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Advancing Clinical Neuroassessment: The BrainView ERP Platform in Aging and Cognitive Dysfunction Diagnosis and Monitoring

Annie TL Young[1], Slav Danev[2] and Jonathan RT Lakey[1]

[1]*Department of Surgery and Biomedical Engineering, University of California Irvine, California, USA.*

[2]*Medeia Inc, Santa Barbara, CA, USA.*

***Correspondence:**
Jonathan RT Lakey, PhD, MSM, Department of Surgery, 333 City Blvd West, Suite 1600, Orange, California, USA, Phone: 1-949-824-8022, Fax: 1-714-456-6188.

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ABSTRACT

The increasing demand for objective, neurophysiological tools to assess brain function in clinical settings has led to the development of advanced technologies, such as the BrainView qEEG discriminant database by Medeia Inc. The BrainView system provides a comprehensive approach to understanding cognitive processing changes due to aging and pathological conditions. This platform leverages key biomarkers like the N100, P300, and N400 event-related potentials (ERPs) to identify electrophysiological abnormalities and offer insights into cognitive processing across aging and neurological disorders. Age-related cognitive decline is often marked by alterations in these ERP components, particularly in attention, memory, and semantic processing. However, ERP alterations are more severe in pathological aging and disease. Additionally, these ERPs have proven essential in understanding conditions such as traumatic brain injury (TBI), schizophrenia, autism spectrum disorder (ASD), stroke, Alzheimer's disease (AD), and others. The BrainView system's ability to detect subtle changes in brain function makes it a critical tool for early diagnosis, monitoring disease progression, and evaluating therapeutic interventions. With its extensive dataset, advanced statistical methods, and clinical focus, BrainView aids clinicians in making more informed decisions regarding patient care. As the database expands to include additional disorders, its role in personalized medicine and improving patient outcomes is set to grow. The BrainView ERP Platform represents a transformative advancement in neurophysiology and neuropsychology, offering a comprehensive, efficient, and accurate solution for brain health assessments, ultimately paving the way for a new standard in clinical neuroassessment.

Keywords

BrainView, qEEG, Event-related potentials, ERP, Cognitive processing, Neurophysiology, Neurological disorders, Neuro-degenerative disorders, Clinical assessment, N100, P300, N400.

Introduction

Brain function evaluation is a critical challenge in healthcare, as brain disorders affect roughly one in three people worldwide [1]. Reliable, objective measures of brain function, especially in clinical settings, are in high demand. Event-Related Potentials (ERPs), measured via electroencephalography (EEG), show promise as a "vital sign" for the brain. Despite extensive research supporting their reliability, ERPs remain underutilized in clinical practice [2-8]. EEG, the first non-invasive method for measuring human brain activity, has evolved significantly over time. Early studies focused on sensory processing and simple detection tasks, and with the advent of signal averaging, ERPs became a cornerstone of cognitive neuroscience [9-22]. ERPs offer excellent temporal resolution, making them valuable for detecting subtle cognitive abnormalities sometimes even before clinical symptoms appear [23]. However, their spatial resolution is limited, hindering precise localization of neural activity [24]. Despite this limitation, ERPs complement imaging techniques due to their superior temporal resolution. ERPs are small voltage changes in the brain in response to stimuli, such as sounds or words, providing insights into sensory and cognitive processes [4,23]. These responses are measured on a millisecond (ms) scale, which is essential for studying rapid cognitive processes like attention and perception.

EEG signals arise from postsynaptic activity in neural ensembles, primarily cortical pyramidal cells, which generate electrical potentials that propagate throughout the brain [9,25,26]. Despite advances in neuroimaging, ERP remains a key tool for studying cognitive processing.

Evoked Potentials (EPs) capture time-locked brain responses associated with specific cognitive, sensory, or motor events [27]. Unlike non-task-based quantitative EEG (qEEG), ERPs are task-based, correlating neuronal activity with cognitive functions such as working memory and executive function. The ERP waveform reflects the integrated synaptic activity of neurons firing synchronously, offering a neural correlate for cognitive processes [28].

This research led to the development of the BrainView ERP Platform by Medeia Inc. **[5,6].** BrainView aims to integrate ERPs into clinical practice by offering a portable, FDA-cleared system that delivers automated, standardized, and clinically intuitive results. The platform measures three key ERPs the N100, P300, and N400 which correspond to sensory, attention, and cognitive processes, respectively [7,8,29]. These ERPs are triggered by specific stimuli, providing a rapid, quantifiable assessment of brain function.

