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The Iowa Gambling Task: A Review of the Historical Evolution, Scientific Basis, and Use in Functional Neuroimaging

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Abstract

The Iowa Gambling Task (IGT) provides a framework to evaluate an individual decision-making process through a simulated card game where the risks and rewards vary by the decks chosen. Participants are expected to understand the logic behind the allocation of gains and losses over the course of the test and adapt their pattern of choices accordingly. This review explores the scientific work on studying problem gambling via the IGT while employing neuroimaging techniques. We first concentrate on the historical evolution of the IGT as a mechanism for studying gamblers' behavioral patterns. Our research will also discuss the prefrontal cortex as this region of the brain is most affected by changes in behavioral patterns. In this review, we describe a number of features that may be useful in investigating decision-making patterns that lead to gambling addiction. We discuss the evidence base to date including experiments involving gambling behavior in different groups of participants (e.g., males and females, adults and minors, patients and controls) and alterations to experiment conditions that provide more thorough understanding of thought patterns in potential gamblers. We conclude that psychological testing combined with functional imaging provide powerful tools to further examine the relationships between functional impairment of the brain and a person's ability to objectively anticipate the end results of their decisions.

Keywords

Iowa Gambling Task, gambling disorders, brain imaging, decision making

Introduction

Gambling, the wagering of money on the outcome of a particular activity where that outcome is uncertain (Korn & Shaffer, 1999), enjoys widespread popularity in the United States (Welte, Barnes, Wieczorek, Tidwell, & Parker, 2002). National surveys indicate that approximately 125 million Americans have gambled at some point in their lives (National Gambling Impact and Policy Commission (U.S.) [NGISC], 1999). More recent studies carried out in the State of Maryland in 2010 (Shinogle et al., 2011) revealed that 90% of the population in Maryland have had a gambling experience. Of those residents who did gamble, 15.3% gambled every week, and 21.9% gambled every month. Moreover, 3.4% of people surveyed were categorized as probable pathological gamblers. It has been suggested that problem gambling affects an individual's social and psychological behavior in a manner similar to substance abuse; both are addictive disorders, characterized by similar deviant behaviors, reward processing, and impaired decision making (American Psychiatric Association [APA], 2013**).** Neurobiologists have established that the decision-making process evident in addictive disorders is enabled by the brain reward system and a set of reinforcement stimuli; this brain reward system is largely based on the activity of ventral striatum and the medial prefrontal

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cortex (MPFC; Clark, 2010; Euston, Gruber, & McNaughton, 2012; Haber, 2011).

Most studies of problem gambling refer to the formal definition of gambling disorder put forward by the American Psychiatric Association in 2013: gambling disorder is defined as recurring problematic gambling behavior leading to clinically significant impairment. At the same time, scientists may sometimes elaborate on the essence of problem gambling differently. After surveying recent studies on problem gambling, we have defined two dominating viewpoints.

There has been extensive discussion among gambling disorder researchers regarding definitions of problem gambling. From one point of view, a gambler is a person who can no longer control the desire to gamble (Jazaeri & Habil, 2012). Jazaeri and Habil (2012) and Potenza, Kosten, and Rounsaville (2001) suggest that gambling is the process where anticipation of possible, yet unguaranteed reward develops in consequence to a risky act of losing an object of material value (money, valuable, possessions, etc.). Others posit that gambling addiction is characterized by the development of mental patterns that resemble specific patterns of abnormal activity in the brains of substance-addicted individuals (Galanter, Kleber, & Brady, 2014; Reilly & Smith, 2013). This apparent similarity creates a benchmark classification dilemma—whether to list problem gambling along with addictive disorders or not. Initially, problem gambling was classified as an impulse control disorder as per the *Diagnostic and Statistical Manual of Mental Disorders* (4th ed.; *DSM-IV*; American Psychiatric Association [APA], 1994) list (APA, 1980). The *Diagnostic and Statistical Manual of Mental Disorders* (5th ed.; *DSM-5*; APA, 2013) list was reviewed and updated in 2013. Following review, gambling disorder was transferred into the "substance-related and addictive disorders" category. Change of gambling disorder's status has accumulated considerable scientific attention (APA, 2013). Both theorists and clinical practitioners have demonstrated that problem gamblers are very similar to substance abusers (Reilly & Smith, 2013). Although gambling addiction is not linked to substance consumption, the psychological mechanism behind developing addiction in both cases is nearly identical: just as drug users need greater and greater doses of the substance, problem gamblers need more frequent gambling activity to feel satisfied. Substance abusers and problem gamblers equally demonstrate poor decision-making abilities; in particular, their choice patterns are characterized by an inability to take into account long-term consequences (Krmpotich et al., 2015). However, not all scientists have readily embraced this terminological alteration. For example, most of the research published before 2013 considers pathological gambling as an impulse disorder (Quintero, 2017). It has also been suggested that estimating the extent of gambling addiction is arbitrary, because gambling disorder should be regarded as the final stage of the gambling continuum.

Quality of life is, to a large extent, dependent on one's ability to make decisions. Indeed, impairment of the decision-making process puts individuals at risk for incorrectly assessing the long-term consequences of their choices which is typical of individuals with Parkinson's disease, schizophrenia, substance addiction and gambling disorder. In-depth analysis of issues that impede decision-making has accelerated the discovery and development of optimal treatment options for mental illnesses. Building the biological basis behind the decision-making process allows us to correctly model and predict behavior of individuals in so-called risky (gambling) groups. Thus, researchers across a variety of disciplines including cognitive psychology, social psychology, and neuroscience, among others, have focused on the decision-making process.

The prefrontal cortex plays an important role in the decision-making process (Anderson, Bechara, Damasio, Tranel, & Damasio, 1999; Bechara, Damasio, Damasio, & Anderson, 1994; Coutlee & Huettel, 2012; Domenech & Koechlin, 2015; Jazaeri & Habil, 2012). Therefore, any impediment to the ventromedial prefrontal cortex (VMPFC) potentially compromises an individual's decision-making skills (Santos, Seixas, Brandão, & Moutinho, 2011). When the ventromedial region suffers damage, individuals may lose the ability to foresee the consequences that may result from their actions (Bechara et al., 1994; Bechara, Damasio, Damasio, & Lee, 1999; Bechara, Tranel, & Damasio, 2000; Yechiam, Busemeyer, Stout, & Bechara, 2005). For instance, impairments of the ventromedial frontal lobes' functioning effect on the rationality of participants' decisions and subsequently lead to the emergence of irrational behavioral tendencies (Camille, Griffiths, Vo, Fellows, & Kable, 2011).

