Review

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Role of Executive Functions in Substance Use Disorder

Madde Kullanım Bozukluğunda Yürütücü İşlevlerin Rolü

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ABSTRACT

This review aims to emphasize the critical role of executive functions in substance use disorder (SUD), share recent findings, and highlight the need for further national research in this field. The review comprehensively examines the role and significance of executive functions in light of the diagnostic evolution and the social aspects of SUD. Executive functions—comprising the core components of inhibitory control, working memory, and cognitive flexibility—are essential for planning, decision-making, impulse control, and problem-solving. The review discusses evidence that deficits in executive functions not only serve as significant risk factors for the initiation and progression of SUD but also exacerbate as substance use advances. Furthermore, deficits in executive functioning have been shown to exert a decisive influence on clinical outcomes, including treatment adherence and continuity, and are closely associated with high relapse rates. Current approaches advocate for a thorough evaluation of executive functions when assessing the cognitive impairments related to SUD, and they recommend incorporating cognitive rehabilitation programs aimed at improving executive functions within treatment protocols. In this context, the advantages and limitations of self-report scales, neuropsychological tests, and general cognitive screening tools used in the cognitive assessment of individuals with SUD are discussed. Ultimately, a better understanding of executive functioning deficits in SUD is deemed crucial for improving clinical practices and guiding future research.

Keywords: Substance use disorder, substance addiction, executive functions, neuropsychology

ÖZ

Bu derlemenin amacı, yürütücü işlevlerin madde kullanım bozukluğundaki kritik rolüne dikkat çekmek, güncel bulguları paylaşmak ve bu alanda yapılacak ulusal araştırmalara olan ihtiyacı vurgulamaktır. Derlemede, madde kullanım bozukluğunun tanısal evrimi ve toplumsal boyutları ışığında, yürütücü işlevlerin rolü ve önemi kapsamlı bir şekilde ele alınmıştır. Yürütücü işlevler, temel bileşenleri olan inhibisyon kontrolü, çalışma belleği ve bilişsel esneklik aracılığıyla, bireylerin planlama, karar verme, dürtü kontrolü ve problem çözme süreçlerinde hayati rol oynamaktadır. Madde kullanım bozukluğunda gözlenen yürütücü işlev kayıplarının, madde kullanımının başlaması ve bozukluğun ortaya çıkışında önemli bir risk faktörü olduğu ve madde kullanımı ilerledikçe bu kayıpların şiddetlendiği tartışılmıştır. Ayrıca, yürütücü işlev bozukluklarının tedavi sürecinde, uyum ve devamlılık gibi klinik sonuçlar üzerinde belirleyici etkileri olduğu ve yüksek nüks oranlarının bu kayıplarla yakından ilişkili olduğu belirtilmiştir. Güncel yaklaşımlar, madde kullanım bozukluğundan kaynaklanan bilişsel bozuklukları değerlendirirken yürütücü işlevlerin kapsamlı bir şekilde incelenmesini ve bu işlevlerin iyileştirilmesine yönelik bilişsel rehabilitasyon programlarının tedavi protokollerine dahil edilmesini önermektedir. Bu bağlamda, madde kullanım bozukluğu olan bireylerin bilişsel değerlendirmelerinde kullanılan öz-bildirim ölçekleri, nöropsikolojik testler ve genel bilişsel tarama araçlarının avantajları ve sınırlılıkları tartışılmıştır. Sonuç olarak, madde kullanım bozukluğunda yürütücü işlev bozukluklarının daha iyi anlaşılmasının, klinik uygulamalar ve gelecek araştırmalar için kritik bir öneme sahip olduğu değerlendirilmiştir

Anahtar sözcükler: Madde kullanım bozukluğu, madde bağımlılığı, yürütücü işlevler, yönetici işlevler, nöropsikoloji

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Introduction

Psychoactive substances have been used throughout human history, both in medical applications and for recreational purposes (Berridge 2013, Nathan et al. 2016, Frone 2019). However, problematic use patterns—particularly those involving the misuse of morphine derivatives during wartime—have led to significant societal issues (Uzbay 2009, Kelley et al. 2019). Substance use disorder (SUD) was first classified as a psychiatric condition in 1952 (APA 1952, Nathan et al. 2016). Historically referred to as "substance addiction," the terminology has evolved over time, leading to considerable variation in the literature (APA 1980, APA 1994, Güleç et al. 2015). In the 2000s, the term "addiction" was criticized for its definitional ambiguity and stigmatizing connotations, and the term "substance use disorder" was recommended as a replacement (Rosenthal and Faris 2019). Accordingly, in the fifth edition of the Diagnostic and Statistical Manual of Mental Disorders (DSM-5), the American Psychiatric Association formally adopted "substance use disorder" as the diagnostic label (APA 2013). Under this classification, substances such as tobacco, caffeine, alcohol, cannabis, hallucinogens, inhalants, opioids, sedative-hypnotics and anxiolytics, as well as stimulants such as amphetamines and cocaine, are included (APA 2013).

