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Understanding Impulsivity through P300 among Clinical Population: A Systematic Review

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Abstract

Impulsivity has been conceptualized as a predictive factor among various problem behaviours of people who are clinically diagnosed with psychiatric disorders. In recent decades, there has been an attempt to understand impulsivity in terms of brain activities. The trait impulsivity is measured through P3a and P3b amplitudes to understand how they might change in pathological populations. Altered P300 is a biomarker for psychotic disorders, neurotic disorders, and various disorders related to addiction. Overall, P300 can be associated with impulsivity and inhibitory control. However, in different psychiatric disorders, the nature of changes in P300 indicated different types of underlying processing in decision-making and response inhibition.

Keywords: Impulsivity; P300; Psychopathology; Addiction; Psychosis

Introduction

The last few decades have indicated a paradigm shift in understanding any psychopathology under the light of brain functioning. Therefore, to understand and predict human behavior, understanding the internal mechanism of the brain is imperative. Recently, impulsivity has been regarded as a core psychological component of personality that determines or predicts certain types of psychopathologies.

What is Impulsivity?

Impulsivity is defined from various perspectives, from a biological and neuropsychological perspective, it is characterized by failure in inhibiting a potentially risky impulse for the individual or the others around (Chamberlain, 2007). From a cognitive viewpoint, impulsivity is the inability to inhibit behavioural impulses and thoughts. It considers impulse control as an important component of executive functions. It plays an important role in one's social and personal functioning (Chudasama, 2011). Barratt (1994) distinguished three dimensions of impulse:

A. Motor (action without thinking),

B. Cognitive (quick cognitive decision-making), and
C. Non-planning (decrease in orientation towards future) factors.

According to DSM-V, impulsivity is defined in terms of an aspect of disinhibition, and considered as an immediate reaction to stimuli, an unplanned reaction on the spur of the moment or with no regard for its consequences, the problem in programming or adhering to programs, sense of urgency and self-harming behaviour in the time of emotional turmoil. Furthermore, impulsivity has been regarded as defining factor of personality types (such as, sensation seeking) and disorders (such as emotionally unstable personality disorder).

Now, in recent times, there have been attempts to understand impulsivity in terms of brain activities, one of them being by measuring electrophysiological activities. Different types of brain signals are thought to be associated with different types of behaviour. The most widely studied brain signal associated with impulsivity is P300.

What is P300?

P300 wave is an event-related brain potential measured using electroencephalography (EEG). It refers to a spike in brain activity approximately after 300ms following the presentation of the target stimulus. The number of attentional resources devoted to the task & the degree of information processing required, while the latency is considered a measure of stimulus classification speed, unrelated to behavioural response time (Sandy, 2020).

Therefore, P300 is one of the most studied electrophysiological measurements that is used to understand the nature of changes in brain activities due to impulsivity. The current research is an attempt to understand the nature of changes in P300 amplitude in various disorders.

In this article, we would like to see how the P300 differs in different psychopathologies and healthy individuals.

Methods

Aim & Objectives

The current research aims to identify the changes in P300 due to impulsivity in different psychopathologies.

The objectives are as follows

1. To understand if there are any changes in P300 in psychosis.
2. To understand if there are any changes in P300 in mood & anxiety-related disorders.
3. To understand if there are any changes in P300 in substance addiction-related disorders.
4. To understand if there are any changes in P300 in gambling-related disorders.
5. To understand if there are any changes in P300 in internet addiction disorders.
6. To understand if there are any changes in P300 in conduct and other related disorders.

Inclusion & Exclusion Criteria

1. All relevant articles and abstracts published in English are to be included and articles published in any other language are to be excluded.
2. Review and meta-analysis are to be excluded.
3. Articles and abstracts published from 2007 onwards are to be included.

