Neuropsychological Trends

33
April 2023 - Special Issue

Why we need to assess dysfunctional decision-making process in addictions within a comprehensive framework

Laura Angioletti[1,2]

[1] International research center for Cognitive Applied Neuroscience (IrcCAN), Catholic University of the Sacred Heart, Milan, Italy

[2] Research Unit in Affective and Social Neuroscience, Department of Psychology, Catholic University of the Sacred Heart, Milan, Italy

DOI: https://doi.org/10.7358/neur-2023-033-angi laura.angioletti1@unicatt.it

ABSTRACT

This theoretical contribution focuses on the neurocognitive disorder of addiction as it is one of the clinical disorders in which a deficit in decision-making has been most frequently explored in the neuroscientific literature. The decision-making deficit in substance use disorders and behavioral addictions, in particular gambling disorder and internet gaming disorder, is here highlighted. There is currently no consensus or shared understanding of how to assess decision-making given its complexity and close connection to executive functions; therefore, without claiming to be exhaustive, three examples of methodologies and studies showcasing potential approaches to assess decision-making process in addictions have been proposed. Determining possible vulnerabilities in decision-making processes can be important for identifying people who are more likely to develop an addiction, as well as for treatment options, or may be less likely to adhere to addiction treatment.

Keywords: assessment; decision-making; addiction; substance use disorder; behavioral addictions

1. Introduction

When considering a condition in which there is an evident impairment at the level of decision-making, it is possible to refer to the field of addiction, a clinical neuropsychiatric disorder in which the decision-making deficit has been widely explored in the neuroscientific literature. In fact, in substance use disorders (SUDs) and behavioral addictions, (BAs) what is observed is an inability to "make the right decision" or to maintain the determination (i.e., the decision) to "stop the addictive behavior".

Traditional research on the neuropsychology of decision-making has examined this deficiency at the level of decision-making in addictions with cognitive laboratory tests (Bechara, 2005). Also, before it was suggested that brain structure abnormalities in individuals with addictions could be related not only to drug use but also to the predisposition of development addiction disease(Makris, Gasic, et al., 2008). Recently, an impairment at the level of decision-making process has been identified as both cause and consequence of SUD (Verdejo-Garcia et al., 2018), and it has been consistently associated with lower adherence to addiction treatment and relapse.

Indeed, it has been determined that the deficit at the level of decision-making processes can be explained by the impairment of the neural bases that support the individual's executive functioning (Balconi & Campanella, 2021). Executive functions are a family of high-order functions, encompassing functions such as inhibitory control, cognitive flexibility, emotion regulation, regulation of reward systems and the decision-making processes, that orchestrate the capability of the individual to provide an appropriate goal-directed behavior to the situation and contextual demands (Miller & Cohen, 2001).

Given these premises, it becomes evident how determining possible discrepancies or vulnerabilities in decision-making processes may be important for identifying individuals who are more likely to develop an addiction, as well as for treatment options, such as for targeting patients that could benefit from motivation-focused rehabilitation methods or could be less likely to adhere to addiction treatment. Moreover, to provide a comprehensive effort-based motivation and decision-making measure may be especially helpful to identify patients with lack of motivation and decision-making vulnerabilities, that could be at greater risk of relapse. Thus, it becomes critical to evaluate and address these unique decision-making processes in patients with addiction to determine their relative burden and clinical relevance.

With this in mind and without claiming to be exhaustive, the following sections will describe the decision-making impairment in SUDs and BAs and will provide examples of research lines that have attempted to evaluate decision-making and executive functions impairment in addictions.

2. Decision-making impairment in Substance Use Disorders (SUDs)

At the neurophysiological level, addiction researchers have frequently focused on the prefrontal cortex (PFC) as a pivotal neural hub that supports executive functions and neurocognitive processes (Goldstein & Volkow, 2011). Despite the PFC's deeply interconnected function, two separate PFC systems have been linked to various subcomponents of the frontal functioning. The "cool" executive functions network encompassing the anterior cingulate cortex (ACC), lateral inferior cortex, and dorsolateral prefrontal cortex (DLPFC) that supports working memory, inhibitory control, task switching, and conflict monitoring (Badre et al., 2009; Koechlin et al., 2003), and the "hot" executive functions network that comprehends the ventral, medial, and orbitofrontal structures (VMPFC, OFC) and supports the valuation, emotion regulation, and decision-making processes (all functions involved in reward/emotion-related aspects) (Balconi et al., 2015b, 2015; Balconi & Finocchiaro, 2015; Bechara et al., 2005; Peters & Büchel, 2010).