Iowa Gambling Task (IGT)

The Iowa Gambling experiment was created to determine the nature of impairment in decision making (Bechara et al., 1994). The neuroimaging techniques implemented within the framework of the IGT experiment allow for real-time monitoring of neural processes lying at the core of the decision-making process. In this regard, the objectives of the IGT are to (a) study the adverse effects of neural and cognitive brain activity on decision making and (b) investigate the extent of functional impairment of the prefrontal cortices which, in turn, leads to alteration of mental processes related to decision making.

As originally described by Bechara et al. (1994), the IGT presents participants with four decks of cards of similar appearance and size. Participants are given a $2,000 loan of fake money and instructed that the goal of the task is to maximize the amount of money earned on this initial loan. They are then asked to select a card from any of four different card decks, with a single card chosen for each trial. There are 100

Table 1. Overview of Different Iowa Gambling Tasks.

	Gains				Losses			
Reference	Deck 1	Deck 2	Deck 3	Deck 4	Deck 1	Deck 2	Deck 3	Deck 4
ABCD task Bechara, Damasio, Damasio, and Anderson (1994)	+100	+100	+50	+50	–150 to –350	–1250 or 0	–25 to –75	–250 or 0
A'B'C'D' task Bechara, Tranel, and Damasio (2000); Li, Lu, D'Argembeau, Ng, and Bechara (2010)	+100	+100	+50	+50	–150 to –350	–1250 or 0	–25 to –75	–250 or 0
E'F'G'H' task Bechara, Tranel, and Damasio (2000); Li et al. (2010)	+1250 or 0	+25 to +75	+150 to +350	+250 or 0	–100	–50	–100	–50
Modified ABCD task Bechara, Damasio, Tranel, and Damasio (2005)	+100	+100	+50	+50	–1250	–1250	–250	–250
Modified ABCD task Cassotti, Aïte, Osmont, Houdé, and Borst (2014)	8-12	8-12	4-6	4-6	15-35	125	2-8	25

selection trials. The total number of trails is not disclosed to participants (Lin, Chiu, Cheng, & Hsieh, 2008).

There are no limitations on how often a participant can switch between the decks of cards. Participants are told that certain cards yield more benefit compared with others. With each selection, participants win or lose a predetermined amount of money.

The gains and losses associated with any decks are the same for every participant. Two of the four decks bring a higher immediate reward, but the penalty amounts in these decks are also higher, resulting in less long-term gain. The other two decks yield lower immediate gains but the penalties associated with these decks are also considerably lower. The participant must figure out the pattern of reward allocation to maximize long-term financial gain. It is expected that nongamblers from a control group will prefer the lower-risk decks while people with gambling addiction will be tempted by high immediate gains resulting in greater long-term loss.

To test this hypothesis, some alternative scenarios were introduced: for example, a game with E'F'G'H' decks where high-risk decks bring better reward in the long run (see Table 1 for an overview of these variations). F' and H' are labeled as disadvantageous decks with lesser immediate penalties but yielding an unsatisfactory profit in the longer term; E' and G' are advantageous decks as far as greater punishment amount is eventually offset by higher net gain (Bechara, Tranel, & Damasio, 2000; Singh & Khan, 2012). We discuss the findings of studies that have used IGT to inform an interdisciplinary approach to future research in the area.

Human Subject Studies on IGT

Studies using the IGT have focused on the evaluation of impairments in decision making among four different primary populations in the past 20 years: individuals with neurological disorders (Castrioto et al., 2015; Labudda et al., 2009; Levine et al., 2005; Mimura, Oeda, & Kawamura, 2006; Sinz, Zamarian, Benke, Wenning, & Delazer, 2008), individuals with psychiatric disorders (Barry & Petry, 2008; Bechara et al., 2001; Brown et al., 2015; Clark, Manes, Antoun, Sahakian, & Robbins, 2003; Geurts, Van der Oord, & Crone, 2006; Kester et al., 2006; Nakamura et al., 2008; Noël, Bechara, Dan, Hanak, & Verbanck, 2007; Quednow et al., 2007; Roca et al., 2008; Toplak, Jain, & Tannock, 2005; Verdejo-García, Rivas-Pérez, Vilar-López, & Pérez-García, 2007), nonclinical populations (Brand, Recknor, Grabenhorst, & Bechara, 2007; Fein, McGillivray, & Finn, 2007; Garon & Longard, 2014; Hooper, Luciana, Conklin, & Yarger, 2004; Lamm, Zelazo, & Lewis, 2006; Lehto & Elorinne, 2003), and animal models (Proctor, Williamson, Latzman, de Waal, & Brosnan, 2014; de Visser et al., 2011). The IGT has been conducted in samples with the following psychiatric diagnoses: gambling disorder (Linnet, 2013), schizophrenia (Kim, Kang, & Lim, 2016), substance abuse (Hagen et al., 2016; Körner, Schmidt, & Soyka, 2015), depression (Must, Horvath, Nemeth, & Janka, 2013), psychopathy (Blair, Colledge, & Mitchell, 2001; Takahashi, Takagishi, Nishinaka, Makino, & Fukui, 2014), disruptive behavior disorder (Schutter, Van Bokhoven, Vanderschuren, Lochman, & Matthys, 2011), bipolar disorder (Ono et al., 2015), obsessive compulsive disorder (Zhang et al., 2015), borderline personality disorder (LeGris, Toplak, & Links, 2014), and Asperger syndrome (Johnson, Yechiam, Murphy, Queller, & Stout, 2006). Other studies have focused on neurological conditions such as traumatic brain injuries (Cotrena et al., 2014), epilepsy (Wandschneider et al., 2013), Alzheimer's (Jacus, Gély-Nargeot, & Bayard, 2018), and Parkinson's diseases (Toplak, Sorge, Benoit, West, & Stanovich, 2010).

The majority of reviewed studies found that participants with impairment (such as patients with frontal lobe damage (Ouerchefani, Ouerchefani, Allain, Rejeb, & Le Gall, 2017)) primarily choose cards from decks yielding lesser net amounts. In contrast, control participants largely selected from the decks that yield overall higher net values (Beitz, Salthouse, & Davis, 2014). To estimate the *score* of the experiment, all choices from disadvantageous decks were summed up and then deducted from the total amount of advantageous choices. Another aspect of estimation involved calculating how many advantageous or disadvantageous choices were made in total after five rounds of selections (20 choices per round).

Bechara et al. (2000) found no perceptible behavioral variations in participants taking part in ABCD and variant EFGH tasks. Devised as an alternative to the original IGT experiment, EFGH tasks employ a reverse scenario where the participants first have to deal with a sequence of money losses while the reward is deliberately held back until a later stage of the trial.

Neither the delay in rewarding the individual (as in one EFGH task variation) nor delayed punishment (a variation of the ABCD task) changed outcomes when compared with the original IGT experiment. Nonetheless, even though the consequences of the task were altered, individuals suffering from VMPFC impairments which were subjected to an earlier testing still failed to reconsider their ordinary choice patterns in further experiments.

