International Journal of
Psychology
(IJP)

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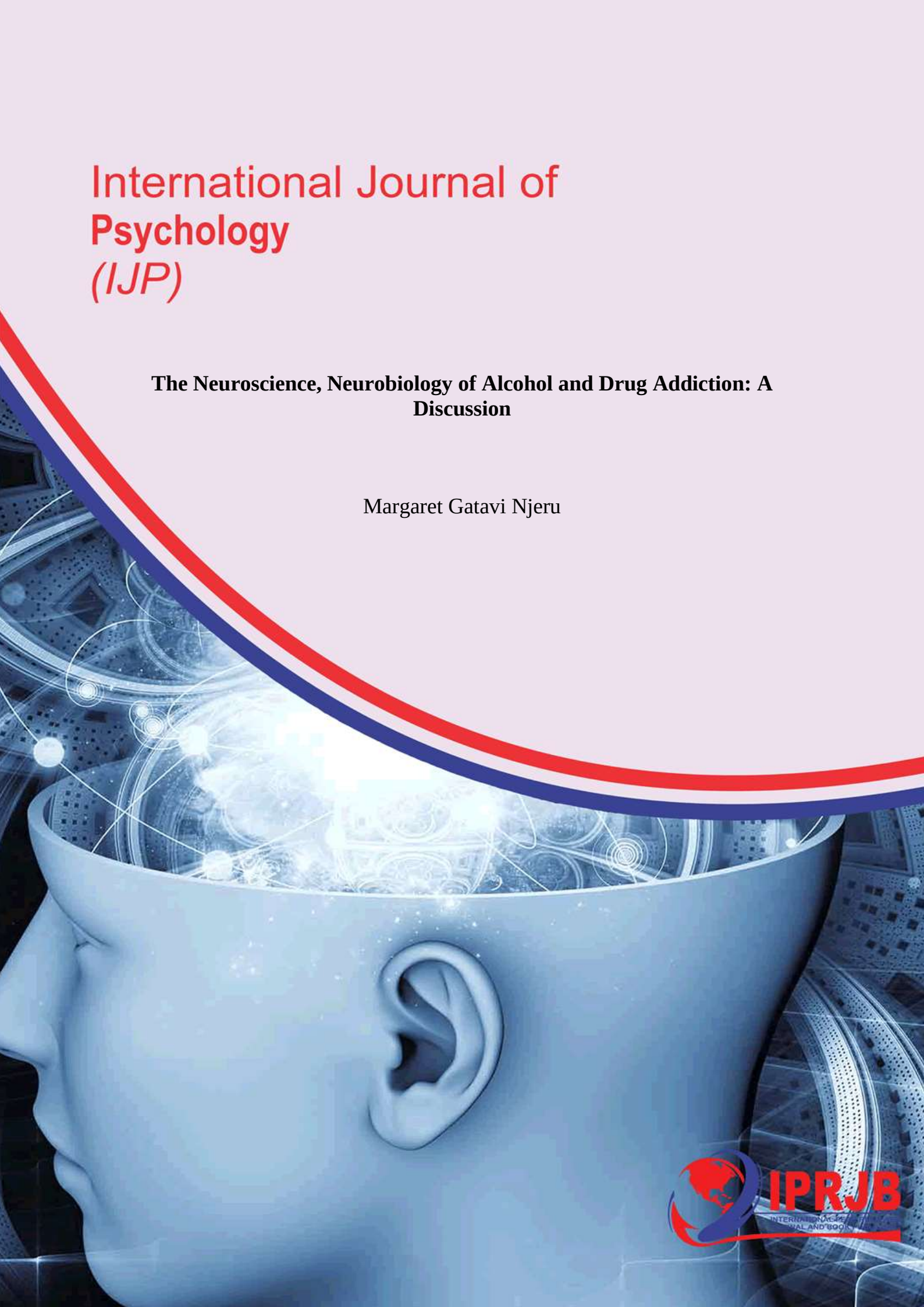

International Journal of Psychology
ISSN 2957-6881 (Online)
Vol 8, Issue 4, No. 3, pp 33 - 42, 2023

www.iprjb.org

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Article History

Received 10th November 2023

Received in Revised Form 23th November 2023

Accepted 2nd November 2023

How to cite in APA format:

Njeru, M. . (2023). The Neuroscience, Neurobiology of Alcohol and Drug Addiction: A Discussion. *International Journal of Psychology*, *8*(4), 33–42. https://doi.org/10.47604/ijp.2222

Abstract

Purpose: The purpose of this paper is to discuss the neuroscience and neurobiology of alcohol and drug addiction. The study of neuroscience and neurobiology of alcohol and drug addiction will help to understand the relationship between addiction and brain functioning.