In patients with addiction, Makris and colleagues (2008) discovered a link between the thinner PFC and poorer judgment and decision-making ability(Makris, Oscar-berman, et al., 2008). Specifically, reductions in right prefrontal activity during decision-making may reflect impaired working memory, stimulus reward valuation, or cue reactivity in substance-dependent individuals (Tanabe et al., 2007). In several recent studies, it has been demonstrated that individuals with SUD showed a strong lateralization effect in the dorsolateral portion of the PFC, which is involved during the decisional process: individuals with SUDs displayed an increase of left hemisphere activation in response to immediate reward choices, and this cortical unbalance effect has been associated to the lower performance in the decision-making performance at the Iowa Gambling Task (IGT) (Balconi et al., 2015; Balconi, Finocchiaro, & Campanella, 2014a, 2014; Balconi, Finocchiaro, & Canavesio, 2014; Balconi & Finocchiaro, 2015; Finocchiaro & Balconi, 2017).

3. Decision-making impairment in Behavioral Addictions (BAs)

With reference to BAs, interestingly, previous research has shown that the manifest behavior of individuals with BAs on the IGT, in particular Gambling Disorder (GD), is equivalent to that of patients with SUDs (Goudriaan et al., 2006).

Thus, identifying and elucidating the neural substrates that underlie decision making deficit in these patients may elucidate the mechanisms that contribute to continued high-risk behaviors in pathological gamblers (Balconi et al., 2015b). At least two underlying types of dysfunctions have been identified where reward signals turn in favour of immediate outcomes in the case of decisions: (1) hyperactivity in the emotional system, mediated by frontal and medial structures such as the OFC, ACC and amygdala, which exaggerate the rewarding impact of external reinforcers, and (2) hypoactivity in the prefrontal cortex (such as left ventromedial areas, VMPFC, and mainly the DLPFC), which predicts the long-term consequencesof a given action and that is a critical component for working memory and executive processes. Damage or dysfunctional conditions to either of these systems can alter the normal functioning of the decisional processes in SUDs, but also in GD (Balconi et al., 2015b).

Besides, previous studies used the IGT, which notoriously offers an index of the participant's capacity to elaborate and determine likelihood of reward and loss, with the aim of exploring decision making deficit and reward mechanisms in individuals with Problematic Internet Use (PIU) (Ko et al., 2010; Nikolaidou et al., 2016; Sun et al., 2009). Interestingly, contrasting findings at the IGT were reported so far, perhaps due to differences in methodology. The IGT overall performance of users with PIU was impaired when matched with controls in Sun and colleagues' work (Sun et al., 2009), whereas Ko and colleagues observed that they performed better than controls (Ko et al., 2010). Nikolaidou and colleagues (2016) reported higher skin conductance responses in relation to trials with greater degree of penalty, suggesting a higher sensitivity to loss and punishment and showing a difference from other addiction profiles (Nikolaidou et al., 2016). Therefore, the question of whether individuals with PIU share potential similarities in behavioral decisionmaking abilities and neurophysiological functioning with other addictions still remains open.

Also, a positive correlation between Internet Addiction Test scores and IGT performance was identified, suggesting the ability of the PIU sample to implement fruitful learning from reward and loss trials and, consequently, preserved decision-making processes (Balconi & Angioletti, 2021). This result goes in contrast with previous research showing impaired decision-making processing in PIU (Balconi et al., 2017), and with research suggesting similarities in behavioral decision-making abilities and neurophysiological functioning with other addictions.

However, in line with previous evidence suggesting preserved decision-making and sensitivity to punishment in PIU (Balconi et al., 2018; Sun et al., 2009), a recent study compared the IGT performance of individuals with gambling disorder with a PIU clinical sample and control subjects. Despite both patient groups performed worse at the IGT than healthy controls, Internet Gaming Disorder patients performed poorer only at the beginning of the task (Wölfling et al., 2020). This last finding implies that, though both groups of patients tended to process information more spontaneously when facing a rewarding condition, the monetary dysfunctional effect mainly occurred in gambling patients, while IGD patients, in contrast, tended to shift toward more adaptive decision-making strategies (Wölfling et al., 2020). Such study adds to the literature suggesting preserved decision-making processes (at least the behavioral level) in PIU (Balconi & Angioletti, 2021).