ERP components reflect the brain's processing of stimuli over time. Early components, such as the N100, are associated with sensory and perceptual processing, often occurring without conscious attention. Later components, like the P300 and N400, relate to cognitive processing, typically requiring conscious attention. However, certain cognitive ERP components can occur even without conscious awareness [30]. The N100, P300, and N400 responses are sensitive to changes in brain function, making them valuable for monitoring cognitive health and detecting subtle changes not always visible through traditional behavioral tests [2,29,31-36]. Current methods for evaluating cognitive function, such as the Mini-Mental State Exam (MMSE), are subjective and error-prone, with misdiagnosis rates as high as 43% [2]. This highlights the need for objective, reliable measures of cognitive impairment. ERPs, as time-locked neural responses, offer precise information about brain processes, complementing behavioral measures [37]. They are particularly valuable in cases where participant responses are difficult to obtain, such as with infants or minimally verbal individuals [37].

Technological advancements in portable EEG devices and software have made ERPs more accessible outside of research laboratories, transitioning them into clinical practice [38-40]. The BrainView Platform seeks to make ERP assessments practical for clinical use, offering new insights into cognitive function and establishing a robust framework for brain health monitoring.

ERPs provide several advantages in research, particularly when behavioral data is difficult to obtain or inadequate for capturing underlying brain processes. For example, ERPs can detect auditory discrimination in infants, where traditional behavioral tests are not feasible [41,42]. They also serve as biomarkers for early diagnosis and monitoring of disorders such as autism, language disorders, and dyslexia, although further research is needed for widespread clinical use [37]. Additionally, ERPs contribute to foundational research on brain processing of language and sensory integration [43-45]. As neurological disorders and aging become more prevalent, the need for objective measures of brain health intensifies. This paper explores the role of ERPs specifically the N100, P300, and N400 components in assessing brain disorders. It examines how abnormalities in these components aid in the detection of neurological disorders, discusses the significance of each ERP component, and introduces the BrainView ERP Platform as a tool for measuring these responses. Furthermore, the paper explores how aging affects cognitive function and ERP responses, highlighting the correlation between aging and cognitive decline.

BrainView QEEG/ERP Discriminant Database

Medeia Inc. is tackling a long-standing challenge in clinical neurophysiology: the construction of a reliable, normative quantitative EEG (qEEG) database. Over the years, creating such databases has proven difficult, mainly due to the complexity of defining a "normal" population and the lack of standardized procedures in the field. Despite these challenges, Medeia is pioneering a solution with the BrainView ERP Platform, which incorporates a qEEG discriminant database complete with patient profiles [46]. This platform is developed according to rigorous scientific and methodological standards, closely following existing normative databases but with significant improvements in scope and precision.

Normative and discriminant qEEG databases are crucial in clinical science, providing a benchmark for comparing an individual's EEG metrics with those of a representative population. This comparison helps clinicians identify electrophysiological abnormalities that may indicate various brain disorders. However, these databases are not standalone diagnostic tools. Proper interpretation requires a holistic approach, considering factors such as patient symptoms, medications, and age-related changes. Medeia's goal is to enhance clinical assessments by integrating advanced tools like ERPs with key EEG metrics, thus improving diagnostic accuracy.

BrainView is a comprehensive solution designed to assist in clinical EEG assessments (Figure 1). With FDA 510K clearance (K192753, K212684), international patents, trademarks, and educational resources, BrainView is already deployed in over 800 clinical and research centers across the United States. The platform's strength lies in its ability to provide a detailed and accurate view of an individual's brain function through the integration of qEEG metrics, such as Z-scores for power, asymmetry, coherence, and phase, alongside ERPs like N100, P300, and N400 biomarkers critical for tracking cognitive processes.

BrainView's database is built from a large and diverse dataset, including data from more than 60,000 subjects in the eyes-open-closed state, ranging from ages 4 to 85 [46]. This extensive dataset forms a solid foundation for accurately detecting and differentiating abnormal EEG values, which is essential for clinical

assessments and monitoring disease progression. Additionally, the ERP biomarkers are pivotal in tracking brain function and cognitive changes, making BrainView a powerful tool for assessing a wide range of brain disorders, including Alzheimer's disease, attention-deficit/hyperactivity disorder (ADHD), post-traumatic stress disorder (PTSD), schizophrenia, and others. A key feature of BrainView is its discriminant function, which allows clinicians to classify patients based on their EEG and ERP profiles. This functionality is vital for early diagnosis, tracking disease progression, and evaluating treatment outcomes. ERPs, in particular, can help detect subtle cognitive impairments that may otherwise go unnoticed, offering clinicians valuable insights into a patient's brain health. Looking ahead, Medeia Inc.'s plans to expand the BrainView discriminant database to cover a broader range of neurological, developmental, and mental health disorders. The continued integration of ERPs alongside traditional qEEG metrics will further enhance personalized medicine approaches in neuropsychological assessments, ultimately improving diagnostic accuracy and patient outcomes.