Methodology: The study utilized a systematic review of literature to study alcohol and drug addiction by identifying parts of the human brain responsible for addiction, stages of addiction, elements of addiction, and effects of different drugs on the brain. The main theories of addiction guiding the research were the Incentive-Sensitization theory and the Disease Theory.

Findings: The outcome from the paper showed addiction is a chronic illness that contributes to significant impairments in social function, health, and in lack of control over drug use. The three stages of addiction are intoxication/ binge, withdrawal, and anticipation. Also, it was found out basal ganglia, extended amygdala, and the prefrontal cortex are the main parts of the brain responsible for drug addiction.

Unique Contribution to Theory, Practice and Policy: The outcome from the paper has contributed towards advancing the knowledge of drug addiction by establishing evidence-based approaches for identifying the neurobiology and neuroscience of drug addiction. Findings can be utilized in developing policies and frameworks that guide the use of drugs, especially prescription drugs like opioids. Moreover, findings help in advancing the practice in medicine by recommending new pharmacological and non-pharmacological treatments to prevent and control addiction.

Keywords: *Neuroscience, Neurobiology, Drug Addiction*

International Journal of Psychology
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INTRODUCTION

Alcohol and drug addiction are one of the topics that has been widely researched in efforts to determine how they occur and factors leading to people abusing substances. The understanding of drug and substance use disorders including alcohol addiction has been revolutionized through numerous scientific breakthroughs. Addiction, which in the past, was seen as a character flaw or moral failure by an individual, has now been classified among chronic illnesses whose characteristics are related to significant impairments in social function, health, and lack of control over drug use (National Library of Medicine, 2016). American Psychiatric Association (2013) has defined drug addiction as a relapsing disorder where an individual feels the urge to take drugs and losses control in limiting taking it, eventually creating the emergence of negative emotional state such as irritability and anxiety when they fail to take the drug. Additionally, studies have revealed factors such as environmental, developmental, genetic, social, and behavioral that contribute to alcohol and drug addiction. Over the past decade, studies by (Koob & Volkow, 2016; Swift & Aston, 2015; Lewis, 2017) have gone deeper into understanding the neuroscience and neurobiology of alcohol and drug addiction in order to understand the relationship between addiction and brain functioning. The purpose of this paper is to discuss neuroscience and neurobiology of alcohol and drug addiction. The paper identifies the role of brain in addiction, theories of addiction, elements of addiction, and effects of different drugs on the brain.

Parts of Brain Responsible for Addiction

The understanding of drug and substance addiction as a medical disorder has demonstrated the role of different parts of the brain that drive changes in individual behavior and characteristics. Research on neurobiology and neuroscience of addiction has proven that alcohol and drug addiction is a chronic brain disease based on frequency of reoccurrence and challenges in recovery (Substance Abuse and Mental Health Services Administration (US) & Office of the Surgeon General (US), 2016). As such, understanding the basic biology of human brain helps to understand parts of the brain that cause addiction. Unlike other body organs that sometimes go to rest, the brain is a unique organ that is constantly functioning under a mixture of electrical and chemical processes that control most functions in the body. Moreover, the processes are responsible for controlling how a person reacts to changes in the environment such as smells, and sensory stimuli. Brain is composed of billions of nerve cells, referred to as neurons, which communicate with each other through neurotransmitters. Neurons occur in clusters (known as networks) responsible for different functions including learning, thinking, emotions, and memory. Additionally, other networks stimulate muscles into actions while others collect and interpret stimuli from sensory organs such as the skin, ears, and eyes (Powledge, 1999). The disruption of normal functions of these networks triggers the addiction cycle.