Although the evidence related to decision-making processes in individuals with PIU showed a halfway profile between the preserved function and a pathological condition, this mechanism is still understudied and research on larger clinical PIU samples are needed.

4. How to assess the decision-making impairment in addictions?

4.1 Assessing the stages of dysfunctional decision-making

In their review, Verdejo Garcia and colleagues (2018) explored decision-making impairments in addiction in the framework of a unified model of decision-making, which posits that decision-making is implemented by the integration of a variety of cognitive control processes (Coutlee & Huettel, 2012; Ernst & Paulus, 2005). According to the model's underlying assumptions, decision-making involves at least three stages, including i) preference formulation, ii) choice implementation, and iii) feedback processing, each of which includes a variety of cognitive control processes.

Firstly, the preference formation stage includes the components of reflection, that is related to information sampling, and the uncertainty and risk evaluation, that are appraisal processes which support risk and reward evaluation (such as comparing the potential benefits and dangers of drug use to other forms of enjoyment or abstinence/recovery) (Verdejo-Garcìa & Bechara, 2009).

Secondly, the choice implementation stage includes the allocation of motivational resources for response initiation; the inhibition of competing actions (i.e., cognitive inhibition); and self-regulation to override alternatives with comparable perceived values (Strait et al., 2014).

Thirdly, at least three outcome-evaluation processes are included in the feedback processing/learning stage: the reward and punishment learning, that is strictly related to the motivational valence (determining the attention to gains versus losses), the memory recency (weighting more recent outcomes versus earlier outcomes), and the consistency process, that is the coherence between the feedback history and subsequent decisions (Ahn et al., 2016).

For each decision-making stage, several classical laboratory tasks have been proposed for examining the cognitive processes underlying these stages and evidence related to the performance of individuals with SUDs at these tasks have been provided (Verdejo-Garcia et al., 2018).

For instance, for the first stage related to the formation preference, authors stated that studies applied Information Sampling Task and the Beads Task on individuals with SUDs (e.g., binge drinkers and chronic users of cannabis, cocaine, amphetamines and opiates) to measure reflection impulsivity and showed that such individuals are satisfied to use less information to make their decisions relative to healthy controls (Banca et al., 2016; Stevens et al., 2015). These results suggest that people with SUDs are more prone to tolerate uncertainty and risk during formation of preferences.

Or again, through the application of tasks that measured decision-making under risk, such as Coin Flipping Task, the Cups Task, the Balloon Analogue Risk Task, the Randomized Lottery Task, and the Cambridge Gamble Task, and under ambiguity, such as the IGT, consistent findings across a broad range of substance use disorders (e.g., alcohol, cannabis, cocaine, and opiates) showed that addicted individuals prefer risky over safe alternatives (Brand et al., 2008) and a disadvantageous decision-making under ambiguity (Balconi, Finocchiaro, & Campanella, 2014a; Balconi, Finocchiaro, & Canavesio, 2014; Balconi & Finocchiaro, 2015).

If on the one hand this review has the advantage of proposing the evaluation of the different stages of decision making in patients with SUDs through various cognitive laboratory tasks typically also used in the neurosciences, on the other hand it does not deal with the evidence of an impairment in one or more of these stages of the decision-making process in BAs. Moreover, the current theoretical contribution strives to provide an overview of possible evaluation approach and tasks and it does not focus on the aspects dedicated to decision-making treatment; however, it should be noted that recent larger theoretical monographs and systematic reviews also proposed neuropsychological interventions for decision-making impairment and executive functions in addictions (Balconi & Campanella, 2021; Verdejo-García et al., 2019).

4.2 Assessing the multiple features of impaired decision-making

More recently, it has been underlined how a sound and comprehensive conceptualization of decision making as an umbrella construct, encompassing its cognitive, affective, motivational, and physiological subcomponents, is still lacking. This might hinder the effective assessment of a variety of decision-making deficits and the development of tailored addiction treatment (Rochat et al., 2019).

