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Review Article

Neuroscientific and Biometric Methodologies in Forensic Contexts: A Critical Review

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Abstract

There has been registered a significant increase of neuroscientific and biometric methodologies applied to forensic procedures in recent years. This paper describes some of innovative techniques in the forensic field, such as: Polygraph with the Control Question Test and Infrared Technology, Functional Magnetic Resonance Imaging, Event-Related Potentials, Brain Fingerprinting Technology, Positron Emission Tomography, Polygraph with Guilty Knowledge Test, Autobiographical-Implicit Association Test, Machine Learning, Functional Near-Infrared Spectroscopy, Regional Cerebral Blood Flow. These methodologies are directed towards the investigation of specific areas of psychological-forensic interest. In particular, here will be disclosed methodologies aimed at identifying lies, detecting recidivist behaviours and identifying memory traces. The techniques outlined in their main aspects are of different types and can help in understanding human behaviour in forensic proceedings. Still, these techniques are actually under development and experimentation. They are promising in providing useful data in legal field but require further scientific validation, and their use is always recommended as an integration of other traditional evidence and methods. In the context of legal psychology, the techniques described appear to be valuable complementary tools in the pursuit of truth. It will be interesting to follow any future directions of research, with a specific request for studies that vary, depending on the characteristics of the defendant and on the nature of legal proceedings. In conclusion, this work presents a comprehensive review of emerging neuroscientific and biometric methodologies applied to forensic contexts. The topic is timely and relevant, and offers to readers a valuable overview of technologies and machine learning applications in forensic psychology.

Keywords

Neuroscientific Methodologies, Forensic Psychology, Lies, Recidivist Behaviors, Memory Traces

1. Introduction

Forensic psychology, in its assessment aspects [1], is a multidisciplinary field that shows great attention to the most up-to-date mental tests for its various areas of action [2] and also to the technological innovations [3, 4] that have emerged in recent years.

Criminal violent behaviour is the result of a combination of multiple factors of different nature: clinical factors, relational factors, and environmental factors [5].

Criminal behaviour can be influenced by substance use, lack of family support, association with deviant environments,

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precarious economic conditions, low education, unemployment, and housing instability. These factors correlate both with psychopathological relapse and with antisocial behaviour and violent recidivism [6, 7].

People convicted of crimes can present various psychopathological conditions. Some authors report a very high incidence of attention deficit hyperactivity disorder (ADHD) [8]. Many criminal acts stem from impulsive behaviours or loss of emotional control, such as anger [9].

In recent years, neurosciences in the forensic field have been particularly used to identify lies, detect traces of memory, or prevent recidivist behaviours [10].

2. Methodologies for Identifying Lies

2.1. Polygraph with “Control Question Test”

Polygraph with the "Control Question Test (CQT)" [11] and Infrared Technology are tools capable of detecting autonomic physiological activations (heart rate, blood pressure, respiration, sweating) associated with certain critical questions.

The Control Question Test involves applying four sensors to the subject: one around the chest and one on the abdomen to measure changes in the depth and rhythm of respiration, one on the arm to record heart activity, and one on fingers to detect even the smallest changes in perspiration. The CQT requires the subject to be asked both crime-related questions and control questions. If responses to the relevant questions show a significant increase in physiological responses (e.g., sweating, increased heart rate, etc.) compared to responses to the control questions, this may suggest that the person is lying.

Infrared technology, on the other hand, involves thermography capable of measuring the infrared emissions from the face.

This methodology, involving the polygraph and CQT, can provide useful information, but the accuracy of the results is not always clear; consequently, the reliability is not high. Factors such as stress, psychological variables and medical variables can influence the results [12].

2.2. Functional Magnetic Resonance Imaging (fMRI)

Functional Magnetic Resonance Imaging (fMRI) is a technique that detects brain activity in real-time [13]. It is based on measuring changes in cerebral blood flow associated with neural activity. fMRI captures images that show variations in blood oxygen levels. These images allow identification of brain areas involved in mental activity.