In 1994, Bechara et al. conducted a study involving patients with behavioral deviations caused by damage to the prefrontal cortex, specifically the VMPFC. Patients with impaired functioning of the VMPFC demonstrated poor performance on the IGT, whereas control participants demonstrated an understanding of the reward and punishment contingencies of the task, typically choosing more cards from the advantageous decks by the end of experiment. Patients with impaired function of the VMPFC, however, did not improve their performance as the experiment progressed.

Bechara et al. (1996) later presented the results of a study comparing the IGT performance of seven patients with disrupted VMPFC function and damage to other parts of the brain (i.e., frontal lobe) with the performance of 12 healthy patients. In this study, researchers detected that healthy patients showed a strong tendency for anticipatory skin conductance response (SCR) in response to less advantageous decks that would result in greater losses. Bechara, Tranel, and Damasio (2000) also found that problem gamblers who suffer from orbitofrontal lesions demonstrated weak or unusual anticipatory SCRs during IGT tests, whereas healthy participants' SCRs increased whenever they were making risky choices. These findings suggest that problematic gamblers fail to develop anticipatory SCRs normally demonstrated by control groups, contradicting the hypothetical assumption that gambling addicts are overreacting to wins or punishments (Frackowiak, 2004). Indeed, among problem gamblers, the magnitude of SCR for advantageous decks was minor. For the VMPFC-lesions patients, VMPFC damage was correlated with adverse effects on IGT performance. In particular, the patients with damage to VMPFC failed to exhibit any anticipatory SCRs that may have prevented them from choosing disadvantageous decks. Therefore, improper functioning of VMPFC obstructed the process of making the right choice for these patients.

Given that the IGT is structured in such a manner that the system for allocating gains and losses is not clear to participants for the majority of the experiment, Bechara, Damasio, Tranel, and Damasio (1997) sought to investigate whether the patients made conscious choices during the IGT and whether their decisions were based on learning from previous positive/negative experiences. For these purposes, 10 participants from a control group (without VMPFC damage) and six participants suffering from malfunction of VMPFC were invited to take part in the experiment. The researchers collected and summarized data after the participants completed at least 10 rounds of selections and subsequently identified four phases of task awareness: prepunishment, prehunch, hunch, and conceptual phases (Bechara et al., 1997).

The prepunishment phase occurs prior to incurring any losses. The prehunch phase describes the period before patients have developed an understanding of the task's reward contingency. This is followed by the hunch phase when patients have started forming expectations about the reward and punishment associated with each deck. The final phase is the conceptual period when patients begin to understand the objectives and get a sense of the task. Despite having sufficiently good net results, approximately one third of healthy participants did not progress toward the conceptual period. Based on this observation, the study concluded that, prior to developing an explicit comprehension of the task's logic, participants were able to learn the IGT rules implicitly which means using intuition to draw unobvious conclusions based on the dynamics of the experiment. In contrast, half of the patients with damaged VMPFC had poor overall performances, although at least 50% of these patients advanced to the conceptual period of task awareness.

Based on these results, researchers concluded that the decision-making process could be negatively affected by damage to the VMPFC. The experiment also showed that the inability to generate anticipatory SCR signals degrades the quality of a patients' decision-making (Dunn, Dalgleish, & Lawrence, 2006). SCR signals were absent in patients with VMPFC lesions, resulting in their inability to make rational choices between advantageous and disadvantageous decks. The authors suggest that as early as the primary stage of the IGT, participants in control groups have gained a partial understanding about the potential advantages of the decks through implicit learning mechanisms and have acquired strong preferences for *good* decks.

Decision Making and Brain Activation

Decision making is defined as the process of consciously choosing one particular option while simultaneously rejecting other existing options (Buelow & Suhr, 2009); the ability to make an efficient decision in particular circumstances reflects executive function. Executive function requires the use of an individual's memory, to preplan future possible outcomes or to develop future expectations based on past experiences.

Somatic Marker Hypothesis (SMH) suggests that somatic signals are regulated in emotion circuitry such as the VMPFC to help with the decision-making process (Bechara, Damasio, & Damasio, 2000; Bechara, Damasio, Tranel, & Damasio, 2005; Damasio, Everitt, & Bishop, 1996, Dashtestani et al., 2018). The neural loops' main components also include anterior cingulate cortex (ACC), dorsolateral prefrontal cortex (DLPFC), and striatum (Toplak et al., 2005). Multiple studies have hypothesized that advantageous choices are modulated by somatic signals, which are produced jointly by brain regions such as the amygdala, insular cortex, brainstem nuclei, somatosensory cortex, and MPFC (Noël et al., 2007; Toplak et al., 2005). Meanwhile, additional research has found that the lentiform nucleus and insular cortex are predominantly involved in the process of making decisions, especially in terms of processing the decision and at the initial stage of anticipation (Lin et al., 2008).

Participants in some IGT studies have demonstrated activation of different somatic markers at the anticipatory and experimental stages (Li, Lu, D'Argembeau, Ng, & Bechara, 2010). Other studies have established that, apart from MPFC, all other areas of the DLPFC, VMPFC, orbitofrontal cortex (OFC), and ACC were activated in the course of IGT-related decision making (Zeeb, Baarendse, Vanderschuren, & Winstanley, 2015). Most IGT brain imaging studies focus only on the MPFC or OFC but do not discuss learning probability related to other brain areas (Lin et al., 2008).

Brain Imaging Studies

The IGT has been conducted in combination with a variety of functional brain imaging techniques, such as positron emission tomography (PET), functional magnetic resonance imaging (fMRI), electroencephalography (EEG), functional near-infrared spectroscopy (fNIRS), and magnetoencephalography (MEG). PET, fNIRS, and fMRI methods can be used to indirectly assess blood flow in the areas of the brain previously associated with decision making. fMRI looks at blood-oxygen-level dependent (BOLD) signal and fNIRS similarly can assess the changes in hemoglobin (HbO) and deoxygenated hemoglobin (Hb). Visual stimulation induces focal neural activation by increasing blood flow to areas of the brain related to decision making. Electric and magnetic signals generated by the brain can be monitored using EEG and MEG. Comparison of brain monitoring techniques that has been conducted during IGT Task shows that there isn't a convergence in findings from studies examining decision-making using the IGT. The findings sample size of the problem gambling group recruited in these studies are not big. The studies also show the heterogeneity of applications.