Thus, with the aim of assessing dysfunctional decision-making in addiction, Rochat and colleagues (2019) proposed a taxonomy of transdiagnostic features of decision-making in addiction and a related assessment battery. Authors included tasks for measuring the following cognitive processes: reward sensitivity, attentional bias and associative processes, inhibition, cognitive flexibility, updating, and mental time travel. Additionally, they stated that the detail of measures proposed in this battery should only be considered as examples of laboratory tasks or self-assessments that could be used to evaluate any process that falls under the framework of processes involved in poor decision-making in addiction.

However, what is interesting about this battery is that the authors also propose to measure processes that have been less taken into consideration by the literature on decision-making impairment, but which can broaden the investigation on the process itself, namely interoception and social cognition.

4.2.1 Evaluating the interoceptive dysfunction in addiction

Indeed, in relatively recent years, Noël and colleagues (Noël et al., 2013b, 2013a) extended the dual-process perspective in addiction (proposing a dichotomy between impulsive-automatic and reflective-controlled determinants of behavior (Bechara, 2005; Koob & Le Moal, 2001; McClure & Bickel, 2014)) to a "triadic" model integrating a third system related to interoceptive processes.

In fact, research suggested that interoceptive system dysfunction may affect how drugs are processed as well as how self-awareness is regulated. This could lead to underestimating the severity of a disorder, failing to recognize an illness (or lacking insight), denying it, or dissociating intention from action (Goldstein et al., 2009; Goldstein & Volkow, 2011; Verdejo-Garcia et al., 2012), in particular when drug induced damage to the insula interrupts the interoceptive input signalling the current state of the body. Lack of insight is a significant problem in drug treatment because some people who need help may not understand why they need treatment. This diminished perception of the need for therapy and/or underestimation of the severity of addiction may lead to poor decision-making in the context of ongoing drug abuse or addictive behaviors despite frequent negative outcomes (Brevers & Noël, 2013; Goldstein et al., 2009; Goldstein & Volkow, 2011).

In their battery, Rochat and colleagues (2019) proposed to encompass the following tasks for measuring different dimensions of interoception: the Heartbeat Detection Task (Barrett et al., 2004) with confidence rating (Garfinkel et al., 2015) to measure both interoceptive accuracy and awareness; the awareness section of the Body Perception Questionnaire (Porges, 1993) to measure interoceptive sensibility; and the Visual-Perception Judgement Task with confidence rating (Moeller et al., 2016) to measure self-awareness.

If on the one hand the link between decision-making and interoception has been clarified since this diminished perception of the need for therapy or of the severity of addiction may lead to poor decision-making in the context of drug maintenance, on the other hand, additional studies are still needed to clearly clarify the link between the decision-making deficit and social cognition in addictions.

Certainly one of the strengths of Rochat and colleagues (2019) proposal is that it underlines the need to investigate the decision-making process as an umbrella construct that includes cognitive and affective processes underneath it, and underlines how it is essential to go beyond the use of decision-making laboratory tasks general and multideterminate and identify specific impairments in decision-making processes to favor psychological interventions adapted to the specific dysfunctions of the person.

4.3 Assessing executive functions and decision-making impairment

As last point, we mention here a battery of neurocognitive tests and tasks dedicated to the evaluation of executive functions in addictions, the Battery for Executive Functions in Addiction (BFE‑A), that has been recently developed to target the need of assessing this deficit in SUDs (Balconi et al., 2022; Balconi & Campanella, 2021; Crivelli et al., 2022).

This tool encompasses specific selected tests to measure the executive functions and to assess their impairment as prerequisite of the neurocognitive deficit in substance use disorders. The BFE-A includes subtests to measure short/long-term memory, working memory, focused attention, verbal and non-verbal cognitive flexibility, attention regulation and suppression of interference and inhibitory control.

One innovative methodological point of this tool is the presence of two computerized cognitive tasks whose application has been strictly related to the context of addiction through the use of addiction-related word and addiction-related background pictures: the Modified Stroop Task for Addiction (MSTA) and the Modified Go/No-Go task for Addiction (MGTA).

The MSTA of the BFE-A is a computerized neurocognitive task devised to investigate the integrity of attention regulation processes and of mechanisms allowing for the control of interference due to semantic incongruence or salience of stimuli related to substance use. Four alternative though comparable versions of the MST were created for this battery, focused on specific substance use pictures and different primary substances of abuse: stimulants, opioids/sedatives/hypnotics, alcohol, and cannabis.