In the forensic field, the technique is used to study the brain areas activated during an interview or interrogation [14].

The brain areas associated with truth-telling and lying differ: lies tend to require more cognitive effort, activating areas such as dorsolateral prefrontal cortex (responsible for executive functions and planning), anterior cingulate cortex (involved in managing cognitive conflict), and parietal cortex (for controlling and manipulating information) [15]. Truthful responses do not tend to activate these areas strongly, since they do not require the same cognitive effort.

The fMRI technique offers several advantages over the polygraph, including: greater spatial precision (fMRI provides precise images of the brain areas activated, showing which brain regions are involved in the process of lying), direct monitoring of brain changes (fMRI allows real-time observation of changes in brain areas associated with lying), and no interference of stress related variables (sweating or heart rate).

Although fMRI can detect brain activity, it is not always clear whether a specific brain area is exclusively activated by lying [Schauer F.], since many of the same areas are involved in other cognitive processes, such as complex thinking or memory. There is a possibility of false positives [16]: sometimes brain activity can be influenced by anxiety, disbelief, or fatigue factors.

The use of fMRI in courts is a subject of debate, and its application in legal or investigative practices is not yet established. Moreover, this technique requires specialized and expensive equipment, yet the interpretation of results is not always clear. Further studies are needed to advance this area of research.

2.3. Event-Related Potentials (ERPs)

Event-Related Potentials (ERPs) are a neurophysiological technique used to study the brain’s response to specific stimuli [17]. This methodology uses electrodes placed on the scalp to record the electrical activity that occurs in response to sensory, cognitive, or motor events [18].

ERPs are recorded applying surface electrodes on scalp. The evoked potential consists of a specific variation of bioelectrical signal that follows a stimulation of a sensory pathway or a motor event. It embraces oscillation of the electric potential and has a waveform characterized by a series of positive or negative deflections, defined *components.*

ERPs various components occur at specific time intervals after the stimulus is presented. These components are generally classified basing on their latency (the time between the stimulus and the brain's response) and their polarity (positive or negative).

Some of the most studied components [19] include:

a) N100: A negative component that appears about 100 milliseconds after the stimulus. It is related to the initial processing of sensory information.
b) P300: A positive component that appears about 300 milliseconds after the stimulus. It is often associated with attention and decision-making processes.
c) N400: A negative component that appears about 400 milliseconds after the stimulus, generally linked to linguistic and semantic processing.

Differences in ERPs between truth and lies can be used to identify deceptive behaviour [20]. Some research suggests that lying can alter specific ERP components, such as N100, N400, and P300, reflecting an increase in cognitive activity and emotional conflict [21].

The use of ERPs for lie detection is still under research but has the potential to overcome some of limitations of the polygraph. ERPs are less susceptible to external manipulations or influences such as anxiety or nervousness because they directly measure brain activity related to the cognitive process of lying [22].

Regarding the limitations of the method, it can be said that ERPs may be influenced by psychological variables (e.g., intense emotions or fatigue) or psychiatric conditions [23] (e.g., depression, Attention Deficit Hyperactivity Disorder, anxiety disorders, schizophrenia) and are not always definitive in determining whether someone is lying. Moreover, the interpretation of the data requires highly qualified experts.

Further studies are needed to determine their reliability and practical applicability in the forensic and investigative contexts [24].

2.4. Brain Fingerprinting

Brain Fingerprinting is a neuroscientific technology developed to identify whether an individual recognizes specific information related to a crime, in order to determine if he/she has knowledge of particular details of an event. The technique is based on measuring brain waves to record the brain's cognitive response when exposed to information that the subject has previously encountered. It can be used in forensic investigations to determine whether a person is involved in a crime, without asking directly to tell the truth.

The scientific principle behind Brain Fingerprinting is based on the fact that the human brain responds distinctively when it recognizes information that is already known or relevant [25]. If a person is involved in a crime or has knowledge of specific details related to a crime, the brain will respond differently than the brain of a person who has no access to that information.