Figure 1: An image of the BrainView Neural Scan System developed by Medeia Inc. The BrainView system is portable, easy-to-use, and non-invasive. The BrainView system is a 21-channel EEG/ERP amplifier with a dedicated laptop and testing supplies. The system utilizes high-quality circuit boards and components to allow for high-quality brain measurements, as well as essential heart rate variability data.

In conclusion, BrainView represents a significant advancement in clinical EEG assessments. By incorporating ERPs such as N100, P300, and N400 into its discriminant database, it provides a much more nuanced and accurate tool for detecting and monitoring brain disorders. This not only aids in early diagnosis and disease tracking but also supports the evaluation of treatment efficacy. With its extensive database and sophisticated analytical tools, BrainView is poised to become the gold standard in neurophysiological and neuropsychological assessments, revolutionizing the way clinicians approach brain health.

The BrainView Technology

BrainView is an innovative platform designed to advance the science of brain vital signs through cutting-edge technology. Operating in just 25 minutes, it seamlessly integrates with cloud technology, facilitating efficient client management (Figure 2a and 2b). BrainView enables rapid, objective, and automated recording and analysis of EEG and ERP data, using portable devices to collect, process, store, and report brain metrics. Its core feature is the use of ERPs to assess cognitive function by comparing an individual's results to established reference ranges, providing valuable insights into brain health and cognitive well-being.

Figure 2a: Patient preparation for a BrainView clinical EEG assessment.

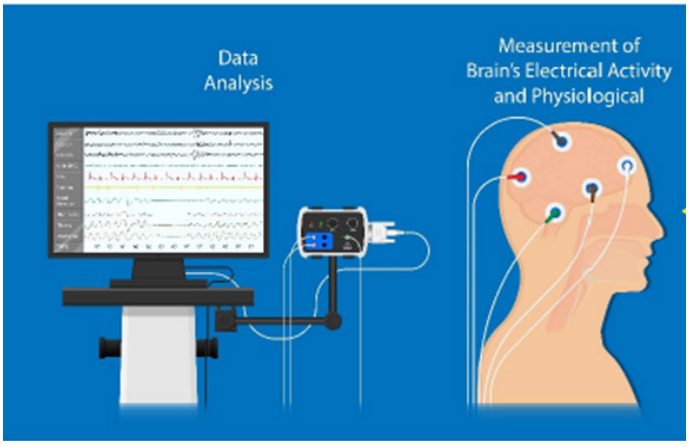

Figure 2b: An illustration of a BrainView setup for an EEG test, where brain electrical activity is measured during a qEEG.

ERPs are brain responses to specific stimuli, measurable via EEG, offering objective and quantifiable data on brain activity, including cognitive impairments. They have been validated for assessing concussion-related brain dysfunction [2-4,47,48). Traditional ERP methods, however, are often time-consuming and require controlled laboratory environments, limiting their applicability in real-world settings.

To overcome these limitations, Medeia Inc. developed BrainView — a rapid, portable, and semi-automated system designed for quick deployment in clinical assessments. With over 25 years of research, BrainView leverages scientifically validated ERP responses as objective indicators of cognitive brain function. By integrating ERP data with cloud-based technology, the platform provides a reliable, portable, and automated system for assessing cognitive health in various environments. Key ERP metrics measured by BrainView include the N100 (auditory sensation), P300 (basic attention), and N400 (cognitive processing). Figure 3 demonstrates how these metrics are used to differentiate between healthy individuals and those with diseases, such as traumatic brain injury (Figure 3a), as well as between younger and older individuals (Figure 3b).

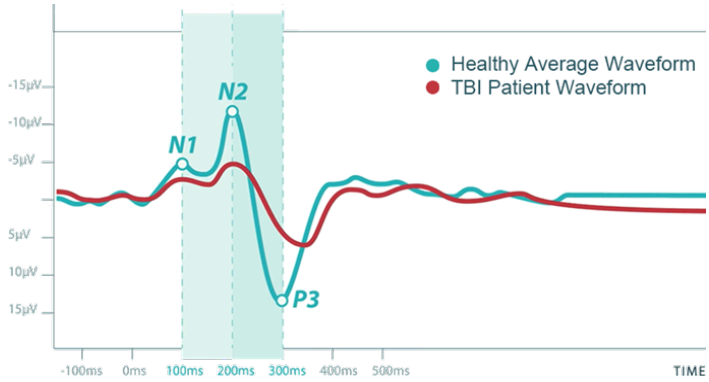

Figure 3a: An example of how BrainView utilizes ERP metrics to distinguish between a healthy individual and one with disease (e.g., traumatic brain injury).