Search strategy

Search on Pubmed was done using the terms ((P3) OR (p300)) AND (Impulsivity)) AND (adult)) AND (psychiatric disorder or clinical population). All the articles from books & documents, clinical trials, and randomized clinical trials were combed for relevant studies. The abstract of the studies was then selected as per the inclusion criteria. Studies that did not include EEG or ERP measurements

were excluded. The review and meta-analysis articles were also excluded. Finally, the years of search were customized to include studies for the last 15 years, i.e., 2007 onwards. Figure 1 illustrates the search process till the final selection of articles. The search was updated on September, 2022.

Search coding

The selected papers then taken for further review. They were sorted as per the ICD 11 coding and studies on similar population were kept in one group. Thus, the major groups (viz. Psychosis, Mood & Anxiety related disorder, Substance addiction related disorder, gambling related disorder, Internet addiction disorder, & Personality related disorder) were made for further discussion on pattern of electrophysiological waves during planning and decision-making tasks. The studies conducted on non-clinical population were clubbed together to discuss on nature of electrophysiological responses of brain during various gambling tasks which might evoke impulsivity. The number of articles for the groups are as follows:

Psychosis = 3.
Anxiety-related disorder = 3.
Substance addiction-related disorder = 9.
Gambling-related disorder = 2.
Internet addiction disorder = 5.
Personality related disorder = 9.

The total number of articles selected for review on a healthy population is 07. Table no. 1 illustrates the list of ERP studies on pathological groups & Table no. 2 illustrates the list of studies on healthy populations.

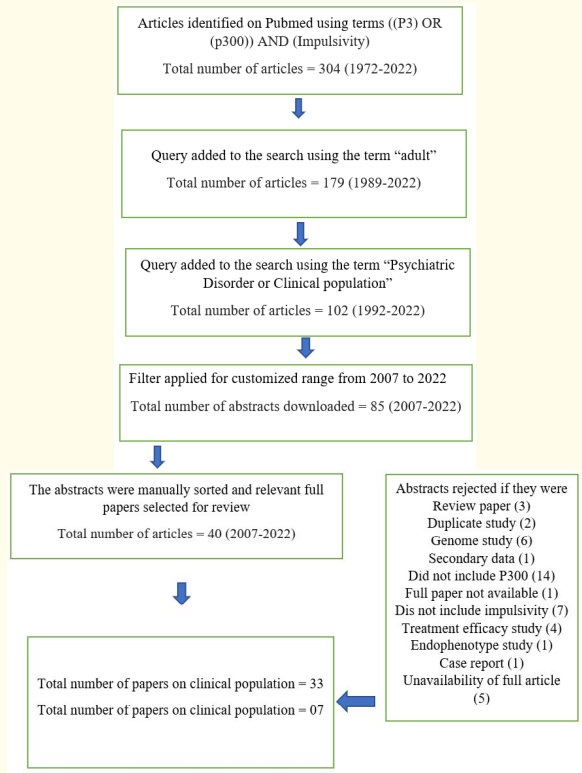

Figure 1: Illustration of Literature search.