During a Brain Fingerprinting test, the subject is presented with specific visual or verbal stimuli related to details of the crime, such as photographs, words, locations, events or other information that should be known to the perpetrator but not to an innocent person. For example, in a robbery case, an investigator may show images of the crime scene or words representing objects used during the crime.

The test relies on a device called an EEG (electroencephalogram) or, in some cases, other neuroimaging techniques that monitor the brain's electrical activity. When a person recognizes information, the brain generates a spike in activity that can be measured and recorded through electrodes placed on the scalp. The physiological response is typically associated with a specific brain wave, known as P300 (a brain wave that indicates the recognition of a stimulus), which occurs when the brain reacts to relevant information.

If the brain of a suspect shows a P300 response or other distinctive responses when stimuli related to the crime are presented (e.g., specific details known only to the person who committed the crime), this could suggest that the suspect has detailed knowledge of the event (in other words, the person may be involved in the crime). If the person does not recognize the details, there will be no significant brain response.

In forensic settings, Brain Fingerprinting has been proposed as a useful tool in investigations to identify perpetrators of crimes or to exclude innocent suspects. It is particularly useful in scenarios where the investigation focuses on specific details that only the perpetrator can know, such as:

a) Specific details of the crime scene;
b) Objects used in the crime;
c) Details of a victim or witnesses.

Since it focuses on specific crime details, Brain Fingerprinting can be used to exclude suspects unaware of certain facts, reducing thereby the risk of false accusations [26]. Additionally, the method has been considered promising for identifying those with direct knowledge of a crime, improving the accuracy of identifying the perpetrator.

Despite its potential, Brain Fingerprinting is not yet widely accepted as evidence in courts. Its legal validity is a subject of debate, since not all legal systems are ready to consider it a definitive proof method.

The method only works if the subject has actual knowledge of relevant details. In some cases, a suspect may not have an access to specific information even if he/she is involved in a crime. Thus, the effectiveness of the test could be reduced.

Brain activity can be influenced by various factors, such as anxiety, stress or psychological conditions. The brain response may not always be directly related to truth or falsehood; still other explanations may justify the recorded responses. Brain Fingerprinting requires advanced equipment, such as EEG and specialized software, which are expensive and not always readily available. This limits its large-scale application. Brain Fingerprinting is a promising neuroscientific methodology in the field of lie detection in forensic settings, but its application is still in development and experimental stages. Future advancements in neuroscience and brain imaging technologies could further improve reliability and adoption of this technique.

2.5. Positron Emission Tomography (PET)

Positron Emission Tomography (PET) is a diagnostic neuroimaging technique that uses a radiopharmaceutical to provide three-dimensional images of brain metabolic activity [27]. This tool detects areas with increased blood flow, which correspond to regions with higher neural activity. PET can be used, for example, to observe brain activity during an interrogation and identify brain areas involved in processing truth and/or lies in real time [28].

When a person lies, brain areas involved in executive function, cognitive monitoring and inhibitory control (such as the dorsolateral prefrontal cortex) tend to show increased activity.

The main brain areas involved in lying, as detected by PET [29], are:

1) Dorsolateral Prefrontal Cortex (DLPFC): this region is crucial for cognitive control, planning, and processing complex responses. During lying, this area may become more active because the brain has to process false information and suppress the truth.
2) Anterior Cingulate Cortex (ACC): the ACC is involved in monitoring cognitive conflict and integrating emotional information. When lying, there may be a conflict between truth and lies, leading to greater activation in this area.
3) Parietal Cortex: involved in managing spatial and sensory information, but also in integrating complex mental information. Activation in this region may be related to the attempt to construct a coherent story while lying.

However, there are limitations. The brain areas associated with lying may also be activated for other reasons, such as morphological changes in the brain or very strong emotional states. Additionally, PET has "low timing": unlike functional magnetic resonance imaging (fMRI), that provides near real-time data, PET has lower temporal resolution, making it less suitable for observing rapid changes in brain activity during an interrogation. Finally, PET is costly and invasive because it requires the injection of radioactive isotopes.