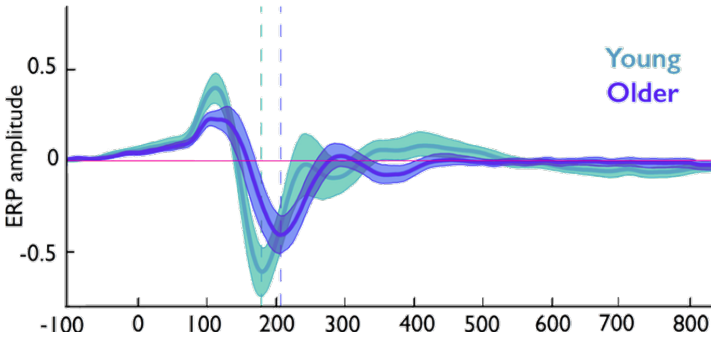

Figure 3b: An example of how BrainView uses ERP metrics to differentiate between the health of younger and older individuals.

Key ERP Components and Their Roles in BrainView

1. N100 (Auditory Sensation): The N100 waveform peaks around 100 ms after an auditory stimulus, reflecting early sensory processing. BrainView measures responses to deviant (louder) versus standard (quieter) tones, offering insights into the timing and intensity of auditory processing. The platform compares these responses to reference data, providing valuable feedback on auditory sensory function.
2. P300 (Basic Attention): The P300 is a positive waveform that peaks around 300 ms after exposure to unexpected auditory stimuli (e.g., deviant tones). BrainView quantifies both the timing and magnitude of P300 responses, detecting variations such as dual-peak configurations, which might indicate changes in attention or cognitive processing. The P300 serves as a crucial measure of attention and perception, remaining stable over time for individuals.
3. N400 (Cognitive Processing): The N400 waveform peaks around 400 ms after a stimulus, reflecting cognitive processing related to language and semantic integration. BrainView measures responses to both congruent and incongruent word pairs, with the N400 waveform exhibiting a broader peak compared to the N100 and P300.

Quantifying ERPs: Amplitude and Latency

ERPs are characterized by two main factors: amplitude and latency.

- Amplitude (magnitude) refers to the size of the electrical voltage change in microvolts (μV), indicating the number and synchronization of cortical neurons involved in generating the response. Larger amplitudes suggest greater neuronal involvement, although higher amplitude does not always indicate a better response excessive activation may be linked to conditions like noise sensitivity.
- Latency (timing) measures the time it takes for the ERP response to peak (in milliseconds), providing insight into the speed of cognitive processing. Faster latencies indicate quicker sensory, attentional, and cognitive processing, while slower latencies may reflect delays, such as those seen in sensory hearing loss.

BrainView simplifies the interpretation of ERP data by measuring both latency and amplitude of key components. The platform captures voltage changes with millisecond precision, ensuring high temporal resolution for assessing the brain's rapid responses to stimuli.

In summary, BrainView accelerates and simplifies the process of brain health evaluation. By measuring auditory sensation, attention, and cognitive processing, it provides a comprehensive view of cognitive function, delivering actionable results that are easy to interpret for decision-making in clinical assessments.

Introduction to ERPs

ERPs are brain responses to specific stimuli, measured using EEG [37]. ERPs are derived by averaging time-locked EEG activity, reflecting the collective electrical activity of thousands of neurons, especially postsynaptic potentials from cortical pyramidal neurons [4,49]. To isolate the brain's response to a stimulus, EEG signals are synchronized with the event. Since raw EEG signals include noise from unrelated neural activity and external interference, the stimulus is presented multiple times, and the responses are averaged to produce a clearer signal. ERPs reflect a range of cognitive processes, from sensory input to behavioral responses. This includes anticipatory activities like the Contingent Negative Variation (CNV), which prepares the brain for task-related stimuli [13,22,50]. Signal averaging techniques and standardized electrode

placements, such as the 10/20 system, have made ERPs widely used and replicable [17,51-54]. Cognitive EPs, or ERPs, are reliable measures of cognitive function and are part of the "brain vital sign" framework [2,40,55]. Key auditory ERP components N100, P300, and N400 are used to assess sensory processing, attention, and cognitive processing, respectively, offering a sensitive, objective way to track brain function [13,21,35,56-58].

N100: Auditory Sensory Processing and Attention

The N100 (or N1) is a negative deflection in the ERP waveform occurring between 80 ms and 120 ms after an auditory stimulus [59]. It is primarily generated in the supratemporal auditory cortex, with maximal amplitude recorded over fronto-central scalp regions [59,60].

The N100 reflects early neural responses to sensory stimuli, especially those involving sudden changes in the auditory environment, such as shifts in intensity or the onset/offset of sounds [61,62]. It is typically evoked by unpredictable stimuli, regardless of task demands, and is most commonly observed in response to auditory stimuli, though it can also be elicited by visual, olfactory, somatosensory, and pain stimuli [63-68].