The addiction process occurs in a three-stage cycle starting with intoxication, or binge, followed by withdrawal, and finally anticipation (preoccupation). Continued use of alcohol and other substances makes the cycle more severe leading to dramatic changes in the function of the brain that reduces the ability of a person to control substance use; hence, leading to addiction. The main parts of the brain that get disrupted, and have been identified as those responsible for addiction, are basal ganglia, extended amygdala, and prefrontal cortex. Substance Abuse and Mental Health Services Administration (US) & Office of the Surgeon General (US) (2016) found out disruptions in these three areas lead to substance-associated cues triggering substance seeking, reduction in the sensitivity of brain system that experiences

reward or pleasure, and reduced functioning of the brain executive control systems that affects individual's impulses, emotions, ability to make decisions, and regulate actions.

Basal Ganglia

The basal ganglia are a group of structures found deep within the brain whose role is to coordinate body movements and taken part in making a person learn routine behaviors and habits. The basal ganglia are responsible for controlling functions of the brain such as rewarding and emotions. The two main regions found in the basal ganglia, and are associated with drug and substance use disorders are the dorsal striatum and the nucleus accumbens. The dorsal striatum is responsible for forming routine behaviors and habits while the nucleus accumbens helps in motivation and experiencing of rewards. Psychotic substances like alcohol have been associated with the disruption of normal functioning of the basal ganglia (Goldstein *et al*, 2007). Findings from neurobiological studies have shown substances that cross the blood brain barrier are capable of affecting the normal functioning of the basal ganglia directly when the drug reaches the basal nuclei and indirectly when the substance affects pathways linking to other regions of the brain (Deitrich, 2011). Additionally, substances are made of metabolic products that affect neurons found in the basal ganglia leading to disruptions in the structure's normal functioning. As a result of these disruptions due to continued use of the drug, the victim develops habitual substance seeking behaviors. Welcome, & Pereverzev (2013) study showed basal ganglia acts as an error monitoring and processing system (EMPS) of the brain required in cognitive processing. Alcohol intake has been linked to the modulation of the EMPS capacity of the basal ganglia. As such, addiction is more likely to occur if the basal ganglia part of the brain fails to monitor errors and process key cognitive functions.

Extended Amygdala

Extended amygdala is a sub-region located below the basal ganglia in the brain. The part plays the role of regulating how the brain reacts to stress through behaviors such as flight or fight. It also regulates negative emotions like anxiety, irritability, and unease (US) & Office of the Surgeon General (US), 2016). Extended amygdala is highly involved in functioning of neural systems that compose of subcortical and cortical structures responsible for modulating behaviors associated to initial intake of drugs to addiction. Brain imaging studies have been applied to define individual and social consequences of disruptions of extended amygdala. Research done by Kilts (2001) revealed the role of amygdala in causing subsequence behavioral processes triggered by drug use leading to addiction. There were demonstrations of dysfunction of memory and reward learning through functional imaging tests of the human amygdala. Additionally, the extended amygdala interacts with other parts of the brain like the hypothalamus. Hypothalamus is responsible for controlling activities of hormone-producing glands; hence, controlling a person's reactions to stress and anxiety. Therefore, a disruption in the extended amygdala affects other body coordination's and regulations that may lead to negative emotions. Moreover, the extended amygdala plays a critical role during the withdrawal cycle of addiction. Once a victim develops withdrawal symptoms, the extended amygdala recruits stress systems of the brain such as the CRF, (corticotrophin- releasing hormones that drive the body response to stress) dynorphine, and norepinephrine leading to the development of negative emotional states during withdrawal (Koob & Volkow, 2016). Alcohol being one of the highly abused substances has been linked to the disruption of extended amygdala resulting to addiction. According to Roberto et al., (2012), alcohol-related behaviors and mechanisms related to alcohol dependency have been linked to synaptic transmission in

the central amygdala. Long-term emotional disturbances related to alcohol abuse are associated with neurotransmitters that form the extended amygdala.