SUD is widely recognized as a major public health concern due to the increasing diversity of substances and rising prevalence rates worldwide (European Monitoring Centre for Drugs and Drug Addiction 2023a, 2023b, United Nations Office on Drugs and Crime 2024). In particular, stimulants such as cocaine and methamphetamine, along with newly developed synthetic substances, have been associated with overdose-related deaths and other serious health consequences (Turkish National Police Counter Narcotics Department 2023, European Monitoring Centre for Drugs and Drug Addiction 2023a, 2023b, United Nations Office on Drugs and Crime 2024). The COVID-19 pandemic has also adversely affected substance use behaviors, with reports indicating a marked increase in use during the pandemic period (Cisneros and Cunningham 2021, Allen et al. 2023, Lin et al. 2023). A significant rise in overdose incidents and related mortality was reported during this time (Cisneros and Cunningham 2021, Pavarin et al. 2022, Allen et al. 2023, Lin et al. 2023). This pattern has been attributed not only to heightened psychological stress, loss, uncertainty, and social isolation, but also to possible neurological alterations caused by the SARS-CoV-2 virus (Ornell et al. 2020, Cisneros and Cunningham 2021). Individuals with SUD have been identified as a high-risk group, both in terms of increased susceptibility to COVID-19 infection and heightened vulnerability to complications due to the more severe course of the illness (Wang et al. 2021, Krawczyk et al. 2022, Pavarin et al. 2022, Allen et al. 2023, Lin et al. 2023). Furthermore, the increasing involvement of children and adolescents in substance use is a significant cause for concern. A striking example is the seizure of 37 kilograms of cannabis and synthetic cannabinoids disguised as candy in Sweden (European Monitoring Centre for Drugs and Drug Addiction 2022). Similarly, in Türkiye, there has been a growing number of cases involving the use of synthetic cannabinoids through electronic cigarettes, further exacerbating the public health threat (Turkish National Police Counter Narcotics Department 2023). The Turkish Drug Report indicates that the average age in substance use-related deaths is 34, with 35% of cases involving individuals under the age of 30 (Turkish National Police Counter Narcotics Department 2023, Karaaziz and Çelikay Söyler 2024). The high prevalence of substance use among young people highlights the urgent need for both preventive and early intervention strategies in addressing addiction. In this context, understanding the cognitive and psychological mechanisms underlying substance use is of critical importance for increasing treatment success rates and developing effective intervention strategies (Bruijnen et al. 2019a, Diamond and Ling 2020, Kosten et al. 2020, Anderson et al. 2021, Bunaciu et al. 2024).

SUD emerges as the result of a complex interplay of biopsychosocial factors. Among the social and environmental contributors to the development and maintenance of the disorder are poverty, low educational attainment, unemployment, job and housing insecurity, experiences of discrimination, and limited access to healthcare services (Shim and Compton 2018). Research indicates that men are more likely to engage in substance use, typically for recreational purposes, whereas women are more likely to use substances to alleviate unwanted physical symptoms such as pain (Back et al. 2010, Katz et al. 2013, Saha et al. 2016). Age is another key risk factor, with evidence indicating that the likelihood of substance use increases during adolescence. This developmental period is critical, as the emergence of self-

regulation skills and effective coping mechanisms at this stage is known to serve as a protective buffer in adulthood (Brumback et al. 2021). Low educational attainment also poses a significant risk; both an individual's and their parents' level of education have been shown to play an important role in predicting vulnerability to substance use (Öztürk et al. 2015). Health conditions that cause pain are among the leading contributors to substance use risk, followed by psychological problems and personality disorders, with the risk being especially elevated in individuals with borderline or antisocial personality disorders (Katz et al. 2013, Öztürk et al. 2015, Saha et al. 2016, Brennan et al. 2017, Strang et al. 2020). Parental substance use is another critical determinant, with studies reporting that the risk of developing substance use problems is seven times higher in children exposed to maternal addiction (Yule et al. 2013) and five times higher when the father is substance-dependent (Lieb et al. 2002, Kahraman 2019). One of the most critical etiological factors is cognitive dysfunction. In recent years, a growing body of evidence has highlighted the pivotal role of executive functions in both the development and treatment of SUD (Le Berre et al. 2017, Wimberley et al. 2020, Anderson et al. 2021, Dellazizzo et al. 2022, Emek-Savaş 2023b, Wang et al. 2023).

Addictive substances reinforce the urge for repeated use by inducing an intense sense of pleasure, commonly referred to as euphoria (Sayette 2016, Liu et al. 2023). With continued use, tolerance to the substance develops, leading individuals to consume progressively larger amounts to achieve the same effect (Cami et al. 2003, O'Brien 2011). As tolerance increases, control over substance use diminishes, and attempts to reduce or discontinue use often trigger withdrawal symptoms (Cami et al. 2003). The physiological and psychological distress associated with withdrawal further fuels compulsive drug-seeking behavior (Schuckit 2016). During this process, the relief of withdrawal symptoms makes substance use highly reinforcing, progressively driving the individual into a self-perpetuating cycle of diminished control over use (O'Brien 2011). The literature emphasizes the critical role of executive functions in regulating core processes implicated in SUD, including the capacity to resist urges and to delay immediate gratification in pursuit of long-term goals (Tang et al. 2019, Snoek 2024).

Impairments in executive functions play a critical role both in the initiation of substance use and in the risk of relapse following treatment (Le Berre et al. 2017, Wimberley et al. 2020, Anderson et al. 2021, Dellazizzo et al. 2022, Emek-Savaş 2023b, Wang et al. 2023). Current findings indicate that substance use negatively affects executive functioning, while pre-existing executive function deficits may also increase the risk of developing a SUD (Snyder et al. 2015, Everitt and Robbins 2016, Hagen et al. 2016, Ramey and Regier 2019, McPhee and Hendershot 2023). Studies show that when executive dysfunction is present, individuals struggle to resist substance use (Ramey and Regier 2019, McPhee and Hendershot 2023), demonstrate poor adherence to treatment protocols, and are more likely to drop out of treatment prematurely (Domínguez-Salas 2016, Tolomeo et al. 2016, Kosten et al. 2020); furthermore, even among those who complete treatment, relapse rates remain alarmingly high (Yılmaz et al. 2014, Sampedro-Piquero et al. 2019, Erga et al. 2021). Studies have shown that cognitive impairments can occur even in individuals who use substances only occasionally and recreationally, without meeting the diagnostic criteria for SUD (Vonmoos et al. 2013, Woodward and Braunscheidel 2023).