Few studies have addressed the correlation between gambling disorders and neuroimaging results. Previous works have mostly focused on the study of functional neuroimaging abnormalities such as fMRI. van Holst, van den Brink, Veltman, and Goudriaan (2010) extensively reviewed studies examining decision-making deficits in problem gamblers using fMRI. Based on this review, previous studies on pathological gamblers suggested high functional activity on the ventral tegmental-orbitofrontal cortex. Specifically, in a study using a modified version of the IGT called the "Mouse Game," Linnet, Røjskjær, Nygaard, and Maher (2006) found healthy controls exhibited overall higher functional activity than pathological gamblers while healthy controls had more ability to change their behavior after negative feedback than pathological gamblers. Tanabe et al. (2007) conducted modified IGT and reported a group of brain regions are activated during decision making in healthy control and pathological gamblers. These regions included the OFC, ventromedial dorsal, ventrolateral/anterior insula, ACC, ventral striatum, and parietal and occipital lobes. Later Forbush et al. (2008) and Roca et al. (2008) found higher functional activity in healthy controls than pathological gamblers during IGT.

Furthermore, consistent with findings by Power, Goodyear, and Crockford (2012) and Tanabe et al. (2007) also reported healthy participants and pathological gamblers experience activation over the same brain areas during the IGT task using fMRI. This experiment sought to study the processes occurring in the medial temporal, prefrontal, and parietal lobes together with the activity of the cerebellum. Although processes detected in the brains' of control participants and problem gamblers bore some resemblance, the experiment nevertheless identified several variations. For example, when problem gamblers selected the high-risk decks, researchers could immediately detect a substantial increase in the activity within the OFC (Rolls & Grabenhorst, 2008), caudate nucleus (Haruno & Kawato, 2006), and amygdala. Similarly, Crockford, Goodyear, Edwards, Quickfall, and el-Guebaly (2005) established that the visual presentation of gambling cues produced differential responses in the prefrontal cortices of the problem gamblers and healthy participants. In this study, researchers conducted the IGT with 10 control group participants and 10 problem gamblers. These two groups were subjected to fMRI scanning during demonstration of a video containing gambling material and scenes about nature. Notably, gambling scenes triggered increased brain activity for both healthy and affected participants. However, problem gamblers exhibited more intensive activity within the *right* side of the DLPFC compared with controls. Later studies, however, found that substance dependent (SD), problem gambling (PG), and

substance dependent problem gambling (SDPG) patients were likely to exhibit reduced activity of the VMPFC in the course of IGT trials (Tanabe et al., 2007).

Brevers, Noël, He, Melrose, and Bechara (2016) described the results of fMRI imaging during the performance of the IGT task on 15 gamblers (card games such as poker) and 15 control participants. Participants in the control group included nonproblem gamblers, while all others had varying stages of gambling addiction. The fMRI analyses showed lower dorsolateral prefrontal and orbitofrontal activity for the participants from the problem gambling group in comparison with controls. To date, there has been little research using brain imaging techniques (such as PET or fMRI) evaluating neural network performance during the decision-making process. However, Ernst et al. (2002) employed[15] O-labeled water positron emission tomography scans while individuals performed the IGT. The study found that decision making triggered activity bilaterally, primarily in the right hemisphere of the brain. Activation was seen in the dorsolateral prefrontal complex, right anterior cingulate gyrus, OFC, right inferior parietal cortex, lateral cerebellum, anterior insula, and thalamus.

A number of recent studies have used fNIRS during the performance of IGT. In Bembich et al. (2014), 11 healthy participants were invited to participate in a study that sought to examine how IGT-related decisions influence activation of DLPFC, as well as variation in oxyhemoglobin levels. They found that activation of DLPFC closely depended on the factors of risk preprogrammed for each deck and in two stages of the test. The first indications of an increase in the regular activity of DLPFC were detected in the first stage of the experiment. The DLPFC showed no activation in the second part of the experiment, which may be explained by the activation of the VMPFC sector at that stage. VMPFC activation cannot be measured with the fNIRS technique. Another study showed that increase in levels of PFC activity in connection to gains and punishments is typically occurring in DLPFC regions of female participants, whereas men did not demonstrate such tendencies (Cazzell, Li, Lin, Patel, & Liu, 2012). Suhr and Hammers (2010) found that deficiencies in IGT performance are frequently driven by a lack of cerebral oxygenation in left and right dorsolateral cortexes. Moreover, outcomes of other IGT-based studies which encompass application of NIRS-based techniques strongly correspond with these findings. Therefore, it has been scientifically verified that advantageous choices in IGT are conditioned by increased activity in the frontal lobes/DLPFC. A major limitation is that the study by Suhr and Hammers (2010) focuses only on cortical signals generated by patients during the entire experiment; specific signals activated by a certain event or stage of experiment were not taken into consideration.

Another imaging technique that has been used to monitor brain activity is the EEG, which is considered a reliable measurement of event-related brain potentials (ERPs) given its capacity to support high temporal resolutions. Using EEG for evaluation of IGT participants' behavior showed that bilateral frontal and parietal networks were most actively involved in the process of decision making in connection to advantageous decks (Bourdaud, Chavarriaga, Galán, & Millán, 2008). In a similar experiment (Schutter, de Haan, & van Honk, 2004), researchers detected an increase in cortical activity in both sides of the brain and demonstrated that more intensive activity in the left PFC was related to less advantageous choices made by the participants. This finding suggests that an individual's propensity for disadvantageous decision making can be explained by a lack of sensitivity regarding punishment and excitement about gain prospects. Sadato et al. (1998) posit that the alpha wave activity of IGT task participants is likely to be correlated with the regional cerebral flow. However, this does not mean that this tendency is similarly caused by cortical inactivity. These findings confirm that alpha wave activity should be assessed in conjunction with the mental operation by which it is triggered.

Animal Models

Animal models have played an essential role in elucidating the underlying mechanisms of decision-making impairment among individuals with psychiatric or neurological conditions. Rodent IGT (RGT) experiment (de Visser et al., 2011) showed that decision-making strategies employed by rodents are highly similar to human behavioral patterns (Van den Bos, Koot, & de Visser, 2014). At the outset, it takes some time for the rodents to learn the task, however, eventually the animals learn to anticipate the consequences of their choices and have fixed decision-making behavior (de Visser et al. 2011; Zeeb & Winstanley, 2011). Lesion studies have revealed that the rodents subjected to RGT activate the same neural circuitry (i.e., prefrontal cortex area, basolateral amygdala, nucleus accumbens) as would have been activated by humans in similar circumstances (de Visser et al. 2011).

Unlike experiments involving human participants, the rodent model allows for greater flexibility in practice and a greater ability to control for external factors, providing more opportunities to trace the correlation between early impairments in decision making and progressive development of a psychopathological disease (Potenza, 2009). Although RGT experiments may facilitate the development of more effective and individualized treatment, several questions regarding the validity and applicability of RGT data remain unanswered. One such question is whether existing RGT data requires further validation.