The Prefrontal Cortex

The prefrontal cortex, located at the front part of the brain and over the eyes, plays a role in complex cognitive processes known as executive functions. It helps in organizing activities and thoughts, managing time, prioritizing tasks, and regulating actions, impulses, and emotions of an individual. The prefrontal cortex plays a part in drug addiction by determining the adaptive value of pleasure that the nucleus accumbens records while checking the urge to take the drug. Numerous brain functions ascribed to the prefrontal cortex and are essential for the healthy functioning of human brain such as emotion, behavior, and cognition. Disruption of the prefrontal cortex could cause significant negative behaviors. As such, disruptions in the prefrontal cortex leads to the addictive drugs having more power in manipulating the reward circuit (Goldstein & Volkow, 2011). A study conducted by Fowler (2014) revealed the prefrontal cortex is highly vulnerable to alcohol toxicity and continued abuse causes loss of executive functions leading to addiction.

Theories of Addiction

Theories and theoretical model of drug addiction have been developed to help understand drug use and abuse in terms of causes, inhibiting factors, treatments, and other elements. Researchers and other experts in the field have continued with the work of identifying new areas of study through theory development. Theories of addiction are categorized into nature theories, genetic/biological theories, psychological theories, and sociological theories. This discussion aims at understanding the neuroscience and neurobiology of alcohol and drug addiction; therefore, the discussion will focus on genetics and biological theories. According to Brownstein (2015), biological theories of drug abuse claim people most likely to use, or become addicted to drugs, have genetic inherited predispositions related to addiction. The theory emphasizes more on role of heredity and its relationship to drug abuse and addiction. Inherited characteristics within a person affect their ability to metabolize substances leading to effects of the substance. However, the biological make up of a person affects the ability to experience substance use in a number of ways including role of drug intake on individual's emotions, behaviors and traits. Genetics play a very limited role in explaining the behavior of a person in relation to drug use and abuse despite its importance in understanding addiction and drug dependence. Theories below have been developed to explain the biology of drug use and addiction.

Incentive-Sensitization Theory

The incentive-sensitization theory argues that alterations in the brain resulting from chronic administration of some psychoactive drugs may lead to increased urge and craving towards the drug. The theory proposes that behavioral patterns in association to chronic substance use makes an individual more prone to the drug and increases risks of addiction. According to studies by Volkow, Koob, & McClellan (2006), people are more likely to develop biological predispositions to substance abuse because of neurological consequences of past use of the drug. The incentive-sensitization theory operates under these four principles. First, every drug that has a high potential of being addictive has the capability of altering the organization of a person's brain through the adaptive process. Secondly, the altered brain systems are those responsible for motivation, incentive, and reward. Thirdly, the brain systems become

hypersensitive to the drug and its associated stimuli because of neurological changes occurring after the addiction. Lastly, the sensitization of the brain system makes the individual gain desire to take the drug more, creating euphoric effects on drugs (Berridge & Robinson, 2016).

The theory also postulates that addictions occur as a result of peculiar motivation. Subsequent use of a drug causes long-lasting dopamine-related motivation systems referred to as neural sensitization (Mike *et al.*, 2022). The sensitization theory relates to addiction through relating drug use to the alteration of the brain circuit as shown in the four principles above. Addictive drugs activate reward centers in the brain by releasing dopamine in the neural system that creates a motivation associated with the growing urge to use the drug, often known as incentive salience/wanting. Small and fragile neural systems help mediate reward consumption, but independent of dopamine. Continued incentive salience leads to pathological levels referred to drug craving when the person experiences hyper-sensitization effects where a person reaches drug-independence status and is unable to overcome any form of physical withdrawal. Therefore; psychological 'wanting` that is triggered by factors such as anxiety, stress, and environment where the drug is found leads to drug addiction. Under such conditions, the brain reward system is less sensitive to drug related rewards causing a person to desire more drugs.