Current approaches recommend a comprehensive evaluation of executive functions when assessing cognitive impairments associated with SUD (Hagen et al. 2016, Bruijnen et al. 2019a), and advocate for the inclusion of rehabilitation programs aimed at improving these functions as part of treatment (Verdejo-Garcia et al. 2016, Sampedro-Piquero et al. 2019, Kosten et al. 2020). Numerous studies have suggested that such interventions may enhance treatment adherence and reduce relapse rates (Houben et al. 2011, Verdejo-Garcia et al. 2014, Diamond and Ling 2020, Kosten et al. 2020, Anderson et al. 2021, Wiers and Verschure 2021). Moreover, strengthening executive functions from an early age has the potential to reduce the prevalence of SUD. Nevertheless, the number of studies examining the role of executive functions in both the development and treatment of SUD remains limited, highlighting the need for further empirical research in this area.

This review provides a comprehensive examination of the relationship between executive functions and SUD. First, it explores the causal role of executive function impairments in the development of SUD, followed by a discussion of their impact during treatment and the importance of cognitive rehabilitation. Finally, the review addresses neuropsychological tests that can be used to assess executive functions in

the course of treatment. The overarching aim is to highlight the critical role of executive functions in SUD, present current findings, and encourage further national research in this domain. To date, no review in the national literature has specifically addressed the role of executive functions in SUD; thus, the present work is expected to serve as a pioneering contribution to the field.

Executive Functions

Executive functions are defined as higher-order cognitive processes that enable individuals to engage in planned, controlled, and flexible behavior rather than relying on automatic responses or impulses (Diamond 2013, Le Berre et al. 2017, Emek-Savaş 2024). The term executive functions serves as an umbrella concept encompassing three core components —namely, inhibitory control, working memory, and cognitive flexibility (Miyake and Friedman 2012, Diamond 2013).

Inhibitory control is the ability to regulate one's attention, thoughts, emotions, and behaviors in the face of strong internal urges or enticing external stimuli (Diamond 2013, Diamond and Ling 2020). This mechanism allows individuals to resist environmental manipulations, override automatic impulses and habits, and is critically important in the context of SUD (Bij et al. 2020). Inhibitory control operates through several sub-processes, including attentional inhibition, which refers to the ability to direct attention toward relevant goals and ignore irrelevant stimuli; cognitive inhibition, which supports the regulation of thought and memory processes; and self-control, which involves the regulation of emotions and behaviors. Impairments or hypersensitivity in attentional inhibition can weaken control mechanisms in individuals with SUD by increasing reactivity to drug-related cues (Coskunpinar and Cyders 2013, Escudero et al. 2024). Cognitive inhibition facilitates the efficient use of working memory by preventing interference between past and current information, a function often referred to as the interference control mechanism (Tello-Ramos et al. 2019). Self-control, on the other hand, is essential for resisting the immediate rewards associated with substance use in favor of achieving long-term goals. This capacity enables the delay of gratification in pursuit of larger rewards (Diamond 2013, Herchenroeder et al. 2022). In individuals with SUD, avoiding environments and people associated with substance use is recommended to reduce reliance on self-control and minimize the likelihood of relapse (Duckworth et al. 2016).

Working memory is the cognitive system responsible for the temporary storage and simultaneous processing of information (Baddeley 1992). This system not only supports fundamental functions such as language comprehension but also plays a critical role in more complex cognitive processes, including evaluating alternatives, learning from past experiences, and generating predictions about the future (Connor and Maeir 2011, Diamond 2013, Diamond and Ling 2020, Emek-Savaş 2024). In the model developed by Baddeley and Hitch (1974), working memory is explained through three main components: the phonological loop, responsible for the storage and manipulation of verbal information; the visuospatial sketchpad, which processes visual and spatial information; and the central executive, which coordinates these subsystems and regulates attentional control. The central executive plays the most important role in determining overall working memory capacity. In the updated model, a new component called the episodic buffer was introduced to address the limited storage capacity of working memory and to strengthen the link between working memory and long-term memory (Baddeley 2000, Baddeley et al. 2010). In the treatment of SUD, individuals must be able to develop and execute an action plan oriented toward the future. These abilities, referred to under the concept of prospective memory, require the active engagement of executive functions, particularly working memory and planning (Bates et al. 2013, Aktan Erciyes 2022, Uçar 2024). Given the difficulty of resisting substance use during treatment, individuals must be able to evaluate past experiences, their current motivation, and their ongoing progress simultaneously when implementing such plans—that is, they must be capable of using their working memory effectively.

Cognitive flexibility refers to the ability to shift between perspectives, think outside the box, and adapt to changing demands (Diamond 2013, Diamond and Ling 2020). This process involves suppressing a current perspective or instruction and adapting to new circumstances, thereby playing a key role in creativity, problem-solving, and learning (Diamond 2013, Dreisbach and Fröber 2019, Emek-Savaş 2023a, Emek-Savaş 2023b, Kupis and Uddin 2023, Bukowski et al. 2024). Thus, cognitive flexibility depends on the integrated