In conclusion, due to its limitations, such as high costs, invasiveness and temporal resolution, PET is not yet widely used for lie detection, although it remains an interesting area of research in cognitive neuroscience [30].

3. Methodologies for Memory Detection (Memory Detection)

Neuroscientific techniques are also used for memory detection, aiming to trace memory traces in a crime related subject.

3.1. Polygraph with "Guilty Knowledge Test" (GKT)

The polygraph with the "Guilty Knowledge Test" (GKT) is a more reliable polygraph procedure than the previously described Control Question Test (CQT) [31].

During the test, the polygraph monitors physiological responses such as heart rate, respiration, and skin conductance (a measure of sweating). The subject is shown some images or asked questions related to the crime, both relevant and irrelevant.

The GKT is based on the idea that a guilty person possesses secret knowledge (the "guilty knowledge") that only he/she could know (for example, specific details of a crime that have not been made public). If a person is involved in a crime, he/she is likely to show a stronger physiological reaction (e.g., changes in heart rate, sweating, breathing) when presented with secret details related to the crime, compared to general or irrelevant information.

The GKT can be a useful complementary tool in investigations, providing additional information about a suspect's knowledge that might not emerge during an interrogation. However, false positives are possible: in some cases, a person may show a strong physiological response even if not guilty, for example, due to nervousness, fear of being falsely accused or simply because they have heard about the crime in question [32].

In conclusion, the Guilty Knowledge Test (GKT) is an interesting and effective method for detecting knowledge of secret crime related details. It has been used in cases such as murders, robberies or sexual assaults. However, its use has been limited, and due to its limitations, it is generally used as a complementary tool in investigations rather than as definitive proof of guilt [33].

3.2. Autobiographical – Implicit Association Test (IAT)

The Autobiographical – Implicit Association Test (IAT) is an indirect measurement tool that establishes associations between concepts based on reaction times to responses. It consists of a computerized test during which the subject is asked to classify stimuli appearing on the screen, with two available response options to be selected as quickly as possible. At the end of the test, the reaction times for the two types of questions are compared. If inconsistencies between reaction times, that should be identical, are found, the subject's response to the critical question is hypothesized to be false.

The theory behind this application is based on the assumption that lies, especially those concerning autobiographical events, may be accompanied by cognitive conflicts that emerge in an individual's implicit responses [34].

The Autobiographical IAT focuses on how a person associates their personal experiences to specific concepts, such as truth and lies. This test could be adapted to detect inconsistencies between what a person claims (lies) and what his/her implicit associations suggest (the truth).

The Implicit Association Test measures the strength of automatic associations between concepts (e.g., "good" and "bad") and categories (such as "me" and "the other"). The test is based on the idea that when two concepts are associated in a person’s mind, the responses to certain word or image combinations will be faster than others, associated less strongly. The speed of the response is therefore an indicator of the strength of the implicit association.

Unlike traditional lie detection methods (such as the polygraph), the IAT is able to reveal implicit associations, that is, what a person may not be consciously aware of feeling or thinking.

Implicit responses may be influenced by a variety of emotional and cognitive factors that are not directly related to truth or lies. For example, the person may be stressed or anxious for reasons unrelated to the content of the question, so affecting the final results [35].

In conclusion, the technique is promising, but the reliability of the IAT in detecting lies, especially in forensic contexts, is still under study.

4. Methodologies for Identifying Recidivist Behaviours

4.1. Machine Learning

Machine Learning is a subset of artificial intelligence (AI) in which computers learn from data and improve with experience without being specifically programmed [36]. A research group from the MacArthur Network at Stanford, led by neuroscientist Anthony Wagner, explored potential ways to employ machine learning to fMRI scans analysis, to identify when a subject recognizes someone he/she is acquainted with, while observing certain photographs. Test participants were placed inside an MRI scanner and shown a series of images, some taken with a camera they wore around their neck, others from cameras assigned to others. Through the analysis of variations in blood oxygenation levels – an indicator used to assess neuron activation – the machine learning algorithms developed by the team have correctly distinguished instances, in which subjects were viewing images from their own life or someone else's life, with more than 90% accuracy [37].