Disease Theory

The disease model of addiction was developed by Jellinek in 1960s after studying alcohol dependency. The theorist relied on old records on substance abuse and addiction dating back 2000 years. Under this model, Jellinek views drug use and excessive drinking as a result of a weak moral character. The four main concepts as derived from the National Council on Alcoholism and Drug Dependence (NCADD) that supports the theory are: the development of tolerance to alcohol; stopping use of alcohol leading to physical withdrawal symptoms; inability to control amount of alcohol consumed, and physical or social impairment related to addiction symptoms. In this theory, people addicted to drug and substances lose control of their mind and have no ability to stop the substance unless with availability of effective interventions. The perspective of the disease theory uses the genetic approach with more emphasize on genetics and inheritance. Addiction is referred to as a disease affecting the brain. Genetics have been highly associated with the development addiction. Genetic make-up of some people makes them more prone to abusing certain drugs than others. The disease theory relates addiction to taking more of the substance than the intended amount, alcohol cravings, high tolerance to the substance, and withdrawal symptoms seen upon removing the substance.

Elements of Addiction

Drug addiction can be associated to a repeating cycle composing of three key stages (intoxication, or binge, followed by withdrawal, and finally anticipation (preoccupation), with each stage highly associated with one of the parts of the brain responsible for addiction described above. Understanding the three cycles helps to identify key symptoms of addiction, prevention and intervention, and approaches towards helping victims recover from addiction (Koob & Volkow, 2010).

Stage 1: Binge/Intoxication

The intoxication stage of addiction cycle refers to the stage when the person starts using a drug or substance. It affects the basal ganglia part of the brain especially the nucleus accumbens and the dorsal striatum. Substance use affects the brain in a number of ways during this stage. First, the substance affects brain reward systems. Nestler (2005) noted all addictive substances are

capable of producing a feeling of pleasure leading to a rewarding effect that has a positive influence on the likelihood and ability to retake the substance. Activities in the nucleus accumbens such as those involved in activating opioids and dopamine signaling system are activated. Also, naturally occurring opioid molecules are responsible for producing mediating effects in addictive substances like alcohol. Secondly, addictive substances trigger stimuli on the individual`s brain. Alcohol and other substances activate the brain reward system by triggering how a person responds to stimuli related to those drugs. A victim starts responding to associated stimuli such as mood, internal states, places and people when using the substance. The stimuli activate the dopamine system triggering a powerful urge to take the substance. The urge may be recurring even with the absence of rewarding effect of the drug. Therefore; a person may be triggered to use the substance when exposed to places, people, or scenarios previously related to drug use. Finally, the sub-region of the basal ganglia known as the dorsal striatum plays a role in addiction during intoxication stage through habit formation. Changes in dorsal striatum, triggered by release of glutamate and dopamine, increase substance-taking and substance-seeking habits (Belin *at al.*, 2009).

Stage 2: Withdrawal/Negative Effects

The second stage of drug and substance abuse cycle is the withdrawal stage characterized by the person experiencing withdrawal symptoms such as negative emotions and physical illness after failing to take the substance. The stage affects the extended amygdala of the brain section. All addictive substances have potential of showing withdrawal symptoms, but the intensity of symptoms vary with the duration of drug uptake and strength of the drug. The diminishing activation of the reward circuit of basal ganglia and activation of stress system in the brain found in extended amygdala causes negative feelings related to withdrawal. Outcome from brain imaging studies reveal a dysfunction of dopamine reward system after long-term use of substances through a decrease of dopamine receptor, 2 (Volkow *et al.*, 2014). A person continues using substances because of strong motivation associated with the negative feeling accompanied by withdrawal actions.

Stage 3: Preoccupation, or Anticipation Stage

The final cycle of drug addiction is the preoccupation stage, whereby a victim starts feeling the urge to use the substance after a period of abstinence. The period depends on the person's level of addiction with some experiencing within few hours and others days. At this stage, the person becomes preoccupied with the substance, through craving. The prefrontal cortex part of the brain which is responsible for controlling executive functions such as organization of activities and thoughts is affected and executive functions inhibited. Executive functions give a person ability to make choices in regards to using or avoiding the substance. As such, disruption of the prefrontal cortex inhibits the ability of the brain to manage such effects as stimuli associated to substance use (Goldstein, 2011). For example, a person finds it hard to avoid drinking alcohol when in a party with friends where the substance is served. Also, a person is unable to control the urge to use substance during stressful situations.

Effects of Different Drugs on the Brain

The brain is affected by different categories and classes of drugs and substances as described below. Drugs have different pharmacokinetics that determine duration it affects the body, which affects its patterns of use (Koob et al., 2015).