functioning of inhibitory control and working memory (Diamond 2013). When solving a problem, the processes of understanding the issue, developing a strategy, and evaluating the outcome depend on the effectiveness of cognitive flexibility (Cochrane 2014, Diamond and Ling 2016, Kupis and Uddin 2023). The literature indicates that cognitive flexibility is impaired in various neuropsychiatric conditions such as different types of dementia, obsessive-compulsive disorder, and attention-deficit/hyperactivity disorder (ADHD) (Emek-Savaş 2023b, Whitton et al. 2014, Uddin 2021), whereas higher levels of cognitive flexibility have been found to exert a protective effect against SUD (Rose et al. 2019, Kupis and Uddin 2023). Indeed, individuals with low cognitive flexibility tend to exhibit excessive persistence and rigidity in their attitudes (Ionescu 2012). In SUD, impaired cognitive flexibility is reflected in individuals' difficulty disengaging from persistent maladaptive patterns of use, and even when treatment is initiated, in their inability to adjust and adhere to it (Domínguez-Salas 2016). Furthermore, the likelihood of relapse following treatment has been shown to increase in parallel with deficits in cognitive flexibility, and research has consistently emphasized the association between cognitive inflexibility and relapse (Desfosses et al. 2014, Domínguez-Salas 2016).

Executive functions that operate on the basis of inhibitory control, working memory, and cognitive flexibility enable the execution of higher-order executive functions, such as reasoning, problem-solving, and planning (Diamond 2013, Yeniad et al. 2013, Schäfer et al. 2024). Reasoning, also referred to as logical thinking, encompasses the cognitive processes that precede functions like problem-solving and decision-making (Simmons 2010, Vierula et al. 2021). Problem-solving is a multifaceted process involving several stages, including understanding the problem, planning and implementing a solution strategy, and evaluating the outcome (Funke et al. 2018, Schäfer et al. 2024). Planning refers to the organization of goal-directed behavior using strategies such as sequencing and plays a critical role in adapting to novel situations (Sorel and Pennequin 2008, Jensen et al. 2024).

On the other hand, impairments in executive functions are not exclusive to SUDs; they have also been observed in various forms of behavioral addiction. Studies have demonstrated associations between executive dysfunction and behavioral addictions such as compulsive eating (Vidmar et al. 2021, Meng et al. 2025), gaming (Chen et al. 2025), gambling (Ngetich et al. 2024), shopping (Trotzke et al. 2020), and pornography use (Sutrisno and Saputra 2025). A core feature shared across these different types of addiction is the continuation of the behavior despite its adverse consequences, along with a loss of control over the behavior itself (Trotzke et al. 2020, Ngetich et al. 2024, Sutrisno and Saputra 2025). Neurobiological findings indicate that SUD and behavioral addictions share common neural mechanisms, particularly those involved in reward processing and executive functioning, and affect overlapping brain regions, such as the ventral striatum, orbitofrontal cortex, and dorsolateral prefrontal cortex (Grant et al. 2010, Ngetich et al. 2024).

Taken together, executive functions are fundamental cognitive processes that significantly influence an individual's daily functioning, as well as academic and occupational success (Snyder et al. 2015, Diamond and Ling 2020, Schäfer et al. 2024). Previous research has shown that these functions are compromised across various neurological and psychiatric disorders, while their integrity serves a protective role. The next section provides a detailed discussion of their role and significance in SUD.

Executive Dysfunction in Substance Use Disorder

The euphoria induced by addictive substances is so intense that it can severely diminish motivation toward non-drug-related rewards (Loganahtan and Wei Ho 2021). While deferring or resisting such a powerful urge is inherently challenging, this difficulty is further compounded by substance-induced impairments in executive functioning (Ramey and Regier 2019). It is well-established that SUD results in cognitive impairments, with executive functioning being the most consistently and severely affected domain (Verdejo-Garcia 2016, Sampedro-Piquero et al. 2019, Lewis et al. 2020, Emek-Savaş 2023b). Substance use has been shown to cause deficits, most notably in inhibitory control (Fernandez-Serrano et al. 2010, Vonmoos et al. 2013, Broyd et al. 2016, Tolomeo et al. 2016, Le Berre et al. 2017, Nowakowska-Domagała 2017, Cohen et al. 2019, Verdejo-Garcia et al. 2019, Wollman et al. 2019, Dellazizzo et al. 2022, Francisco et

al. 2023), as well as in cognitive flexibility (Oscar-Berman et al. 2009, Broyd et al. 2016, Le Berre et al. 2017, Nowakowska-Domagała 2017, Verdejo-Garcia et al. 2019, Wollman et al. 2019, Lewis et al. 2020, Dellazizzo et al. 2022, Woodward and Braunscheidel 2023), and working memory (Morgan et al. 2009, Fernandez-Serrano et al. 2010, Vonmoos et al. 2013, Potvin et al. 2014, Broyd et al. 2016, Tolomeo et al. 2016, Le Berre et al. 2017, Tang et al. 2019, Wollman et al. 2019, Lewis et al. 2020, Dellazizzo et al. 2022, Woodward and Braunscheidel 2023). Impairments in impulse control—dependent on the simultaneous engagement of self-control and inhibitory control—are particularly prominent in SUD. Increases in impulsivity and risk-taking behavior often result in a loss of control over substance use, a dynamic that plays a critical role across all stages of the disorder, from the development of maladaptive use patterns to treatment adherence and outcomes (Barreno et al. 2019, Ramey and Regier 2019, Anderson et al. 2021).

Higher-order executive functions, which depend on the effective interplay of core executive skills, are also compromised in individuals with SUD. Empirical evidence indicates that these individuals exhibit significant impairments in planning (Morgan et al. 2009, Baldacchino et al. 2015, Tolomeo et al. 2016, Tang et al. 2019, Wollman et al. 2019), abstract reasoning (Fernandez-Serrano et al. 2010, Le Berre et al. 2017), and fluency (Fernandez-Serrano et al. 2010, Le Berre et al. 2017, Wollman et al. 2019). Moreover, deficits are also observed in motor functions (Broyd et al. 2016, Cohen et al. 2019, Wollman et al. 2019, Francisco et al. 2023, Wang et al. 2023) as well as in learning and memory processes (Fried et al. 2005, Fernández-Serrano et al. 2011, Griffiths et al. 2012, Potvin et al. 2014, Broyd et al. 2016, Le Berre et al. 2017, Wollman et al. 2019, Dellazizzo et al. 2022, Wang et al. 2023).