Proctor et al. (2014) further researched IGT performance with both human subjects and primates (e.g., chimpanzees and capuchin monkeys). The original IGT was modified by removing penalties, utilizing a zero payoff scenario in its place, and by adding two more reward scenarios. One aim of this study was to develop a more complete understanding of so-called advantageous strategies, defined as strategies that

maximize a reward (Skvortsova, Palminteri, & Pessiglione, 2014). Another aim was to define the reasons behind developing choices which usually lead to low reward payoffs. To meet the aims of the research, the scientists introduced two new reward scenarios in addition to the standard IGT scenario. These additional scenarios contributed to the objective value of their observations, as this allowed them to study patients' emotional response toward their financial gains or losses separately from their reactions to variations in payment scenarios. This modification was intended to provide data on primate behavior when they discover the existence of multiple payoff schemes. Authors found several differences in the decision-making patterns of humans and primates when additional reward structures were introduced. For example, almost equal number of humans and nonhumans demonstrated that they were able to learn from their choices. To determine whether the subjects learned from their choices, the scientists decided to analyze results collected from the experiments involving humans and nonhuman primates separately, employing a less stringent standard for nonhuman primates. To consider the task "learned," the summary of results from 10 consecutive trials for the humans, and 20 consecutive trials for the primates, would need to form a monotonic function. Monotonic function is a function that is entirely nonincreasing or entirely nondecreasing, with no pivot points indicating that an individual had developed a consistent preference for choosing a single group of decks—that is, predominantly high risk or predominantly low risk. Then, LH ratios[1] for both human and nonhuman groups were calculated and compared. Findings showed similarity across the results obtained from human and nonhuman participants; these findings can potentially provide important guidance for further methodological study on IGT strategies. While the importance of the data gleaned from these animal models should not be understated, a more thorough understanding of the aforementioned disorders can only come from experiments with human participants.

Role of Gender and Level of Education

Decision-making paradigms, as with other paradigms, indicate there may be underlying sex differences in information processing. Van den Bos, Homberg, and de Visser (2013) concluded that the decision-making process is not the same for men and women; women tend to dedicate a lot of attention to details in the process of making a decision, whereas men rely on their ability to *grasp the entire picture* and make choices based less on specific facts or data. Differences are generally tied to changes in activation of neural networks dealing with emotional and cognitive control over emotional events these differences become especially obvious when choices have to be made in emotional or unpredictable situations and scenarios where it is not possible to accumulate benefit without simultaneously incurring a loss. Such variations are mainly associated with the peculiarities of neuronal circuits. In particular, researchers have identified gender differences in the way neuronal circuits are activated. Distinct neuronal circuits contribute to reflection/control over emotional experiences. Gender-based differences were also identified in the process of examination and analysis of data.

Surprisingly, one study found a negative relationship between education and performance in IGT. The higher the level of intelligence and education of participants, the more difficult it becomes for them to make advantageous choices. Reviews of individual cases complement the domain of theoretical knowledge pertinent to IGT and provide a pathway for a more coherent interpretation of research findings. IGT findings may also be used as benchmarks for predicting the behavior of vulnerable social groups. However, the study of decision-making processes in the context of the IGT has not produced results that are comprehensive, consistent, or entirely conclusive, suggesting that additional studies of this complicated construct is needed (Buelow & Suhr, 2009).

Limitations

Past scientific observations related to IGT have several critical gaps. Lack of extensive expert knowledge and in-depth analysis of the mental processes that directly influence decision making limits the value of IGT-obtained data. To date, the following issues still need to be clarified (Burdick, Roy, & Raver, 2013): (a) whether the working memory of participants has any impact on the estimation of the deck's possible profit; (b) whether participants may have a bias concerning punishments/losses if such punishments are imposed less frequently for a certain deck in comparison to others; (c) whether participants may have implicit emotional biases that impair decision-making processes; and (d) whether decision-making deficiencies may be potentially remedied based on study findings.

There have also been unexplained, contradictory findings pertaining to IGT performance. Lin et al. (2008) found that participants developed a preference for disadvantageous decks which yield better immediate rewards, while more beneficial decks were disregarded (Castrioto et al., 2015; Mimura et al., 2006). These findings directly contradict the studies of the baseline IGT where healthy patients would be more inclined to choose cards from safe decks. Indeed, many recent studies have shown that participants frequently choose *bad* decks despite the larger penalties associated with them (Stocco, Fum, & Napoli, 2009; Verdejo-García et al., 2007). These inconsistent findings indicate the need to improve the current procedures by imposing higher threshold for acceptance of participants or rebalance the control groups and patient groups. Early experiments with the IGT were aimed at determining overall tendency to select the advantageous or disadvantageous decks and the behavioral data of participants at each selection point was not examined. For example, Nakamura et al. (2008) elaborate on the view that there might be a separate trend for selecting decks

with more frequent gains, although it is generally accepted that IGT participants are normally interested in selecting cards from decks with better long-term outcomes, unless they are driven by the incentive of immediate rewards (Mimura et al., 2006).

Conclusion

Objectivity of IGT conclusions in repeated testing may be clouded by *practice effects*. Under practice effects, the participant who has done a similar experiment before tends to subconsciously seek linkages between the scenarios or draw biased conclusions. Therefore, there is a need to devise scenarios for repeated administration of IGT which would make the experiment more reliable. To meet this goal, Xiao et al. (2013) introduced several alternative IGT scenarios, but researchers did not report any improved results in task performance in healthy or affected participants. Furthermore, patients suffering from certain brain impairments demonstrated a deterioration in task performance, which serves as confirmation of the theory that the decision-making skills of VMPFC-impaired individuals and other affected patients are unlikely to improve over time.

Dunn et al. (2006) assert that the IGT is highly successful in establishing a causal link between the impairment of VMPFC functioning and reduced decision-making ability. In total, 35 participants suffering from damage to the occipital cortex or lateral temporal lobe and 45 participants diagnosed with dysfunction of the frontal lobe were selected for participation in the experiment. Per conclusions reached by Bechara, Tranel, and Damasio (2000), the worst net results at the end of the selection rounds were demonstrated by the patients suffering from amygdala or VMPFC impairments. In contrast, more than 80 participants from the control group completed the task, yielding results in line with comparable studies (Bechara et al., 1994, 1996). Additional experiments showed that the reproducibility of IGT results is sufficiently high and patient behavioral patterns did not change even when certain conditions of the experiment were modified (Bowman, Evans, & Turnbull, 2005).

The IGT is a useful tool in the evaluation of the decision-making process and it has evolved considerably over two decades of use. The ease of pairing the IGT with neuroimaging techniques has allowed IGT to increase in relevance and popularity. As a simulated gambling activity, the IGT experiment is an effective tool to elucidate the roots and causes of deficient decision making in the field of gambling disorder research. A variety of study projects covering the topic of problematic gambling have already resulted in formulation of a disadvantageous decision-making model. This review presented research findings and scientific rationale regarding the peculiarities of the deficient decision-making process. In future, functional neuroimaging may be employed with the IGT to further illustrate the relationships between brain impairments, adverse psychological conditions, and one's ability to predict the consequences of his or her decisions in a realistic manner. This multidisciplinary approach will improve the understanding of the factors that lead to problem gambling and aid in the development of effective recovery tools to address the broader impact of gambling on populations.