International Journal of Psychology
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Alcohol

The consumption of alcohol causes different neurotransmitter systems in the brain such as glutamate and GABA to interact. They produce euphoria and other effects such as anxiety-reducing, motor impairing, and sedating related to alcohol intoxication. Addiction of alcohol involves periods of binge, then withdrawal (Substance Abuse and Mental Health Services Administration (US) & Office of the Surgeon General (US), 2016). Also, a person experiences intense incidence of craving caused by negative emotional states, stimuli and positive emotional states associated with drinking. Intoxication disrupts the balance of chemicals in the brain, and long-term use of alcohol forces the brain to seek ways of compensating effects of alcohol leading to addiction (Model, 2022).

Opioids

Opioids attach to receptors of the brain creating a release of dopamine in the nucleus accumbens. The process causes euphoria, slowed breathing, drowsiness and reduction in pain. Under opioids addiction, the person experiences intense intoxication, tolerance, escalation in use, and withdrawal signs such as physical symptoms, negative emotions, intense stress, sweating, and bodily discomfort. Continued use of opioids affects stimuli associated with effects of substances such as mood and places that trigger intense craving (Substance Abuse and Mental Health Services Administration (US) & Office of the Surgeon General (US), 2016).

Stimulants

Stimulants are highly misused by people as prescription drugs. Stimulants leads to an increase in the amount of dopamine in the brain reward circuit. Also, the drugs boost the level of dopamine in brain regions responsible for making an individual remain more attentive, alert, and vigilant. For example, physicians often prescribe stimulants like dextroamphetamine to people diagnosed with deficit hyperactivity disorder to assist them staying focused on tasks. Moreover, continued uptake of stimulants triggers the release of norepinephrine that affects autonomic functions such as the heart rate. As such, a person becomes more energized and active. Stimulant drugs such as cocaine are highly addictive when taken over a prolonged time (Substance Abuse and Mental Health Services Administration (US) & Office of the Surgeon General (US), 2016). A person who continuously uses these drugs experiences the first cycle of addiction, the binge stage, whereby one can take the drug over a concentrated period lasting few hours to days. Later, the person develops the withdrawal symptoms associated with negative emotions, inactivity and fatigue. In most cases, stimulants disrupt the decision-making capabilities of the brain by affecting the prefrontal cortex (Howard, 2014). Therefore, the person takes the drugs uncontrollably leading to addiction.

Marijuana

Marijuana, also known as cannabis, is one of the most abused substance not only in Kenya but also worldwide. Hana (2022) found out cannabis has the highest prevalence rate among adolescents and youths in the world contributing to major negative health effects including high risks of mental illnesses. Marijuana intake causes a rise in dopamine levels in the basal ganglia region of the brain making the person experience high pleasures. Moreover, marijuana affects receptors in the brain that link to neurotransmitters causing barriers in communication between neurons. The effect of marijuana differs between users, but the most common is the distortion of the motor coordination and perception of time. Also, marijuana follows a similar pattern to alcohol and opioids starting with intoxication followed by withdrawal. Eventually,

the victim develops cravings mostly associated with internal factors such as stress and external factors such as the environment (Lundahl & Johanson, 2011).

CONCLUSION

The study of neuroscience and neurobiology of alcohol and drug addiction shows the use of drugs and substances such as alcohol is highly associated with disruptions of brain circuits leading to addiction. Addiction is associated with experiences of reward or pleasure, stress, habit formation and decision-making. The outcome of the discussion shows three parts of the brain are responsible for drug addiction. These are basal ganglia, extended amygdala, and prefrontal cortex. The paper has also revealed that addiction occurs in three cycles namely; intoxication, or binge, followed by withdrawal, and finally anticipation (preoccupation) and each cycle is associated with one of the identified parts. Also, the level of addiction depends on the class and category of the drug. Researchers continue to conduct more studies on the association of addiction and brain functions with the objective to identifying neurobiological mechanisms underlying the use of substances. As such, future research is expected to come up with interventions in form of new pharmacological and non-pharmacological treatments for controlling addiction.

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