The severity and persistence of executive function impairments vary depending on several factors, including the type of substance used, the method of administration, and the quantity consumed (Monterosso et al. 2005, Field et al. 2010, Le Berre et al. 2017, Poireau et al. 2024). The literature emphasizes that cognitive deficits tend to increase proportionally with both the amount and frequency of substance use (Vonmoos et al. 2013, Le Berre et al. 2017, Ko et al. 2022, Dellazizzo et al. 2022). For instance, in the case of "3,4-methylenedioxymethamphetamine" (MDMA), commonly known as ecstasy, studies have shown that higher lifetime tablet consumption is associated with greater impairments in processing speed and inhibitory control (Halpern et al. 2004, Fernández-Serrano et al. 2011). However, this does not imply that cognitive impairments emerge only in cases of heavy or chronic substance use. In a study by Vonmoos et al. (2013), cognitive deficits were also observed among individuals who used substances recreationally and did not meet the diagnostic criteria for SUD. Comparisons between groups revealed that while chronic cocaine users exhibited marked impairments in working memory, recreational users showed significant deficits in attentional inhibition (Vonmoos et al. 2013). Another study reported that slowed reaction times can be detected even after a single instance of substance use (Woodward and Braunscheidel 2023). Age is another critical factor in SUD; evidence suggests that the earlier the age of first use, the greater the degree of cognitive impairment (Vonmoos et al. 2013, Dellazizzo et al. 2022). Nonetheless, some evidence suggests that age may exert a modest protective effect on the cognitive impairments associated with SUD, with younger individuals exhibiting less pronounced deficits than their older counterparts (Broyd et al. 2016). Longitudinal studies indicate that certain cognitive functions may recover spontaneously following cessation of substance use. Nevertheless, impairments in processes such as impulsive decision-making—driven by heightened reward sensitivity—are likely to persist unless targeted interventions, such as pharmacological treatment or cognitive rehabilitation, are implemented (Le Berre et al. 2017, Nowakowska-Domagala et al. 2017, Tang et al. 2019, Loganahtan ve Wei Ho 2021).

Finally, examining the effects of addictive substances on cognitive functions can be challenging. One major reason is the prevalence of polysubstance use, which makes it difficult to isolate the effects of individual substances. Polysubstance use disorder is characterized by the concurrent use of multiple addictive substances. Contrary to common belief, it is not necessary for diagnostic criteria to be met separately for each substance; rather, the diagnosis of a SUD can be extended by the problematic use pattern of additional substances (Erga et al. 2021). Today, the use of a single substance has become increasingly rare; individuals often engage in polysubstance use, making it difficult to classify cognitive effects by substance type (Uçar 2024). Another factor that complicates the evaluation of substances' cognitive effects is the uncertainty regarding whether the observed executive dysfunctions are a cause or

a consequence of substance use. Current evidence indicates a reciprocal relationship whereby impairments in executive functions increase the risk of substance use, while substance use itself can lead to impairments in executive functioning (Snyder et al. 2015, Emek-Savaş 2023b).

Executive Dysfunction in Substance Use Disorder: Cause or Consequence?

Deficits in executive functions in SUD are considered both a cause and a consequence (Dick et al. 2010, Snyder et al. 2015, Everitt and Robbins 2016, Hagen et al. 2016, Ramey and Regier 2019, Emek-Savaş 2023b, McPhee and Hendershot 2023). For instance, as discussed earlier, substance use disrupts inhibitory control, which in turn contributes to increased impulsive behaviors (Field et al. 2010, Moeller and Paulus 2018). At the same time, poor inhibitory control is closely linked to the loss of control over substance use and the emergence of maladaptive use patterns (Monterosso et al. 2005, McPhee and Hendershot 2023). Impulsive behavioral patterns play a decisive role across all stages of the substance use trajectory—from initiation to treatment—and may significantly shape the course of the disorder (Barreno et al. 2019, Anderson et al. 2021). A salient example of this can be observed in individuals with ADHD, a condition marked by executive dysfunction, who exhibit a substantially higher risk of substance use compared to other groups (Winberley et al. 2020). The presence of comorbid ADHD in SUD cases further complicates the clinical picture (Francisco et al. 2023). Nearly half of individuals diagnosed with ADHD also meet criteria for a comorbid SUD (Jacob et al. 2007, Lee et al. 2011, Francisco et al. 2023). Moreover, the severity of ADHD symptoms has been shown to correlate with increased substance use (Weissenberger et al. 2018, Francisco et al. 2023), while reductions in substance use are associated with improvements in both general functioning and ADHD symptomatology (Thompson et al. 2018, Francisco et al. 2023).

The predictive role of executive functions in academic achievement has been well-documented across numerous studies (Yeniad et al. 2013, Johann and Karbach 2021, Schäfer et al. 2024). Moreover, interventions aimed at improving executive functioning have been shown to enhance academic performance (Baggetta and Alexander 2016, Johann and Karbach 2021). A study by Dean et al. (2018), which investigated academic performance in individuals with SUD, provides further support for the bidirectional relationship between executive functioning and substance use. In this study, participants with SUD were found to have significantly lower childhood academic grade point averages compared to healthy controls. These academic averages were then used to predict cognitive performance, and notably, individuals in the SUD group scored even lower than expected based on their academic history (Dean et al. 2018). These findings suggest that individuals with lower academic performance may be at greater risk for developing substance use problems, and that their cognitive functioning may further deteriorate as a consequence of substance use.