The MGTA of the BFE-A is a computerized neurocognitive task specifically devised to assess executive control and response inhibition in addictive disorders. The task also involves the systematic manipulation of the background on which the Go and No-go stimuli are presented. The background can recall neutral semantic contexts (e.g., physical activity or environments/scenes of daily life) or be semantically associated with substance use contexts, tools, materials, or experiences. As for the MSTA, the MGTA includes four different though comparable sets of backgrounds, associated with different primary substances of abuse: stimulants, opioids/sedatives/hypnotics, alcohol, and cannabis. Performance and error measures includes, for both tasks: response times, response accuracy, and number of omitted responses.

The findings collected through the studies applying this tool provided first data on the potential of BFE-A as a brief but informative neurocognitive screening tool, aimed at highlighting differences of clinical value in executive functions efficiency of patients with addictive disorders (Balconi et al., 2022; Crivelli et al., 2022).

Future advancements of the BFE-A neurocognitive battery application for measuring executive dysfunction in addiction will include i) the recording of the electro- and psycho-physiological correlates and autonomic physiological responses during the administration of the neurocognitive tasks, ii) the extension of the reference target sample to BAs (gambling and internet gaming disorders), and iii) the integration in this battery of specific tasks or tests dedicated to measuring the deficit related to decision-making processes, which takes into account its different stages and the additional cognitive processes related to it.

The findings obtained with the BFE-A would benefit from further testing and integration with additional neuropsychological and psychometric tests to properly assess convergent/divergent validity of the tool as well as with objective neurofunctional markers of cognitive performance (e.g., Event-Related potentials with electroencephalogram, or task-related modulation of cortical blood perfusion as measures by functional Magnetic Resonance Imaging or functional Near Infrared Spectroscopy) to further test the neurophysiological correlates executive functioning in addiction.

5. Conclusive remarks

This theoretical contribution focuses on the neurocognitive disorder of addiction as it is one of the clinical disorders in which a deficit in decision-making has been most frequently explored in the neuroscientific literature.

Currently there is not yet a unified and shared perspective regarding how to measure decision-making in its complexity and in its close relationship with executive functions: here, without claiming to be exhaustive, three examples of approaches and studies displaying possible ways to evaluate decision-making process have been proposed.

However, it is believed that not only for addictions, but also for other clinical or healthy conditions in which it is intended to evaluate potential impairment at the decision-making level, it is necessary to adopt a unified perspective and a comprehensive framework that takes into account the complexity of the decision-making process, of the three stages that compose it (according to the model well described by (Verdejo-Garcia et al., 2018)) and of the high-level cognitive processes to which it is closely related. Moreover, for the measure the decision-making deficit in addictions, there is, to the best of our knowledge, no battery of tests, scripts or tasks that also measures the impact of this deficit under realistic conditions. Therefore, tools that intend to measure this process must take into account the complexity of decision-making as an umbrella construct and propose batteries including multilevel neurocognitive measures.

References

Ahn, W. Y., Dai, J., Vassileva, J., Busemeyer, J. R., & Stout, J. C. (2016). Computational modeling for addiction medicine: From cognitive models to clinical applications. In *Progress in Brain Research* (Vol. 224, pp. 53–65). Elsevier B.V. https://doi.org/10.1016/bs.pbr.2015.07.032

Badre, D., Hoffman, J., Cooney, J. W., & D'Esposito, M. (2009). Hierarchical cognitive control deficits following damage to the human frontal lobe. *Nature Neuroscience*, *12*(4), 515–522. https://doi.org/10.1038/nn.2277

Balconi, M., & Angioletti, L. (2022). Neurophysiology of Gambling Behavior and Internet Use Vulnerability: A Comparison Between Behavioral and EEG Measures. *Clinical EEG and Neuroscience*, *53*(4), 268-277 https://doi.org/10.1177/15500594211038469

Balconi, M., & Campanella, S. (2021). *Advances in Substance and behavioral addiction. The role of executive functions* (M. Balconi & S. Campanella, Eds.; 1st ed.). Springer, Cham. https://doi.org/https://doi.org/10.1007/978-3-030-82408-2

Balconi, M., & Finocchiaro, R. (2015). Decisional impairments in cocaine addiction, reward bias, and cortical oscillation "unbalance." *Neuropsychiatric Disease and Treatment*, *11*, 777–786. https://doi.org/10.2147/NDT.S79696

Balconi, M., Finocchiaro, R., & Campanella, S. (2014a). Reward sensitivity, decisional bias, and metacognitive deficits in cocaine drug addiction.