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Note

1. Number of low variability choices divided by the number of high variability choices.

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References

American Psychiatric Association. (1980). *Diagnostic and statistical manual of mental disorders* (3rd ed.). Washington, DC: Author.

American Psychiatric Association. (1994). *Diagnostic and statistical manual of mental disorders* (4th ed.). Washington, DC: Author.

American Psychiatric Association. (2013). *Diagnostic and statistical manual of mental disorders* (5th ed.). Arlington, VA: American Psychiatric Publishing.

Anderson, S. W., Bechara, A., Damasio, H., Tranel, D., & Damasio, A. R. (1999). Impairment of social and moral behavior related to early damage in human prefrontal cortex. *Nature Neuroscience*, *2*, 1032-1037.

Barry, D., & Petry, N. M. (2008). Predictors of decision-making on the Iowa Gambling Task: Independent effects of lifetime history of substance use disorders and performance on the Trail Making Test. *Brain and Cognition*, *66*, 243-252.

Bechara, A., Damasio, A. R., Damasio, H., & Anderson, S. W. (1994). Insensitivity to future consequences following damage to human prefrontal cortex. *Cognition*, *50*, 7-15.

Bechara, A., Damasio, H., & Damasio, A. R. (2000). Emotion, decision making and the orbitofrontal cortex. *Cerebral Cortex*, *10*, 295-307.

Bechara, A., Damasio, H., Damasio, A. R., & Lee, G. P. (1999). Different contributions of the human amygdala and ventromedial prefrontal cortex to decision-making. *The Journal of Neuroscience*, *19*, 5473-5481.

Bechara, A., Damasio, H., Tranel, D., & Damasio, A. R. (1997). Deciding advantageously before knowing the advantageous strategy. *Science*, *275*, 1293-1295.

Bechara, A., Damasio, H., Tranel, D., & Damasio, A. R. (2005). The Iowa Gambling Task and the somatic marker hypothesis: Some questions and answers. *Trends in Cognitive Sciences*, *9*, 159-162.

Bechara, A., Dolan, S., Denburg, N., Hindes, A., Anderson, S. W., & Nathan, P. E. (2001). Decision-making deficits, linked to a dysfunctional ventromedial prefrontal cortex, revealed in alcohol and stimulant abusers. *Neuropsychologia*, *39*, 376-389.

Bechara, A., Tranel, D., & Damasio, H. (2000). Characterization of the decision-making deficit of patients with ventromedial prefrontal cortex lesions. *Brain*, *123*, 2189-2202.

Bechara, A., Tranel, D., Damasio, H., & Damasio, A. R. (1996). Failure to respond autonomically to anticipated future outcomes following damage to prefrontal cortex antoine. *Cerebral Cortex, 6*, 215-225.

Beitz, K. M., Salthouse, T. A., & Davis, H. P. (2014). Performance on the Iowa Gambling Task: From 5 to 89 years of age. *Journal of Experimental Psychology: General*, *143*, 1677-1689.

Bembich, S., Clarici, A., Vecchiet, C., Baldassi, G., Cont, G., & Demarini, S. (2014). Differences in time course activation of dorsolateral prefrontal cortex associated with low or high risk choices in a gambling task. *Frontiers in Human Neuroscience*, *8*, Article 464.

Blair, R. J. R., Colledge, E., & Mitchell, D. G. V. (2001). Somatic markers and response reversal: Is there orbitofrontal cortex dysfunction in boys with psychopathic tendencies? *Journal of Abnormal Child Psychology*, *29*, 499-511.

Bourdaud, N., Chavarriaga, R., Galán, F., & Millán, J. D. R. (2008). Characterizing the EEG correlates of exploratory behavior. *IEEE Transactions on Neural Systems and Rehabilitation Engineering*, *16*, 549-556.

Bowman, C. H., Evans, C. E., & Turnbull, O. H. (2005). Artificial time constraints on the Iowa Gambling Task: The effects on behavioural performance and subjective experience. *Brain and Cognition*, *57*, 21-25.

Brand, M., Recknor, E. C., Grabenhorst, F., & Bechara, A. (2007). Decisions under ambiguity and decisions under risk: Correlations with executive functions and comparisons of two different gambling tasks with implicit and explicit rules. *Journal of Clinical and Experimental Neuropsychology*, *29*, 86-99.

Brevers, D., Noël, X., He, Q., Melrose, J. A., & Bechara, A. (2016). Increased ventral-striatal activity during monetary decision making is a marker of problem poker gambling severity. *Addiction Biology*, *21*, 688-699.

Brown, E. C., Hack, S. M., Gold, J. M., Carpenter, W. T., Fischer, B. A., Prentice, K. P., & Waltz, J. A. (2015). Integrating frequency and magnitude information in decision-making in schizophrenia: An account of patient performance on the Iowa Gambling Task. *Journal of Psychiatric Research*, *66-67*, 16-23.

Buelow, M. T., & Suhr, J. A. (2009). Construct validity of the Iowa gambling task. *Neuropsychology Review*, *19*, 102-114.

Burdick, J. D., Roy, A. L., & Raver, C. C. (2013). Evaluating the Iowa Gambling Task as a direct assessment of impulsivity with low-income children. *Personality and Individual Differences*, *55*, 771-776.

Camille, N., Griffiths, C. A., Vo, K., Fellows, L. K., & Kable, J. W. (2011). Ventromedial frontal lobe damage disrupts value maximization in humans. *Journal of Neuroscience*, *31*, 7527-7532.

Cassotti, M., Aïte, A., Osmont, A., Houdé, O., & Borst, G. (2014). What have we learned about the processes involved in the Iowa Gambling Task from developmental studies? *Frontiers in Psychology*, *5*, Article 915.

Castrioto, A., Funkiewiez, A., Debû, B., Cools, R., Lhommée, E., Ardouin, C., . . . Krack, P. (2015). Iowa gambling task impairment in Parkinson's disease can be normalised by reduction of dopaminergic medication after subthalamic stimulation. *Journal of Neurology, Neurosurgery & Psychiatry*, *86*, 186-190.

Cazzell, M., Li, L., Lin, Z. J., Patel, S. J., & Liu, H. (2012). Comparison of neural correlates of risk decision making between genders: An exploratory fNIRS study of the Balloon Analogue Risk Task (BART). *NeuroImage*, *62*, 1896-1911.

Clark, L. (2010). Decision-making during gambling: An integration of cognitive and psychobiological approaches. *Philosophical Transactions of the Royal Society B: Biological Sciences*, *365*, 319-330.