In conclusion, executive dysfunctions observed in SUD can be understood both as a cause and a consequence of substance use. This bidirectional relationship underscores the role of executive deficits as a significant risk factor for the development of substance use problems. Conducting comprehensive cognitive assessments at an early age to identify high-risk individuals and implementing targeted prevention programs for these groups may offer valuable contributions to efforts aimed at preventing and addressing SUD.

Role of Executive Functions in the Treatment of Substance Use Disorder

SUD is associated with high suicide rates, largely due to its physiological and psychological consequences (Geniş et al. 2022, Munch et al. 2023). The treatment of SUD is a complex and demanding process that requires biopsychosocial change and multifaceted intervention (Best and Ivers 2022, Bunaciu et al. 2024). Within this context, executive functions are emphasized as playing a critical role in the planning, implementation, and sustainability of treatment (Copersino et al. 2009, Tolomeo et al. 2016, Bruijnen et al. 2019a, Anderson et al. 2021). Effective engagement in the treatment process—such as making sound decisions, adhering to treatment plans, and regulating the negative effects of substance use—requires individuals to actively draw upon their executive function capacities (Diamond 2013, Herchenroeder et al. 2022, Schäfer et al. 2024). However, the loss of control over substance use, particularly during withdrawal

periods or under the influence of intense cravings, undermines the regulation of emotions, thoughts, and behaviors, thereby compounding the challenges faced during treatment (Diamond and Ling 2020).

Deficits in higher-order executive functions have a direct and detrimental impact on the treatment process of SUD. Indeed, successful treatment requires the active engagement of these functions in planning for the course of recovery and its aftermath, making sound decisions, and effectively implementing those decisions (Diamond 2013, Herchenroeder et al. 2022, Schäfer et al. 2024). In the presence of such deficits, it becomes considerably more challenging to regulate thoughts and behaviors by resisting impulses, as well as to make appropriate decisions and translate them into effective planning and action (Diamond and Ling 2020).

Deficits in executive functions negatively affect treatment adherence, continuity throughout the treatment process, and the therapeutic alliance with clinicians, thereby increasing dropout rates (Copersino et al. 2009, Domínguez-Salas 2016, Tolomeo et al. 2016, Kosten et al. 2020). Moreover, these deficits are known to contribute to relapse—namely, the resumption of substance use following the completion of treatment (Copersino et al. 2009, Yılmaz et al. 2014, Domínguez-Salas 2016, Tolomeo et al. 2016, Barreno et al. 2019, Kosten et al. 2020, Anderson et al. 2021, Sliedrecht et al. 2021). Some studies have reported relapse rates as high as 70% following treatment (Sampedro-Piquero et al. 2019, Erga et al. 2021). Under the influence of cognitive impairments, individuals are more likely to make impulsive decisions and resume substance use rather than delaying gratification (Moeller and Paulus 2018, Ramey and Regier 2019).

These findings point to a bidirectional causal relationship between executive function deficits and SUD, underscoring the significant influence of these deficits on treatment adherence, relapse, and overall treatment outcomes. Therefore, integrating interventions that specifically target the rehabilitation of executive functions into the treatment of SUD emerges as a critical strategy for enhancing treatment effectiveness and reducing the risk of relapse.

Enhancing Executive Functions during the Treatment of Substance Use Disorder

The literature emphasizes the necessity of incorporating cognitive training and rehabilitation programs, specifically targeting executive functions, into treatment protocols to improve the effectiveness of interventions for SUD (Teichner et al. 2001, Verdejo-Garcia et al. 2016, Sampedro-Piquero et al. 2019, Kosten et al. 2020). Research suggests that strengthening core executive functions such as working memory (Houben et al. 2011, Wiers and Verschure 2021), impulse control (Anderson et al. 2021), and decision-making abilities (Verdejo-Garcia et al. 2014) can significantly enhance treatment outcomes (Diamond and Ling 2020, Kosten et al. 2020).

A variety of cognitive training programs and intervention strategies aimed at enhancing executive functions have been developed and tested, and these approaches have been shown to yield positive outcomes across all age groups (Diamond and Ling 2016, 2020). These interventions primarily aim to strengthen individuals' behavioral self-regulation by reducing impulsivity, thereby offering meaningful support throughout the treatment process (Anderson et al. 2021). Notably, improvements in working memory have been found to positively influence other executive functions, particularly inhibitory control, and thus working memory enhancement has become a frequent target in cognitive rehabilitation efforts (Bickel et al. 2011, Houben et al. 2011, Amunts et al. 2020, Wiers and Verschure 2021). For instance, Bickel et al. (2011) implemented a cognitive training program designed to improve working memory in individuals with stimulant use disorder. Participants engaged in a series of tasks involving the visual and auditory presentation of words and numbers. The study reported that this cognitive training led to improvements in delay discounting test performance, which assesses self-control—specifically, participants demonstrated enhanced ability to delay gratification. Similarly, Houben et al. (2011) showed that enhancing working memory in individuals with alcohol use disorder could reduce substance consumption. Following a cognitive training intervention that included working memory tasks administered over at least 25 days,

participants exhibited a decrease in alcohol intake, and this reduction was sustained even at a one-month follow-up assessment.