Disorder	*First Author*	*Year*	*Country*	*N*	*Task*
1. Schizophrenia & Schizoaffective Disorder (6A20 & 6A21)	Hoptman	2018	U.S.A	42	Go-NoGo
2. Violent, Non-violent patients & Nonviolent psychosis (6A20)	Krakowski	2016	U.S.A	108	Go-NoGo
3. Long-term Schizophrenia (20+ yrs) (6A20)	Sumich	2013	South London	28	Novelty Oddball
4. Obsessive Compulsive Disorder(6B20)	Dayan-Riva	2019	Israel	76	Visual Oddball
5. Obsessive Compulsive Disorder(6B20) & Internet Gaming Disorder (6C51.0)	Kim	2017	Korea	77	Go-NoGo
6. Adult Bipolar & Disorder & ADHD (6A60 & 6A05)	Ibanez	2012	Argentina	50	Iowa Gambling Task
7. Bulimia Nervosa (6B81)	Marlotti	2013	Italy	34	Three tone oddball
8. Alcohol Use Disorder (6C40)	Sehrig	2019		74	BART
9. Heavy v/s light drinker (6C40)	Kruesch	2014	Belgium	30	Go-NoGo
10. Binge drinking and alcohol mixed with caffeinated beverages (AmCBs) (6C40 & 6C48)	Watson	2014	U.S.A	60	Visual Oddball & Go-NoGo
11. Substance Abuse Disorder (6C4F)	Steele	2014	Mexico	89	Go-NoGo
12. Alcohol Dependence (6C40)	Chen	2007	U.S.A	115	
13. Alcohol abstinent with MDD (6C40 & 6A70)	Fein	2017	U.S.A	48	Visual Oddball
14. Offenders from a court-ordered residential substance abuse treatment facility (6C4F)	Venables	2015	U.S.A	166	International Affective Picture System
15. Methamphetamine use disorder (6C47)	Wei	2018	China	43	Gambling
16. Former heroin and cocaine addiction (6C48)	Morie	2014	U.S.A	41	Neutral & emotional Go-NoGo
17. Problem gamblers (6C50)	Lole	2015	Australia	36	Electronic gaming machine gambling
18. Gamblers (6C50)	Oberg	2011	Canada		Gambling task
19. Internet Gaming Disorder (6C51.0)	Park	2017	Korea	47	oddball
20. Internet Gaming Disorder (6C51.0)	Park	2017	Korea	77	Auditory oddball
21. Gaming Disorder & OCD (6C51 & 6B20)	Kim	2017	Korea	77	Go-NoGo
22. Pathological gamers & Casual gamers (6B51)	Duven	2015	Germany	30	Computer Game
23. Problematic Internet use (6C5Y)	Yau	2015	U.S.A	66	BART
24. Internet addiction disorder (6C5Y)	Dong	2010	China	24	Go-NoGo
25. Conduct Disorder (6C91) & Borderline Personality Disorder (6D10)	Bauer	2020		224	Auditory Stimuli
26. ASPD(Prisoners) (6D10)	Drislane	2013	U.S.A	143	International Affective Picture System
27. Psychopathy & Antisocial Personality (6D10)	Verona	2012	U.S.A	45	Go-NoGo

28. Borderline Personality Disorder (6D10)	Schuermann	2011	Germany	36	IOWA Gambling Task
29. Intermittent Explosive Disorder (6D10)	Koelsch	2009	Germany	78	Auditory Oddball
30. Violent offenders (6D10)	Munro	2007	Canada	30	Go-NoGo
31. Child sex offender (6D32)	Rosberg	2018	Switzerland	61	Go-NoGo
32. Externalizing behavior & psychopathology (6C9Y)	Brennan		U.S.A	89	Modified Oddball
33. Psychopathic traits (6C9Y)	Kim	2014	South Korea	30	Go-NoGo

Table 1: List of studies on different psychopathologies measuring P300.

First Author	*Year*	*Country*	*N*	*Task for ERP*
1. Ribordy	2020	Switzerland	65	Visual Go-NoGo
2. Kim	2016	Korea	157	Loudness dependence auditory evoked potentials (LDAEP) & Go-NoGo
3. Schmüser	2016	Germany	38	Go-NoGo
4. Kam	2012	Canada	85	Go-NoGo
5. Carlson	2010	Canada	72	Expectance AX-CPT
6. Kamarajan	2008	U.S.A	40	Gambling
7. Dimoska	2007	Australia	40	Stop signal task (Visual & Auditory)

Table 2: List of studies on Healthy populations measuring changes in P300.

Results & Discussion

Psychosis & P300

A study (Sumich et. al., 2013) suggests schizophrenic women generally had higher anterior P300 amplitudes than schizophrenic. Also, novel stimuli elicit higher P300 amplitude in schizophrenic women than schizophrenic men in novelty oddball tasks.

Another study (Krakowski et. al., 2016) claims negative emotional stimuli elicits impulsive behavior in violent schizophrenics. In their study, the P300 decreased when they made an error of commission (i.e. response inhibition) in the Go-NoGo task.