In summary, the technique uses algorithms to analyse large amounts of data and identify patterns and correlations. When applied to recidivist behaviours, machine learning attempts to predict the likelihood that an individual will commit a crime again, basing on various factors, such as: demographic data, socioeconomic conditions, criminal history, rehabilitation treatments and programs, individual psychology and psychopathology, and behavioural monitoring in prison.

Some machine learning techniques used to analyse recidivist behaviours include: supervised classification (e.g., Support Vector Machines [38], Random Forest [39], K-Nearest Neighbours [40], and Logistic Regression [41]), neural networks and deep learning, regression models (logistic or linear regression [42]), clustering and group analysis (K-means clustering [43]), and reinforcement learning [44].

Owen D. Jones declares: "At this stage, it's merely a proof of feasibility, but theoretically, it represents a biomarker for recognition"; and further adds: "We can imagine multiple legal implications" [45]. One day, such indicators could help assess the accuracy and reliability of eyewitness memory. Neuroscientists hope to better understand the biological correlates of recidivism – for example, Kiehl analysed thousands of fMRI and structural MRI scans conducted on inmates in high-security prisons in the United States to see if the brains of people who committed new crimes (or were re-arrested) appeared different from those of non-recidivists. The ability to quantify the likelihood that a criminal will commit a new crime in the future is crucial for the success of inmate rehabilitation states the author [46].

In conclusion, machine learning holds great potential for predicting recidivist behaviours. However, the use of such technologies must be approached with caution, considering data biases and ethical implications. With these premises, machine learning could represent an important resource for reducing recidivism and improving the justice system in a not-too-distant future [47].

4.2. Functional Near-Infrared Spectroscopy

The functional Near-Infrared Spectroscopy (fNIRS) has been regarded as a complementary technique to fMRI and EEG to assess brain activity [48].

In a study [49], aggression in subjects diagnosed with behavioural addiction (BA) was implicitly assessed using the point subtraction aggression paradigm (PSAP) test along with measurements of oxy- and deoxyhaemoglobin dynamics in the prefrontal cortex (PFC) during the test, using functional near-infrared spectroscopy.

Although no apparent increase or decrease in haemoglobin concentrations was observed in the PFC of either BA patients or healthy control subjects, abnormal correlations within the PFC network were present in BA patients.

An insufficient number of researches using fNIRS to elucidate the neural basis of aggressive and violent behaviour suggests that these findings require further study.

4.3. Regional Cerebral Blood Flow and AI

The study correlates the use of neuroimaging and AI to predict recidivism. The authors of this study [50] suggest improvements in predicting recidivism in forensic psychiatry by incorporating neuroimaging data into AI-based risk assessment models.

Specifically, the authors demonstrated that the inclusion of resting regional cerebral blood flow (rCBF) measurements in an extended AI-based prediction model containing neural measurements from eight brain regions resulted in increased predictive performance compared to traditional empirical risk factors in a long-term follow-up of forensic psychiatric patients.

The nature of antisocial and criminal behaviour is complex and dynamic, and blood flow measurements in a single specific brain region likely explain only a small portion of the variance in criminal behaviour.

In summary, preliminary results of AI-based neuroprediction studies have produced promising results. However, although the technique is interesting and promising, it is still unreliable and requires further study.

5. Conclusions

There is a rapid increase in neuroscientific methodologies applicable in forensic settings, focusing on the study of the brain and physiological responses to provide "objective evidence." Techniques like EEG, fMRI, PET, etc., offer new perspectives on the knowledge of individuals involved in legal proceedings.