The necessity of incorporating cognitive training and rehabilitation programs into the treatment process for SUD is well recognized. However, studies have shown that longer treatment durations and an increased number of sessions are associated with higher dropout rates. Accordingly, it is recommended that treatment plans prioritize individualized, time-efficient, and targeted interventions (Copersino et al. 2009, Brorson et al. 2013, Hagen et al. 2016, Lappan et al. 2020). To maximize treatment efficacy, impaired cognitive domains—particularly executive functions—should be identified, and tailored rehabilitation protocols should be integrated into the therapeutic process (Bruijnen et al. 2019a, Diamond and Ling 2020, Kosten et al. 2020). Crucially, such integration relies on the comprehensive assessment of cognitive functioning prior to intervention (Hagen et al. 2016, Bruijnen et al. 2019a). At this stage, selecting appropriate and psychometrically valid assessment tools is essential for accurate screening and intervention planning.

Assessment of Cognitive Functions in Substance Use Disorder

Various executive function tests are employed to assess cognitive functioning in individuals with SUD. In a study comparing the effectiveness of executive function tests such as the Stroop Test (Stroop 1935, Emek-Savaş et al. 2020) and the Trail Making Test (Reitan 1955, Taşkıran et al. 2025) within a SUD sample, the Behavior Rating Inventory of Executive Function for Adults [BRIEF-A (Roth et al. 2005)] demonstrated greater sensitivity than other instruments (Hagen et al. 2016). However, it is important to note that the BRIEF-A is a self-report measure, and individuals with SUD often exhibit limited insight into their own cognitive deficits. As a result of this reduced self-awareness, discrepancies may arise between self-report measures and objective performance-based assessments (Bruijnen et al. 2019b). Therefore, it is recommended that self-report measures be supplemented with performance-based tests during cognitive assessment.

It is well established that SUD affects multiple cognitive domains, and cognitive screening tests are commonly employed to conduct a comprehensive assessment (Ko et al. 2022). Among the most frequently used screening tools are the Mini Mental State Examination [MMSE (Folstein et al. 1975, Güngen et al. 2002)], the Montreal Cognitive Assessment [MoCA (Nasreddine et al. 2005, Selekler et al. 2010)], and the Addenbrooke's Cognitive Examination-Revised [ACE-R (Mioshi et al. 2006, Yıldız 2011)] —all originally developed for the detection of dementia and mild cognitive impairment (Crivelli and Balconi 2021, Ko et al. 2022, Balconi et al. 2022).

The MMSE demonstrates limited sensitivity in the domains of executive functioning and memory, and its discriminative power in SUD is constrained due to ceiling effects (Ridley et al. 2018, Ko et al. 2022). Although the ACE-R offers a more comprehensive assessment than the MMSE, there is insufficient empirical support for its validity in the context of SUD (Ko et al. 2022). The widely used MoCA has shown acceptable levels of sensitivity and specificity (Ridley et al. 2018, Bruijnen et al. 2019a, Ko et al. 2022); however, it has been criticized for insufficiently evaluating cognitive functions that are particularly vulnerable to substance use, such as visual memory and delayed recognition (Copersino et al. 2009), and for the lack of significant group differences across many of its subtests (Bruijnen et al. 2019b, Brooks et al. 2024). In conclusion, these tests are considered inadequate for comprehensive assessment and are recommended to be used in conjunction with additional neuropsychological measures.

A common characteristic of the cognitive screening tests widely used in the context of SUD is that they were originally developed for the assessment of other neurological conditions (Copersino et al. 2009, Hagen et al. 2016, Bruijnen et al. 2019a). Given that each disorder presents with its own distinct clinical course and executive function deficits, the design and emphasis of these tests are inherently shaped by their original purpose (Amunts et al. 2020, Crivelli and Balconi 2021). As a result, certain cognitive skills may be assessed unnecessarily, while other processes, particularly those compromised by SUD, may not be adequately examined (Amunts et al. 2020, Berry et al. 2021a). Consequently, the literature repeatedly

highlights the need for neuropsychological assessments specifically tailored to the cognitive dysfunctions associated with SUD (Balconi et al. 2022).

To partially address this gap, the Brief Evaluation of Alcohol-Related Neuropsychological Impairments (BEARNI) was developed to assess functions commonly affected by alcohol use disorder, such as executive functions, visuospatial skills, and ataxia (Ritz et al. 2015). However, a study comparing BEARNI to other tests reported that it classified nearly all patients as cognitively impaired, indicating a very low level of specificity (Pelletier et al. 2018, Ko et al. 2022). As a result, due to these psychometric limitations and its design being restricted to alcohol-related impairments, the BEARNI has not adequately met the broader assessment needs of the field.

Table 1. Neuropsychological instruments commonly used to assess executive functions in substance use disorder

Test	Turkish Standardization	Original Intended Use	Type of Assessment	Cognitive Functions Assessed
BEAT (Berry et al. 2021b)	Uçar (2024)	Substance Use Disorder	Executive Function Test Battery	Inhibitory Control, Working Memory, Cognitive Flexibility, Planning/Organization, Attention, Psychomotor Speed, Verbal Memory, Visual Memory, Prospective Memory, Abstraction, Visuospatial Skills, Motor Skills, Language
BEARNI (Ritz et al. 2015)	No Turkish standardization available.	Alcohol Use Disorder	Executive Function Test Battery	Working Memory, Cognitive Flexibility, Verbal Memory, Visuospatial Skills, Motor Skills
MoCA (Nasreddine et al. 2005)	Selekler et al. (2010)	Mild Cognitive Impairment	General Cognitive Screening	Executive Functions, Attention, Memory, Visuospatial Skills, Language, Orientation
ACE-R (Mioshi et al. 2006)	Yıldız (2011)	Mild Cognitive Impairment	General Cognitive Screening	Orientation, Attention, Memory, Language, Visuospatial Skills
MMSE (Folstein et al. 1975)	Güngen et al. (2002)	Mild Cognitive Impairment	General Cognitive Screening	Orientation, Attention, Memory, Language, Visuospatial Skills
BRIEF-A (Roth et al. 2005)	No Turkish standardization available.	Executive Function Assessment in Adults	Self-Report Scale	Inhibitory Control, Working Memory, Cognitive Flexibility, Planning/Organization

BEAT: Executive-Function Assessment Tool, BEARNI: Brief Evaluation of Alcohol-Related Neuropsychological Impairments, MoCA: Montreal Cognitive Assessment, ACE-R: The Addenbrooke's Cognitive Examination-Revised, MMSE: The Mini Mental State Examination, BRIEF-A: Behavior Rating Inventory of Executive Function for Adults.