Journal of Addiction Medicine, *8*(6), 399–406. https://doi.org/10.1097/ADM.0000000000000065

Balconi, M., Finocchiaro, R., & Canavesio, Y. (2014). Reward-system effect (BAS rating), left hemispheric "unbalance" (alpha band oscillations) and decisional impairments in drug addiction. *Addictive Behaviors*, *39*(6), 1026–1032. https://doi.org/10.1016/j.addbeh.2014.02.007

Balconi, M., Finocchiaro, R., & Canavesio, Y. (2015). Left hemispheric imbalance and reward mechanisms affect gambling behavior: The contribution of the metacognition and cortical brain oscillations. *Clinical EEG and Neuroscience*, *46*(3), 197–207. https://doi.org/10.1177/1550059413513261

Balconi, M., Finocchiaro, R., & Canavesio, Y. (2015b). Reward sensitivity (Behavioral activation system), cognitive, and metacognitive control in gambling behavior: Evidences from behavioral, feedback-related negativity, and P300 effect. *Journal of Neuropsychiatry and Clinical Neurosciences*, *27*(3), 219–227. https://doi.org/10.1176/appi.neuropsych.14070165

Balconi, M., Losasso, D., Balena, A., & Crivelli, D. (2022). Neurocognitive impairment in addiction: A digital tool for executive function assessment. *Frontiers and Psychiatry*, *13*, 1–5. https://doi.org/10.3389/fpsyt.2022.955277

Balconi, M., Venturella, I., & Finocchiaro, R. (2017). Evidences from rewarding system, FRN and P300 effect in internet-addiction in young people. *Brain Sciences*, *7*(7), 1–16. https://doi.org/10.3390/brainsci7070081

Balconi, M., Venturella, I., & Finocchiaro, R. (2018). Brain oscillations, inhibitory control mechanisms and rewarding bias in web addiction. Two opposite young subjects' clusters? *Neuropsychological Trends*, *23*, 35–66. https://doi.org/10.7358/neur-2018-023-bal1

Banca, P., Lange, I., Worbe, Y., Howell, N. A., Irvine, M., Harrison, N. A., Moutoussis, M., & Voon, V. (2016). Reflection impulsivity in binge drinking: Behavioural and volumetric correlates. *Addiction Biology*, *21*(2), 504–515. https://doi.org/10.1111/adb.12227

Barrett, L. F., Bliss-Moreau, E., Quigley, K. S., & Aronson, K. R. (2004). Interoceptive sensitivity and self-reports of emotional experience. *Journal of Personality and Social Psychology*, *87*(5), 684–697. https://doi.org/10.1037/0022-3514.87.5.684

Bechara, A. (2005). Decision making, impulse control and loss of willpower to resist drugs: A neurocognitive perspective. *Nature Neuroscience*, *8*(11), 1458–1463. https://doi.org/10.1038/nn1584

Bechara, A., Van, M., & Linden, D. (2005). Decision-making and impulse control after frontal lobe injuries. *Current Opinion in Neurology*, *18*(6), 734–739. https://doi.org/10.1097/01.wco.0000194141.56429.3c

Brand, M., Roth-Bauer, M., Driessen, M., & Markowitsch, H. J. (2008). Executive functions and risky decision-making in patients with opiate dependence. *Drug and Alcohol Dependence*, *97*(1–2), 64–72. https://doi.org/10.1016/j.drugalcdep.2008.03.017

Brevers, D., & Noël, X. (2013). Pathological gambling and the loss of willpower: a neurocognitive perspective. *Socioaffective Neuroscience & Psychology*, *3*(1), 21592. https://doi.org/10.3402/snp.v3i0.21592

Coutlee, C. G., & Huettel, S. A. (2012). The functional neuroanatomy of decision making: Prefrontal control of thought and action. *Brain Research*, 1428, 3–12. https://doi.org/10.1016/j.brainres.2011.05.053

Crivelli, D., Balena, A., Losasso, D., & Balconi, M. (2022). Screening Executive Functions in Substance-Use Disorder: First Evidence from Testing of the Battery for Executive Functions in Addiction (BFE-A). *International Journal of Mental Health and Addiction*. https://doi.org/10.1007/s11469-022-00928-5