Patients with Schizophrenia or schizoaffective disorder had smaller P3s than controls on unsuccessful, and especially successful, stop trials in a study by Hoptman et. al. (2018). P3 amplitudes were larger for successful than unsuccessful stops Stop Signal Reaction Times (SSRTs) negatively correlated with P3 amplitude for successful stop trials in Go-NoGo task.

Therefore, it can be said that the P300 amplitude is higher for novel stimuli and it decreases when there's an error. This implies that people with psychosis have a problem with response inhibition and are more impulsive than their non-psychotic counterparts.

Mood, Anxiety & P300

A study on patients diagnosed with obsessive-compulsive disorder (OCD) showed attentional bias and altered P300 (Dayan-Riva, 2019) for anger-provoking stimuli in visual oddball tasks. Thus, it can be said that the reduction in P3 seen in the OCD group under the angry condition is associated with compulsive behavior. Another study (Kim et. al, 2017) suggests that prolonged NoGo-N2 latency may serve as a marker of trait impulsivity in IGD, and reduced NoGo-N2 amplitude may be a differential neurophysiological feature between OCD from IGD about compulsivity. Thus, a neurophysiological correlate of the altered response inhibition in IGD and OCD may be a candidate biomarker for impulsivity and compulsivity. P3 amplitude was increased for task-relevant stimuli that require a 'controlled' information-processing modality (involving selective attention and a working memory load), suggesting that patients with Bulimia Nervosa might use their intact effortful processing strategy to compensate for a deficit in suppression of irrelevant informa-

tion (Marlotti et. al. 2013). Anxiety and mood symptoms are seen to be correlated with reduced P3 magnitude discrimination (Ibanez et. al., 2012).

Substance Abuse & P300

A study by Chen et al. (2006) showed that alcoholic subjects had widespread reductions in visual P3 amplitudes during the processing of the target stimuli. This result was similar to healthy individuals with high impulsivity. Another study found that binge drinkers reported significantly greater tendencies to engage in disinhibited behaviors, exhibited significantly larger P3a and P3b amplitudes in the oddball task, and trended to exhibit enhanced P3a amplitudes to no-go stimuli (Watson et.al., 2013). The alterations are not limited to the neural correlates of processing task-relevant stimuli that generate the P3b but are also present when binge drinkers are required to process distracting stimuli that generate the P3a. As the P3a/b components are thought to be mediated by a network of frontal, temporal, and parietal regions, these data suggest that binge drinkers exhibit widespread differences in cortical function related to attentional processing. This study also suggests that these neurocognitive effects appear in context with increases in disinhibited behaviors that may have potentially adverse consequences (e.g., sexual disinhibition while drinking).

However, other studies (Steele et. al., 2013; Morie et.al., 2014) found no significant differences in stimulus-locked P300 amplitude between those who completed or discontinued treatment of substance abuse in Go-NoGo task or substance abstinent patients in visual and emotional Go-NoGo tasks. Even in alcohol-modified condition there was no change in P300, i.e., response inhibition among healthy subjects in the Go-NoGo task (Kruesch et. al., 2014). Rather, Venables et. al., (2015) shows that P3 amplitude reduction was more evident about the Antisocial facet than the Impulsive-Irresponsible facet in their study using International Affective Picture System (IAPS; Lang, Bradley, & Cuthbert, 2008). A more recent study (Fein et. al., 2017), shows that there's no reduction in P3b amplitudes in visual oddball tasks in long-term abstinent alcoholics with major depressive disorders as used to be mentioned in earlier literature. Shehrig et. al. (2019) proposed in their study that risk-inclined patients with Alcohol Use Disorder producing both larger decision P3 and longer RT on high-risk trials suggests considerable decision-making effort, rather than simply high impulsiveness in BART tasks. However, patients with methamphetamine addiction showed significant correlation between gain-99 P300/loss-99 P300 in a gambling task and sensation seeking.