The N100 is recorded in sensory detection tasks like dichotic listening, where participants focus on one ear's information while ignoring the other [69]. Its amplitude is influenced by factors like stimulus intensity, frequency, and interstimulus intervals [70-73]. Additionally, selective attention and arousal affect the N100, with smaller amplitudes when the stimulus is expected [69,74-76].

As an early, automatic response, the N100 signals the brain's initial allocation of attention and sensory processing, making it relevant for studying auditory attention and stimulus detection [77,78]. Developmentally, the N100 undergoes changes that are significant for understanding speech processing and cognitive development, especially in children [79,80].

In clinical populations, alterations in the N100, such as decreased amplitude or delayed latency, are linked to sensory processing disorders or attention deficits, commonly observed in conditions like autism and schizophrenia [76]. The N100 plays a key role in early auditory processing, attention allocation, and sensory detection. It is sensitive to factors such as stimulus unpredictability and attentional focus, making it valuable for studying sensory and attentional mechanisms in both normal and clinical populations.

P300: Cognitive Processing and Attention

The P300 (or P3) is a positive waveform peaking around 300 ms after the onset of a relevant or infrequent stimulus [81-83]. It is a key signal in cognitive research, reflecting brain activity related to working memory, attention, and cognitive control. The P300 is often divided into two subcomponents: P3a and P3b. P3a is linked to automatic, involuntary attention to novel stimuli, while P3b is associated with voluntary attention and task-relevant stimuli, particularly in tasks like go/no-go [83-91]. The P3a is associated with dopaminergic activity and shows a fronto-central distribution, while P3b, linked to norepinephrine activity, is observed more prominently in the parietal region and reflects working memory processes [86,89,90]. The P300 is commonly elicited using the oddball paradigm, where participants differentiate between frequent standard stimuli and rare target stimuli, providing insight into attention and cognitive processes [83,89,92,93]. Structurally, the P300 response is localized in several brain regions, including the prefrontal cortex, anterior cingulate, parietal cortex, and hippocampus [94,95]. The P3b amplitude is influenced by stimulus relevance, attentional resources, and the deviant-to-standard stimulus ratio [84,87,91,92]. Larger amplitudes are associated with more distinct target stimuli and greater attention [86]. In contrast, P3a is more sensitive to stimulus salience and involuntary attention shifts [89-91,96].

The P300 is a valuable tool for assessing attention and memory in both healthy and clinical populations. In healthy aging, the P300 amplitude typically declines, and latency increases, reflecting reduced attentional resources [97]. In clinical conditions like dementia, traumatic brain injury (TBI), ADHD, and neurodevelopmental disorders, significant reductions in P300 amplitude and prolonged latencies are observed [98-100]. The P300 offers critical insights into attention, memory, and cognitive processing, making it a reliable tool for tracking cognitive changes, particularly in neurodegenerative diseases.

N400: Semantic Processing and Language Comprehension

The N400 (or N4) is a negative deflection in the ERP waveform occurring around 400 ms after the presentation of semantically incongruent or unexpected stimuli [23,101,102]. It reflects the brain's process of semantic integration, particularly how words or concepts are linked within context. Typically observed in response to visual or auditory words, the N400 amplitude is more negative when a word is semantically incongruent with its context and less negative when it fits contextually [102-104]. This component is crucial for studying language comprehension and how well concepts are semantically connected during sentence processing or word association tasks.

The N400 is recorded over posterior regions of the scalp, with a larger response in the right hemisphere for visual words and a slight left-hemisphere bias for spoken words [23,102,105]. Intracranial recordings show that areas such as the anterior fusiform, parahippocampal gyrus, and superior temporal sulcus contribute to the N400 response [101,106-108]. The N400 is particularly sensitive to semantic congruity, lexical frequency, and stimulus familiarity. The N400 amplitude provides a measure of semantic processing ease, with smaller amplitudes indicating contextual congruence and larger ones indicating incongruence [109-111]. Repetition of a stimulus reduces the N400 amplitude, reflecting reduced cognitive effort for semantic integration [110, 111].

In clinical settings, the N400 is useful for studying language processing, especially in conditions like autism spectrum disorder [112-117]. Changes in N400 amplitude and latency correlate with the severity of cognitive decline, making it a valuable biomarker

for detecting early signs of cognitive impairment, particularly when combined with tools such as the MMSE [23,109,118,119]. In healthy aging, decreased N400 amplitude and increased latency indicate reduced semantic processing efficiency [114-117]. In dementia, these changes are more pronounced and can help track disease progression and distinguish between different types of cognitive impairment.