Ernst, M., & Paulus, M. P. (2005). Neurobiology of decision making: A selective review from a neurocognitive and clinical perspective. *Biological Psychiatry*, *58*(8), 597–604. https://doi.org/10.1016/j.biopsych.2005.06.004

Finocchiaro, R., & Balconi, M. (2017). Left/Right Hemispheric "Unbalance" Model in Addiction. *Addictive Substances and Neurological Disease*, 383–391. https://doi.org/10.1016/B978-0-12-805373-7.00033-5

Garfinkel, S. N., Seth, A. K., Barrett, A. B., Suzuki, K., & Critchley, H. D. (2015). Knowing your own heart: Distinguishing interoceptive accuracy from interoceptive awareness. *Biological Psychology*, *104*, 65–74. https://doi.org/10.1016/j.biopsycho.2014.11.004

Goldstein, R. Z., Craig, A. D. (Bud), Bechara, A., Garavan, H., Childress, A. R., Paulus, M. P., & Volkow, N. D. (2009). The Neurocircuitry of Impaired Insight in Drug Addiction. *Trends in Cognitive Sciences*, *13*(9), 372–380. https://doi.org/10.1016/j.tics.2009.06.004

Goldstein, R. Z., & Volkow, N. D. (2011). Dysfunction of the prefrontal cortex in addiction: neuroimaging findings and clinical implications. *Nature Reviews Neuroscience*, *12*(11), 652–669. https://doi.org/10.1038/nrn3119

Goudriaan, A. E., Oosterlaan, J., De Beurs, E., & Van Den Brink, W. (2006). Neurocognitive functions in pathological gambling: A comparison with alcohol dependence, Tourette syndrome and normal controls. *Addiction*, *101*(4), 534–547. https://doi.org/10.1111/j.1360-0443.2006.01380.x

Ko, C. H., Hsiao, S., Liu, G. C., Yen, J. Y., Yang, M. J., & Yen, C. F. (2010). The characteristics of decision making, potential to take risks, and personality of college students with Internet addiction. *Psychiatry Research*, *175*(1–2), 121–125. https://doi.org/10.1016/j.psychres.2008.10.004

Koechlin, E., Le Ody, C., & Kouneiher, F. (2003). The Architecture of Cognitive Control in the Human Prefrontal Cortex. *Science*, *302*(5648), 1181-1185. https://doi.org/10.1126/science.1088545

Koob, G. F., & Le Moal, M. (2001). Drug Addiction, Dysregulation of Reward, and Allostasis. *Neuropsychopharmacology*, *24*(2), 97–129. https://doi.org/10.1016/S0893-133X(00)00195-0

Makris, N., Gasic, G. P., Kennedy, D. N., Hodge, S. M., Kaiser, J. R., Lee, M. J., Kim, B. W., Blood, A. J., Evins, A. E., Seidman, L. J., Iosifescu, D. V., Lee, S., Baxter, C., Perlis, R. H., Smoller, J. W., Fava, M., & Breiter, H. C. (2008). Cortical Thickness Abnormalities in Cocaine Addiction-A Reflection of Both Drug Use and a Pre-existing Disposition to Drug Abuse? *Neuron*, *60*(1), 174–188. https://doi.org/10.1016/j.neuron.2008.08.011

Makris, N., Oscar-berman, M., Kim, S., Steven, M., Kennedy, D. N., Caviness, V. S., Breiter, H. C., Gasic, G. P., & Harris, G. J. (2008). Decreased Volume of the Brain Reward System in Alcoholism. *Biological Psychiatry*, *64*(3), 192–202. https://doi.org/10.1016/j.biopsych.2008.01.018.Decreased

McClure, S. M., & Bickel, W. K. (2014). A dual-systems perspective on addiction: Contributions from neuroimaging and cognitive training. *Annals of the New York Academy of Sciences*, *1327*(1), 62–78. https://doi.org/10.1111/nyas.12561

Miller, E. K., & Cohen, J. D. (2001). An integrative theory of prefrontal cortex function. *Annual Review of Neuroscience*, *24*, 167–202. https://doi.org/10.1146/annurev.neuro.24.1.167

Moeller, S. J., Fleming, S. M., Gan, G., Zilverstand, A., Malaker, P., d'Oleire Uquillas, F., Schneider, K. E., Preston-Campbell, R. N., Parvaz, M. A., Maloney, T., Alia-Klein, N., & Goldstein, R. Z. (2016). Metacognitive impairment in active cocaine use disorder is associated with individual differences in brain structure. *European Neuropsychopharmacology*, *26*(4), 653–662. https://doi.org/10.1016/j.euroneuro.2016.02.009