In 2021, Berry et al. (2021b) introduced the Brief Executive-Function Assessment Tool (BEAT), the first instrument specifically developed to provide a comprehensive evaluation of cognitive abilities affected by SUD. During its development, all addictive substances—including alcohol—were considered collectively, and the test's inclusive design has addressed a significant gap in the existing literature (Berry et al. 2021b). The BEAT primarily focuses on executive functions and comprises nearly twenty subtests, including a self-report questionnaire, trail making, clock drawing, figure copying, word list learning, digit span, working memory, motor sequence tasks, abstraction, letter fluency, category fluency, reading, word list recall, naming, delay discounting, visual memory, incidental learning, and prospective memory (Berry et al. 2021b). The test was initially developed using data from an inpatient population and was later re-evaluated for validity in an outpatient sample receiving treatment in ambulatory settings. The findings demonstrated that the test could be effectively employed across both groups (Berry et al. 2021b, Brooks et al. 2024). However, it has been reported that the BEAT lacks sufficient sensitivity to detect acute cognitive changes associated with intoxication and withdrawal states. This limitation has been interpreted to suggest that

the BEAT is more suited to assessing stable cognitive impairments in SUD, which is considered a strength in terms of the test's reliability. While cognitive performance may indeed fluctuate due to intoxication or withdrawal, these fluctuations do not appear to lead to false positive results on the BEAT (Brooks et al. 2024). Nevertheless, particular caution is warranted when the aim is to evaluate individuals specifically during intoxication or withdrawal periods.

As part of an unpublished master's thesis, the BEAT was standardized for the Turkish population and subsequently made available for use in Türkiye (Uçar 2024). The study involved 180 healthy individuals and 79 participants diagnosed with SUD, with the two groups matched on age and educational level. The clinical sample comprised individuals with SUD involving alcohol, cannabis, hallucinogens, inhalants, opioids, sedative-hypnotic or anxiolytic substances, and stimulants. SUD related to tobacco and caffeine were intentionally excluded from the study. In this context, the BEAT was culturally adapted into Turkish, and a comprehensive series of validity and reliability analyses was conducted. The findings revealed that participants with SUD scored significantly lower on the BEAT than their matched healthy counterparts. Among healthy participants, test performance declined with age, improved with higher levels of education, and showed no significant differences by gender. Taken together, these results support the Turkish version of the BEAT as a valid and reliable screening tool for identifying executive dysfunction in individuals with SUD (Uçar 2024). Given that the BEAT represents the first neuropsychological instrument specifically developed for this population and currently lacks an equivalent alternative, it is expected to serve as a valuable tool in both clinical and research settings, with the potential to inform treatment planning and preventive strategies. Nonetheless, its recent development underscores the need for further validation across broader and more diverse clinical samples. Table 1 provides an overview of the neuropsychological tests commonly employed to evaluate executive functions in SUD.

Conclusion

As the global fight against SUD continues, every research contribution to this effort carries substantial significance. The emergence of new synthetic substances—expected to pose serious threats to public health and safety—along with the rising prevalence of substance use and the growing proportion of young individuals affected by addiction, further underscore the urgent need for continued research in this field (European Monitoring Centre for Drugs and Drug Addiction 2023a, 2023b). Given that rates of treatment acceptance and adherence remain notably low and that post-treatment relapse is highly prevalent, there is a clear imperative for studies aimed at enhancing the effectiveness of existing treatment approaches (Sampedro-Piquero et al. 2019, Erga et al. 2021). Within this context, the critical role of executive functions in SUD becomes increasingly evident. Executive functions are not only adversely affected by substance use, but such impairments have also been identified as a significant risk factor contributing to the development and persistence of substance use (Dick et al. 2010, Everitt and Robbins 2016, Hagen et al. 2016, Emek-Savaş 2023b, McPhee and Hendershot 2023). A bidirectional causal relationship appears to exist between executive dysfunction and SUD—one that plays a decisive role across multiple stages, from the emergence of problematic substance use patterns to the planning and implementation of treatment interventions (Ramey and Regier 2019, Kosten et al. 2020, McPhee and Hendershot 2023).

This review has provided an in-depth discussion of the role and significance of executive functions in SUD, with particular emphasis on the adverse effects of executive dysfunction on both substance use patterns and treatment outcomes. To enhance treatment efficacy, the need for comprehensive cognitive assessment and targeted remediation of impaired executive functions has been underscored. Integrating cognitive training or rehabilitation programs into existing treatment protocols is anticipated to yield significant benefits in the management of SUD. Assessment of cognitive functioning—particularly executive functions—during early developmental stages may help identify high-risk individuals before substance use emerges. Prevention programs targeting these groups can then play a proactive role in reducing the incidence of addiction. However, research addressing executive dysfunction in SUD remains limited in the national literature. To sustain an effective response to this public health challenge, greater support for scientific research in this field is urgently needed.

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