In summary, the N400 is a cornerstone of ERP research into semantic processing and language comprehension. It reflects the brain's integration of new information into existing semantic networks, with its amplitude serving as a reliable indicator of semantic congruity. Clinically, the N400 is invaluable for assessing cognitive decline, particularly in detecting early signs of dementia and neurocognitive disorders. Its role in linguistic processing and contextual integration makes it a crucial tool for both research and clinical practice.

Impact of Aging on ERP

Aging significantly affects ERPs, especially the P300 and N400 components, which are crucial for understanding cognitive and neural processing. In healthy aging, older adults often show a reduction in P300 amplitude and an increase in latency compared to younger adults [82,120-127]. These changes are typically more pronounced in men, who exhibit greater increases in latency and faster responses than women [125,128]. Particularly, adults aged 65 and older experience a decline in P300 amplitudes, with females generally showing higher amplitudes than males [129]. This reduction reflects the common age-related declines in cognitive processing speed and attention [23,120]. Some studies suggest that older adults can process sentences adequately into later stages of aging, but others highlight difficulties related to diminished working memory capacity [130-134]. Interestingly, older adults without memory complaints tend to show better P300 responses compared to those who report cognitive concerns [135]. While reductions in P300 amplitude are typical in older adults, these changes are less severe than those observed in individuals experiencing pathological aging. Although general semantic knowledge may increase with age, some studies suggest that semantic processing in older adults may decline [136-138]. Certain studies report decreased accuracy in semantic tasks among older adults, while others see no significant differences compared to younger adults [101,113,117,139-151]. The N400 component, which is linked to lexical-semantic processing, plays a key role in aging research [142,152-154]. This component reflects cognitive processes like memory retrieval and semantic integration, particularly when sentences are contextually incongruent [101,113,155].

Older adults often exhibit a reduced N400 effect, which may result from neuroanatomical changes leading to less synchronized neuronal firing and cognitive resource depletion [146-148,156-159]. Additionally, delayed peak latencies in the N400 component are frequently observed in older adults, suggesting slower, less efficient processing and integration of language [142,145,146,149,152,153,154]. Although the N400 amplitude tends to decrease with age, these changes are less pronounced than in conditions such as Alzheimer's Disease (AD) or Mild Cognitive Impairment (MCI) [23,153,160-163].

In AD, patients show significantly reduced N400 effects, which may serve as biomarkers for early detection [145,151,153,164-167]. Additionally, research on N400 repetition effects indicates that healthy elderly adults typically exhibit delayed N400 responses, while AD patients may display diminished or absent N400 repetition effects, suggesting impaired semantic memory [168-171]. These differences, in conjunction with other behavioral measures and neuropsychological tests, aid in distinguishing normal aging from AD [116,172,173].

Pathological Aging and ERP Changes

In pathological aging, ERP markers like P300 and N400 become increasingly useful in detecting early cognitive decline, particularly in AD and MCI. These conditions exacerbate age-related ERP changes, making it more challenging to distinguish between normal aging and early-stages cognitive decline. P300 abnormalities, such as reduced amplitude and increased latency, are commonly found in AD [23,123,172,174-177]. These changes are most pronounced in the parietal regions [81,178-180]. In MCI, which often serves as a precursor to AD, similar P300 changes, such as reduced amplitude and increased latency, are observed and can predict the progression to AD [123,176,177,181-183]. These changes reflect impairments in cognitive functions such as attention, memory, and processing speed, and are considered valuable biomarkers for the early detection of AD.

P300 latency is sensitive to disease progression in both AD and MCI, correlating with cognitive decline over time. It can help differentiate AD from other conditions like depression or schizophrenia [184-187]. Longitudinal studies suggest that increased P300 latency in MCI patients is associated with a higher likelihood of progression to dementia [171,188]. Differences in P300 latency, particularly in MCI and AD, help distinguish these populations from healthy controls [81,179]. These ERP abnormalities could serve as predictive markers for individuals at high risk of progressing to AD [81,123,171,174-177].
The P300 is more sensitive to advanced stages of dementia and shows a moderate correlation with MMSE scores [185,189]. Research indicates that P300 latency changes are more sensitive to disease progression over the course of a year than other cognitive tests, such as the Cognitive Abilities Screening Instruments (CASI) or the MMSE, in both AD and MCI [190].

The N400 component also undergoes significant changes in pathological aging. In AD, diminished N400 repetition effects signal impaired semantic memory, working memory, and language processing [116,168,169,191]. In contrast, normal aging typically results in only mild reductions in N400 amplitude and latency [116,153,169]. N400 abnormalities in MCI can serve as early indicators of dementia progression, with delayed or diminished N400 effects associated with a higher risk of transitioning to AD [169-171].