Nikolaidou, M., Fraser, D. S., & Hinvest, N. (2016). Physiological markers of biased decision-making in problematic Internet users. *Journal of Behavioral Addictions*, *5*(3), 510–517. https://doi.org/10.1556/2006.5.2016.052

Noël, X., Brevers, D., & Bechara, A. (2013a). A neurocognitive approach to understanding the neurobiology of addiction. *Current Opinion in Neurobiology*, *23*(4), 632–638. https://doi.org/10.1016/j.conb.2013.01.018

Noël, X., Brevers, D., & Bechara, A. (2013b). A triadic neurocognitive approach to addiction for clinical interventions. *Frontiers in Psychiatry*, *4*(12), 1–14. https://doi.org/10.3389/fpsyt.2013.00179

Peters, J., & Büchel, C. (2010). Neural representations of subjective reward value. *Behavioural Brain Research*, *213*(2), 135–141. https://doi.org/10.1016/j.bbr.2010.04.031

Porges, S. W. (1993). *Body perception questionnaire*. Laboratory of Developmental Assessment.

Rochat, L., Maurage, P., Heeren, A., & Billieux, J. (2019). Let's Open the Decision-Making Umbrella: A Framework for Conceptualizing and Assessing Features of Impaired Decision Making in Addiction. *Neuropsychology Review*, *29*(1), 27–51. Springer New York LLC. https://doi.org/10.1007/s11065-018-9387-3

Stevens, L., Roeyers, H., Dom, G., Joos, L., & Vanderplasschen, W. (2015). Impulsivity in cocaine-dependent individuals with and without attention-deficit/hyperactivity disorder. *European Addiction Research*, *21*(3), 131–143. https://doi.org/10.1159/000369008

Strait, C. E., Blanchard, T. C., & Hayden, B. Y. (2014). Reward value comparison via mutual inhibition in ventromedial prefrontal cortex. *Neuron*, *82*(6), 1357–1366. https://doi.org/10.1016/j.neuron.2014.04.032

Sun, D. L., Chen, Z. J., Ma, N., Zhang, X. C., Fu, X. M., & Zhang, D. R. (2009). Decision-making and prepotent response inhibition functions in excessive internet users. *CNS Spectrums*, *14*(2), 75–81. https://doi.org/10.1017/S1092852900000225

Tanabe, J., Thompson, L., Claus, E., Dalwani, M., Hutchison, K., & Banich, M. T. (2007). Prefrontal cortex activity is reduced in gambling and nongambling substance users during decision-making. *Human Brain Mapping*, *28*(12), 1276–1286. https://doi.org/10.1002/hbm.20344

Verdejo-García, A., Alcázar-Córcoles, M. A., & Albein-Urios, N. (2019). Neuropsychological Interventions for Decision-Making in Addiction: a Systematic Review. *Neuropsychology Review*, *29*(1), 79–92. https://doi.org/10.1007/s11065-018-9384-6

Verdejo-Garcìa, A., & Bechara, A. (2009). A Somatic-Marker Theory of Addiction. *Neuropharmacology*, *56*(Suppl 1), 48–62. https://doi.org/10.1016/j.neuropharm.2008.07.035.A

Verdejo-Garcia, A., Chong, T. T. J., Stout, J. C., Yücel, M., & London, E. D. (2018). Stages of dysfunctional decision-making in addiction. *Pharmacology Biochemistry and Behavior*, 164, 99–105. https://doi.org/10.1016/j.pbb.2017.02.003

Verdejo-Garcia, A., Clark, L., & Dunn, B. D. (2012). The role of interoception in addiction: A critical review. *Neuroscience and Biobehavioral Reviews*, *36*(8), 1857–1869. https://doi.org/10.1016/j.neubiorev.2012.05.007

Wölfling, K., Duven, E., Wejbera, M., Beutel, M. E., & Müller, K. W. (2020). Discounting delayed monetary rewards and decision making in behavioral addictions – A comparison between patients with gambling disorder and internet gaming disorder. *Addictive Behaviors*, *108*, 106446. https://doi.org/10.1016/j.addbeh.2020.106446