Gambling & P300

In a study (Oberg et. al., 2011) it was found that gamblers failed to differentiate high from low risk in their bet selections and exhibited a somewhat blunted P300 and induced theta response relative to controls in gambling tasks. The trend for attenuated P3b responses following all outcomes among problem gamblers may suggest that these individuals are generally hypoaroused, and/or may reflect a reduced responsiveness/acquired habituation to gambling outcomes due to repeated exposure to gambling activity (Lole et.al.,2015).

Internet Addiction Gaming Disorder & P300

A study (Dong et.al., 2010) using the Go-NoGo task on internet-addicted individuals (IAD) showed the higher in P3 amplitude in NoGo conditions than the normal group. The peak latency was longer in P3 in NoGo conditions in the IAD inflicted group than in the normal group. This may reflect that IAD individuals need for more cognitive endeavors for participants to successfully inhibit their response impulses. Thus, they had less efficient information processing function than their normal peers which might be related to impaired impulse control. Another study (Yau et.al., 2015) showed blunted P300 response to both negative and positive outcomes in BART among adolescents with problematic internet use, indicating overall decreased sensitivity to feedback which might lead to dysfunctional or impulsive behavior. Study by Park et. al. (2017) also showed decreased P300 amplitudes and delayed latencies in patients with Internet Gaming Disorder (IGD) were sustained after treatment with pharmacotherapy, even though the patients' IGD symptoms improved significantly after treatment. Thus, it suggests decreased P300 amplitudes and delayed latencies are reliable neurobiological markers for IGD and are associated with vulnerability to develop the disorder. Recent studies (Park et. al., 2017a; Park et. al., 2017b) suggested that lower P300 amplitudes are associated with more impaired cognitive capacity in patients with IGD and can be a candidate endophenotypes.

Personality Disorder & P300

Munro et. al. (2007) studied event-related potentials with Go-NoGo tasks among violent offenders who varied on the dimension of psychopathy and non-offender. The offenders made more errors of commission on NoGo trials but this effect was unrelated to the level of psychopathy within the group they produced the enhanced frontal N2 and P3 effect in response to NoGo relative to Go conditions indicative of more nuanced perspective of impulsivity and response inhibition. In a study (Koelsch, 2009), P3a, which receives main contributions from frontal lobe, was found to be significantly smaller in the Moderate intermittent Explosive Disorder (mIED) group compared to the control group, showing that mIED affects cognitive mechanisms of involuntary control of attention (as reflected in the P3a). Thus, increased impulsivity is related to frontal, rather than temporal lobe function.

A study (Schuermann et.al, 2011) on borderline personality disorder (BPD) revealed P300 was insensitive to feedback valence in the control group, while in patients the P300 was increased following negative feedback compared with positive feedback indicating that people with BPD have difficulties in learning from feedbacks or mistakes contributing in impaired decision making. In a study (Dris-lane et. al., 2012), Offenders diagnosed with psychopathy showed diminished cortical orienting to abrupt noxious stimuli, as indexed by diminished probe P3 reactivity to unwarned noise bursts occurring within or between picture-viewing intervals but, those diag-nosed with antisocial personality disorder (ASPD) do not evince this effect indicative of reduced evaluative post-processing of aversive noise probes in psychopathic individuals. All reductions in probe P3 response, psychopathic participants showed the expected relative decrement in probe P3 during the viewing of affective as compared with neutral pictures, interpretable as increased allocation of attentional resources to more engaging perceptual foregrounds. A study (Verona et. al., 2012) on ASPD offenders showed relatively larger frontal No-Go P3 to negative emotional words indicating that they required more effortful processing to perform adequately in emotional contexts. ASPD may be associated with an inability to ignore emotional context when engaging in inhibitory control might be resulting in verbal and self-directed aggression. Similar results were found and further extended in a study (Kim & Jung, 2014) where the psychopathic trait group exhibited reduced frontal activity during response inhibition. Compared to the control group, a sig-nificantly lower current density elicited by NoGo-P3 in the psychopathic trait group was found at the anterior cingulate and superior frontal gyrus in the left hemisphere and the precentral gyrus, anterior cingulate, and inferior parietal lobule in the right hemisphere.