Clark, L., Manes, F., Antoun, N., Sahakian, B. J., & Robbins, T. W. (2003). The contributions of lesion laterality and lesion volume to decision-making impairment following frontal lobe damage. *Neuropsychologia*, *41*, 1474-1483.

Cotrena, C., Branco, L. D., Zimmermann, N., Cardoso, C. O., Grassi-Oliveira, R., & Fonseca, R. P. (2014). Impaired decision-making after traumatic brain injury: The Iowa Gambling Task. *Brain Injury*, *28*, 1070-1075.

Coutlee, C. G., & Huettel, S. A. (2012). The functional neuroanatomy of decision making: Prefrontal control of thought and action. *Brain Research*, *1428*, 3-12.

Crockford, D. N., Goodyear, B., Edwards, J., Quickfall, J., & el-Guebaly, N. (2005). Cue-induced brain activity in pathological gamblers. *Biological Psychiatry*, *58*, 787-795.

Damasio, A. R., Everitt, B. J., & Bishop, D. (1996). The somatic marker hypothesis and the possible functions of the prefrontal cortex [and discussion]. *Philosophical Transactions of the Royal Society B: Biological Sciences*, *351* 1413-1420.

Dashtestani, H., Zaragoza, R., Kermanian, R., Knutson, K. M., Halem, M., Casey, A., . . . Gandjbakhche, A. (2018). The role of prefrontal cortex in a moral judgment task using functional near-infrared spectroscopy. *Brain and Behavior, 8*(11), e01116.

de Visser, L., Homberg, J. R., Mitsogiannis, M., Zeeb, F. D., Rivalan, M., Fitoussi, A., . . . Dellu-Hagedorn, F. (2011). Rodent versions of the Iowa gambling task: Opportunities and challenges for the understanding of decision-making. *Frontiers in Neuroscience, 5*, 109. doi: 10.3389/fnins.2011.00109

Domenech, P., & Koechlin, E. (2015). Executive control and decision-making in the prefrontal cortex. *Current Opinion in Behavioral Sciences*, *1*, 101-106.

Dunn, B. D., Dalgleish, T., & Lawrence, A. D. (2006). The somatic marker hypothesis: A critical evaluation. *Neuroscience & Biobehavioral Reviews*, *30*, 239-271.

Ernst, M., Bolla, K., Mouratidis, M., Contoreggi, C., Matochik, J. A., Kurian, V., . . . London, E. D. (2002). Decision-making in a risk-taking task: A PET study. *Neuropsychopharmacology*, *26*, 682-691.

Euston, D. R., Gruber, A. J., & McNaughton, B. L. (2012). The role of medial prefrontal cortex in memory and decision making. *Neuron*, *76*, 1057-1070.

Fein, G., McGillivray, S., & Finn, P. (2007). Older adults make less advantageous decisions than younger adults: Cognitive

and psychological correlates. *Journal of the International Neuropsychological Society*, *13*, 480-489.

Forbush, K. T., Shaw, M., Graeber, M. A., Hovick, L., Meyer, V. J., Moser, D. J., . . . Black, D. W. (2008.). Neuropsychological characteristics and personality traits in pathological gambling. *CNS Spectrums*, *13*, 306-315.

Frackowiak, R. S. (2004). *Human brain function* (2nd ed.). In K. J. Friston, C. D. Frith, R. J. Dolan, C. J. Price, S. Zeki, J. T. Ashburner, & W. D. Penny (Eds.), Academic Press (p. 1144). Retrieved from https://www.elsevier.com/books/human-brain-function/frackowiak/978-0-12-264841-0

Galanter, M., Kleber, H. D., & Brady, K. (Eds.). (2014). *The American Psychiatric Publishing textbook of substance abuse treatment*. American Psychiatric Publishing.

Garon, N., & Longard, J. (2014). Loss frequency versus long-term outcome in preschoolers' decision making on a child variant of the Iowa Gambling Task. *Applied Neuropsychology: Child*, *4*, 221-229.

Geurts, H. M., Van der Oord, S., & Crone, E. A. (2006). Hot and cool aspects of cognitive control in children with ADHD: Decision-making and inhibition. *Journal of Abnormal Child Psychology*, *34*, 811-822.

Haber, S. N. (2011). Neuroanatomy of reward: A view from the ventral striatum. In J. A. Gottfried (Ed.), *Neurobiology of sensation and reward* (p. 235). Boca Raton, FL: CRC Press/Taylor & Francis.

Hagen, E., Erga, A. H., Hagen, K. P., Nesvåg, S. M., McKay, J. R., Lundervold, A. J., & Walderhaug, E. (2016). Assessment of executive function in patients with substance use disorder: A comparison of inventory-and performance-based assessment. *Journal of Substance Abuse Treatment*, *66*, 1-8.

Haruno, M., & Kawato, M. (2006). Different neural correlates of reward expectation and reward expectation error in the putamen and caudate nucleus during stimulus-action-reward association learning. *Journal of Neurophysiology*, *95*, 948-959.

Hooper, C. J., Luciana, M., Conklin, H. M., & Yarger, R. S. (2004). Adolescents' performance on the Iowa Gambling Task: Implications for the development of decision making and ventromedial prefrontal cortex. *Developmental Psychology*, *40*, 1148-1158.

Jacus, J. P., Gély-Nargeot, M. C., & Bayard, S. (2018). Ecological relevance of the Iowa gambling task in patients with Alzheimer's disease and mild cognitive impairment. *Revue Neurologique*, *174*, 327-336.

Jazaeri, S. A., & Habil, M. H. B. (2012). Reviewing two types of addiction-pathological gambling and substance use. *Indian Journal of Psychological Medicine*, *34*, 5-11.

Johnson, S. A., Yechiam, E., Murphy, R. R., Queller, S., & Stout, J. C. (2006). Motivational processes and autonomic responsivity in Asperger's disorder: Evidence from the Iowa Gambling Task. *Journal of the International Neuropsychological Society*, *12*, 668-676.

Kester, H. M., Sevy, S., Yechiam, E., Burdick, K. E., Cervellione, K. L., & Kumra, S. (2006). Decision-making impairments in adolescents with early-onset schizophrenia. *Schizophrenia Research*, *85*, 113-123.

Kim, M. S., Kang, B. N., & Lim, J. Y. (2016). Decision-making deficits in patients with chronic schizophrenia: Iowa gambling Task and Prospect Valence learning model. *Neuropsychiatric Disease and Treatment*, *12*, 1019-1027.

Korn, D. A., & Shaffer, H. J. (1999). Gambling and the health of the public: Adopting a public health perspective. *Journal of Gambling Studies*, *15*, 289-365.

Körner, N., Schmidt, P., & Soyka, M. (2015). Decision making and impulsiveness in abstinent alcohol-dependent people and healthy individuals: A neuropsychological examination. *Substance Abuse Treatment, Prevention, and Policy, 10*, Article 24.