In summary, ERP markers such as P300 and N400 provide valuable insights into the cognitive changes associated with aging, with distinct patterns emerging in normal versus pathological aging. Normal aging typically results in reduced P300 amplitude and delayed N400 latency, while these changes are more severe in conditions like AD and MCI. The alterations observed in these ERP components may serve as biomarkers for early detection and disease progression in neurodegenerative disorders [27]. Although ERP measures are not yet fully integrated into preclinical AD criteria, their non-invasive nature and ability to track cognitive decline make them promising tools for distinguishing between normal aging and pathological conditions [192]. Incorporating ERP measures into clinical assessments could offer a cost-effective and non-invasive way to monitor cognitive decline in aging and neurodegenerative conditions.

ERP Biomarkers and Their Impact Across Neurological Disorders

The growing demand for objective, neurophysiological measures to assess brain function in clinical settings has led to the widespread use of EEG, valued for its low cost, non-invasiveness, and clinical applicability [2,7,35,193-196]. A key tool derived from EEG for understanding cognitive processing is ERPs, which measure brain responses to specific stimuli. Among the most studied ERPs N100, P300, and N400 each provides valuable insights into different cognitive domains, including sensory processing, attention, and semantic understanding. However, the impact of these ERPs can vary significantly across different neurological and psychiatric disorders. ERPs serve as important markers for sensory, attentional, and cognitive processing [2,197]. The "brain vital signs" framework, which incorporates rapid, automated ERP stimulation sequences, measures the N100 (sensory processing), P300 (attention processing), and N400 (semantic/language processing) responses [13,21,35,102]. This framework has been validated in healthy individuals and is increasingly used in clinical settings, such as assessing brain injury patients and athletes recovering from concussions [196,198,199]. Below is a summary of how the N100, P300, and N400 are altered in various neurological conditions.

N100 (Auditory Sensory Processing)

The N100 ERP is primarily associated with early sensory processing, specifically in auditory and attention-based tasks. This component reflects the brain's initial response to auditory stimuli, and alterations in its amplitude and latency can signal disruptions in sensory processing or attention.

1. **Traumatic Brain Injury (TBI)/Concussion:**

- N100 amplitude is often reduced and latency is delayed following head injuries [47,98,199-202]. These changes indicate compromised auditory processing due to the brain's impaired ability to process sound efficiently after trauma.

2. **Schizophrenia:**

- Individuals with schizophrenia also display a reduced N100 amplitude, which is linked to sensory gating deficits. This reflects difficulties in filtering irrelevant sensory information, leading to cognitive overload and impaired attention [77,203].

3. **Alcoholism:**

- Reduced N100 amplitude is frequently observed in individuals with alcohol dependence [204-206]. This suggests that alcohol consumption impacts early sensory processing, possibly due to neurotoxic effects on the brain's auditory pathways.

4. **Autism Spectrum Disorder (ASD):**

- Children with ASD show delayed N100 latency and reduced amplitude, which can point to sensory processing deficits, particularly in the context of sensory gating issues [207-209]. These abnormalities suggest difficulties in efficiently processing auditory stimuli.

P300 (Attention and Cognitive Processing)

The P300 is a late positive wave that reflects higher cognitive functions such as attention, working memory, and cognitive processing. This ERP is highly sensitive to cognitive dysfunction, making it a key biomarker in many neurological and psychiatric disorders.

1. **Traumatic Brain Injury (TBI)/Concussion:**

- Following TBI, P300 amplitude is often reduced, and latency is delayed, indicating deficits in attention and cognitive processing [39,98,196,199,210-212]. These changes can persist beyond the initial injury, even in individuals who have returned to play, highlighting lingering cognitive impairment. P300 is particularly sensitive to sub-concussive impacts, detecting changes before more traditional imaging methods can.

2. **Stroke:**

- In stroke patients, P300 latency is significantly delayed and amplitude is reduced, especially within the first few weeks following the event [213-215]. Though P300 latency improves over time, the amplitude remains diminished, indicating long-term cognitive processing deficits.

3. **Mild Cognitive Impairment (MCI)/Alzheimer's Disease (AD):**

- P300 latency increases, and amplitude decreases in individuals with MCI and AD, reflecting impairments in attention and memory functions [28,89,216-219]. These changes correlate with the progression of cognitive decline, making P300 a useful marker for detecting early-stage AD and distinguishing MCI from healthy controls.

4. **Multiple Sclerosis (MS):**

- Patients with MS often show delayed P300 latency and reduced amplitude, which are linked to cognitive dysfunction, particularly in attention and memory processes [220-223]. These changes correlate with MRI findings of brain lesions, especially in the frontal and brainstem regions, providing insights into the relationship between brain structure and function.