A study (Brennan et. al., 2017) indicated that externalizing predicted lower P3 amplitude and lower accuracy on "no-go" trials, suggestive of impaired inhibitory control in the real world. However, a recent study (Rosburg, 2018) showed no apparent difference in P3 amplitudes between child sex offenders (CSO) and healthy controls, thus not indicating any lack of systemic response inhibition among CSO. Elevation in P300 amplitude in teenagers is associated with higher or lower conduct disorder problems, thus indicative of more disruptive behavior or impulsivity (Bauer, 2020).

Other Studies on healthy controls & P300

In an earlier study (Dimoska et. al., 2007) with a visual Go-NoGo task, it was larger and faster activation of the successful stop P3 in the High impulsive compared to Low impulsive group, particularly in the central region of the brain which might be suggestive of either the agent or outcome of inhibition acting on response processing near or in the primary motor cortex. In another study (Kamarajan et. al., 2008) with healthy adult males & females with a gambling task, significant differences were found between males and females in P3 components and theta power. Females activated more widespread frontal and parietal areas than males during the outcomes of loss and gain, besides midline frontal activity in males and bilateral frontal activity in females.

A condition requiring response inhibition and conflict monitoring is associated with frontocentral NoGo P3 and situations involving a greater expectancy violation may lead to P3b (Carlson & Thai, 2010).

A study (Kim et. al., 2016) showed Loudness dependence of auditory evoked potential (LDAEP) was positively correlated with No-go-P3 amplitude and Nogo-P3 amplitude was significantly higher in the high LDAEP group compared to the low LDAEP group. Thus, higher LDAEP having higher sensory sensitivity could better respond to positive and negative stimuli with higher reactivity which make them prone to depressive mood or anxiety related to emotional sensitivity.

Schmuser et. al. (2016) showed in a study of healthy controls with Go-NoGo task correlations with N2/P3 regressors revealed stronger activations in response inhibition and attention network in the low impulsive group. The highly impulsive group was characterized by enhanced activity in the more effective, pregenual anterior cingulate cortex possibly indicating overactivity or compensatory activity. Motor impulsiveness is associated with reduced P3 and non-planning impulsiveness is associated with high P3 in frontal areas (Kam et. al., 2012).

In a recent study (Lambert et. al., 2020) with healthy controls it was seen that acute intoxication with alcohol decreased activity in the motor inhibitory control network, acting together with the right inferior gyrus during the P3 inhibition phase that might result in poor inhibitory control.

In conclusion, it can be said that

1. The P300 amplitude differs in psychosis which may explain the response inhibition resulting in impulsive behavior.
2. The reduced P300 is associated with compulsive behavior and the higher P300 is associated with information processing in neurosis.
3. There are alterations in P300 amplitudes in substance-related disorders which might be related to considerable decision-making efforts rather than impulsivity.
4. Attenuated P300 amplitude due to poor feedback processing might be associated with gambling disorder.
5. Lower P300 amplitude is associated with impaired cognitive capacity in Internet addiction disorders.
6. Elevation in P300 amplitudes is associated with conduct-related problems and high impulsivity in conduct and other related disorders.
7. Among the healthy population, P300 is associated with impulsivity and inhibitory control.

P300 is one of the most important components of Event-Related Potential (ERP) to understand impulsive behaviors in various psychopathologies. Though at times the results of some studies might contraindicate some other studies, it's well established that both the P3a & P3b ERP components changes during impulsive decision-making and are associated with impulsivity and response inhibition. Also, the different psychopathologies, even if there's no apparent change in the neuroanatomical structure of the brain, elicit different electrophysiological responses in tasks related to executive functioning. Therefore, it further emphasizes the importance of understanding psychopathologies and overall human behavior in terms of electrophysiology or neural network model.

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