Neuroscientific methodologies in the forensic field promise various outcomes such as lie detection, detecting knowledge or memory of crime details, understanding and predicting recidivist behaviours, and measuring criminal responsibility.

However, among the media and legal and scientific communities, it also raises questions about the potential effects that the results of such tools might have on legal decisions.

In this article, we provide a brief review of recent neuroscientific techniques that could be applied in forensic settings.

Neuroscientific methodologies are diverse and growing, offering new tools and approaches to understanding criminal behaviour, criminal responsibility, and the veracity of statements in legal contexts.

Overall, the studies are promising for assisting evidence. Still, caution is necessary.

Factors such as diagnoses of mental disorders and perceived dangerousness may moderate or alter some results. Some authors are concerned about the prospect of "neurohype" and the possibility that lawyers or judges may overestimate scientific evidence [51].

Stephen J. Morse, an expert in law and psychiatry at the University of Pennsylvania, states: "The most important question is whether the evidence is legally relevant. That is, does it contribute to answering a specific legal question?" The author believes that neuroscience will never revolutionize law because "actions speak louder than images" and because, in a legal context, "if there is a conflict between what neuroscience shows and what behaviour shows, I must take the behaviour into account" [52].

In legal psychology, the techniques described, however, appear to be useful "complementary tools" in the pursuit of truth. It will be interesting to follow any future directions of research, with a specific request for studies that vary, depending on the characteristics of the defendant and on the nature of legal proceedings.

In our opinion, a balanced approach to the issue is desirable, also to avoid the risk of biological determinism and a deterministic view of normal or criminal human behaviour.

Abbreviations

ADHD	Attention Deficit Hyperactivity Disorder
CQT	Control Question Test
fMRI	Functional Magnetic Resonance Imaging
ERPs	Event-Related Potentials
EEG	Electroencephalography
PET	Positron Emission Tomography
DLPFC	Dorsolateral Prefrontal Cortex
ACC	Anterior Cingulate Cortex
GKT	Guilty Knowledge Test
IAT	Implicit Association Test
AI	Artificial Intelligence
fNIRS	functional Near-Infrared Spectroscopy
BA	Behavioural Addiction
rCBF	regional Cerebral Blood Flow

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Giuseppe Manuel Festa: Conceptualization, Writing – review & editing

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Conflicts of Interest

The authors declare no conflicts of interest.

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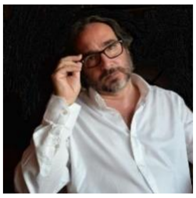
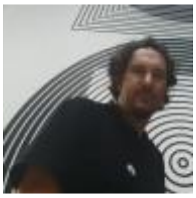
Biography



Giuseppe Manuel Festa is a Psychologist, Specialist in Clinical Psychology, Psychotherapist, Phd in Advanced Methodologies in Psychotherapy and Psychopatology, expirienced Court Expert. Over the years, he has taught at different level courses in various universities (Catholic University of the Sacred Heart in Rome, LUMSA University/Humanitas University Consortium in Rome, etc.), engaged in the field of psychodiagnostics, psychotherapy, clinical and forensic psychology. Actually, he is University Professor and Director of the Postgraduate Course of Psychodiagnostics in the Clinical and Legal Fields at the Pontifical Faculty of Educational Sciences «Auxilium» of Rome. Also, he runs the Interdisciplinary Institute of Advanced Clinical Training «IACT» in Rome and directs Scientific Editorial Series, he is actual Member of the Editorial and Scientific Committee of several journals. He is author of numerous scientific works (publication-range: 2002-present) in journals, chapters of books, volumes and mental test. He is cited and recognized by the Scopus, Web of Science and Google Scholar databases.



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Research Field

Giuseppe Manuel Festa: Psychodiagnostics, Mental Tests, Forensic Psychology, New Technologies in Psychology, Advanced Methodologies in Psychotherapy.

Iginio Sisto Lancia: Clinical Psychology, Psychodiagnostics, Bio and Neurofeedback, Behavioral Addictions, Criminology.