5. **Alcoholism:**

- Alcohol-dependent individuals exhibit reduced P300 amplitude, suggesting persistent deficits in attention and cognitive processing [98,224]. Notably, this reduction can

remain even after extended periods of abstinence, indicating lasting effects on cognitive function.

6. **Attention Deficit/Hyperactivity Disorder (ADHD):**

o P300 amplitude is consistently reduced in both children and adults with ADHD, reflecting impairments in attention and cognitive control [225,226]. This reduction is particularly pronounced as individuals with ADHD age, indicating a chronic difficulty in attention regulation.

7. **Schizophrenia:**

o In schizophrenia, P300 latency is delayed, and amplitude is reduced, particularly during auditory tasks [211,227]. These alterations reflect attention and cognitive processing deficits, and the reduction in P300 amplitude is closely tied to the severity of the disorder [203,228-230]. These ERP changes may also correlate with structural brain abnormalities, such as fronto-temporal atrophy, which affects attentional processes [203,229].

8. **Post-Traumatic Stress Disorder (PTSD):**

o PTSD patients exhibit reduced P300 amplitude, reflecting altered attention and cognitive processing [231,232]. This reduction is particularly evident in responses to neutral stimuli, but trauma-related stimuli may evoke heightened processing. These findings suggest a dissociation in how trauma-related and neutral information are processed in the brain.

9. **Depression**

o In depression, a reduced P300 amplitude is typically observed, particularly in individuals with suicidal ideation, psychotic features, or severe depression [233]. Depression also affects frontal P300 latency [234]. Stroke patients with depression exhibit higher latency and lower amplitude compared to those without depression [235]. These findings are consistent with studies from India, where depression was associated with delayed latency, reflecting disease severity [236].

N400 (Semantic and Cognitive Processing)

The N400 is a late negative wave that is sensitive to the integration of new information into existing cognitive frameworks. It plays a key role in semantic processing, language comprehension, and the processing of unexpected or incongruent information.

1. **Traumatic Brain Injury (TBI)/Concussion:**

o Following a concussion, N400 amplitude is often reduced within days of the injury [211,227]. This suggests impaired cognitive processing, particularly in areas related to language and semantic understanding. Rehabilitation efforts, such as speech therapy, have been shown to help recover some of the N400 responses, indicating the potential for cognitive improvement after TBI.

2. **Mild Cognitive Impairment (MCI)/Alzheimer's Disease (AD):**

o The N400 amplitude is often reduced or absent in MCI and AD patients, indicating deficits in semantic processing and cognitive flexibility. This is particularly useful in predicting the progression of MCI to full-blown dementia, making the N400 a valuable early biomarker for AD [28,171,237,238].

3. **Schizophrenia:**

o Individuals with schizophrenia often exhibit increased N400 latency, which can be linked to impairments in semantic processing. This delay reflects difficulties in integrating and interpreting new information, which is a core feature of cognitive dysfunction in schizophrenia [77,203].

The N100, P300, and N400 are powerful ERPs for understanding cognitive dysfunction in various neurological and psychiatric disorders. N100 is most commonly affected by deficits in sensory processing, particularly in disorders like TBI, schizophrenia, and ASD. P300, reflecting attention and cognitive processing, is widely altered in conditions such as TBI, stroke, MS, ADHD, schizophrenia, and PTSD. Finally, N400 alterations are particularly associated with cognitive and semantic processing deficits in conditions like TBI, MCI, AD, and schizophrenia. Understanding these ERP patterns allows clinicians to better assess and monitor cognitive changes, providing a more nuanced view of neurological and psychiatric conditions.

Conclusion

The integration of advanced neurophysiological tools, such as the BrainView qEEG discriminant database, marks a significant advancement in clinical neuroassessment. Medeia Inc.'s innovative platform, which incorporates key biomarkers like N100, P300, and N400, is designed to not only identify electrophysiological abnormalities but also enhance our understanding of cognitive processing across a variety of neurological and psychiatric disorders. This cutting-edge system is capable of tracking subtle changes in brain function making it an invaluable tool for early diagnosis, monitoring disease progression, and evaluating treatment outcomes.

The strength of BrainView lies in its broad and diverse dataset, advanced statistical methods, and a clear focus on clinical applicability, this powerful solution enables clinicians to make more informed decisions about patient care, ultimately improving the accuracy and effectiveness of neurophysiological assessments. As the database continues to expand to include additional disorders, BrainView's potential to contribute to personalized medicine and enhance patient outcomes will grow even further.

In conclusion, the BrainView ERP Platform represents a pivotal step toward more accurate, efficient, and comprehensive brain health assessments. By providing clinicians with the tools to better understand and monitor brain function, BrainView is poised to become a new gold standard in the fields of neurophysiology and neuropsychology, ushering in a new era of enhanced clinical care.

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