 1993.
22. Farwell LA, Martinerie JM, Bashore TB, Rapp PE, Goddard P. Optimal digital filters for long latency event-related brain potentials. *Psychophysiology* 1993;30:405-12.

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