Krmpotich, T., Mikulich-Gilbertson, S., Sakai, J., Thompson, L., Banich, M. T., & Tanabe, J. (2015). Impaired decision-making, higher impulsivity, and drug severity in substance dependence and pathological gambling. *Journal of Addiction Medicine*, *9*, 273-280.

Labudda, K., Frigge, K., Horstmann, S., Aengenendt, J., Woermann, F. G., Ebner, A., . . . Brand, M. (2009). Decision making in patients with temporal lobe epilepsy. *Neuropsychologia*, *47*, 50-58.

Lamm, C., Zelazo, P. D., & Lewis, M. D. (2006). Neural correlates of cognitive control in childhood and adolescence: Disentangling the contributions of age and executive function. *Neuropsychologia*, *44*, 2139-2148.

LeGris, J., Toplak, M., & Links, P. S. (2014). Affective decision making in women with borderline personality disorder. *Journal of Personality Disorders*, *28*, 698-719.

Lehto, J. E., & Elorinne, E. (2003). Gambling as an executive function task. *Applied Neuropsychology*, *10*, 234-238.

Levine, B., Black, S. E., Cheung, G., Campbell, A., O'Toole, C., & Schwartz, M. L. (2005). Gambling task performance in traumatic brain injury: Relationships to injury severity, atrophy, lesion location, and cognitive and psychosocial outcome. *Cognitive and Behavioral Neurology*, *18*, 45-54.

Li, X., Lu, Z. L., D'Argembeau, A., Ng, M., & Bechara, A. (2010). The Iowa gambling task in fMRI images. *Human Brain Mapping*, *31*, 410-423.

Lin, C. H., Chiu, Y. C., Cheng, C. M., & Hsieh, J. C. (2008). Brain maps of Iowa gambling task. *BMC Neuroscience*, *9*, Article 72.

Linnet, J. (2013). The Iowa Gambling Task and the three fallacies of dopamine in gambling disorder. *Frontiers in Psychology*, *4*, Article 709.

Linnet, J., Røjskjær, S., Nygaard, J., & Maher, B. A. (2006). Episodic chasing in pathological gamblers using the Iowa gambling task. *Scandinavian Journal of Psychology*, *47*, 43-49.

Mimura, M., Oeda, R., & Kawamura, M. (2006). Impaired decision-making in Parkinson's disease. *Parkinsonism and Related Disorders*, *12*, 169-175.

Must, A., Horvath, S., Nemeth, V. L., & Janka, Z. (2013). The Iowa Gambling Task in depression—What have we learned about sub-optimal decision-making strategies? *Frontiers in Psychology*, *4*, Article 732.

Nakamura, M., Nestor, P. G., Levitt, J. J., Cohen, A. S., Kawashima, T., Shenton, M. E., & McCarley, R. W. (2008). Orbitofrontal volume deficit in schizophrenia and thought disorder. *Brain*, *131*, 180-195.

National Gambling Impact and Policy Commission (U.S.). (1999). *National gambling impact study commission final report*. Washington, DC: The Commission.

Noël, X., Bechara, A., Dan, B., Hanak, C., & Verbanck, P. (2007). Response inhibition deficit is involved in poor decision mak-

ing under risk in nonamnesic individuals with alcoholism. *Neuropsychology*, *21*, 778-789.

Ono, Y., Kikuchi, M., Hirosawa, T., Hino, S., Nagasawa, T., Hashimoto, T., . . . Minabe, Y. (2015). Reduced prefrontal activation during performance of the Iowa Gambling Task in patients with bipolar disorder. *Psychiatry Research: Neuroimaging*, *233*, 1-8.

Ouerchefani, R., Ouerchefani, N., Allain, P., Rejeb, M. R. B., & Le Gall, D. (2017). Contribution of different regions of the prefrontal cortex and lesion laterality to deficit of decision-making on the Iowa Gambling Task. *Brain and Cognition*, *111*, 73-85.

Potenza, M. N. (2009). The importance of animal models of decision-making, gambling and related behaviors: Implications for translational research in addiction. *Neuropsychopharmacology*, *34*, 2623-2624.

Potenza, M. N., Kosten, T. R., & Rounsaville, B. J. (2001). Pathological gambling. *Journal of the American Medical Association*, *286*, 141-144.

Power, Y., Goodyear, B., & Crockford, D. (2012). Neural correlates of pathological gamblers preference for immediate rewards during the Iowa Gambling Task: An fMRI study. *Journal of Gambling Studies*, *28*, 623-636.

Proctor, D., Williamson, R. A., Latzman, R. D., de Waal, F. B., & Brosnan, S. F. (2014). Gambling primates: Reactions to a modified Iowa Gambling Task in humans, chimpanzees and capuchin monkeys. *Animal Cognition*, *17*, 983-995.

Quednow, B. B., Kühn, K. U., Hoppe, C., Westheide, J., Maier, W., Daum, I., & Wagner, M. (2007). Elevated impulsivity and impaired decision-making cognition in heavy users of MDMA ("Ecstasy"). *Psychopharmacology*, *189*, 517-530.

Quintero, G. C. (2017). A biopsychological review of gambling disorder. *Neuropsychiatric Disease and Treatment*, *13*, 51-60.

Reilly, C., & Smith, N. (2013). *The evolving definition of pathological gambling in the DSM-5*. Beverly, MA: National Center for Responsible Gaming.

Roca, M., Torralva, T., López, P., Cetkovich, M., Clark, L., & Manes, F. (2008). Executive functions in pathologic gamblers selected in an ecologic setting. *Cognitive and Behavioral Neurology*, *21*, 1-4.

Rolls, E. T., & Grabenhorst, F. (2008). The orbitofrontal cortex and beyond: From affect to decision-making. *Progress in Neurobiology*, *86*, 216-244.

Sadato, N., Nakamura, S., Oohashi, T., Nishina, E., Fuwamoto, Y., Waki, A., & Yonekura, Y. (1998). Neural networks for generation and suppression of alpha rhythm: A PET study. *NeuroReport*, *9*, 893-897.

Santos, J. P., Seixas, D., Brandão, S., & Moutinho, L. (2011). Investigating the role of the ventromedial prefrontal cortex in the assessment of brands. *Frontiers in Neuroscience*, *5*, Article 77.

Schutter, D. J., de Haan, E. H., & van Honk, J. (2004). Anterior asymmetrical alpha activity predicts Iowa gambling performance: Distinctly but reversed. *Neuropsychologia*, *42*, 939-943.

Schutter, D. J., Van Bokhoven, I., Vanderschuren, L. J., Lochman, J. E., & Matthys, W. (2011). Risky decision making in substance dependent adolescents with a disruptive behavior disorder. *Journal of Abnormal Child Psychology*, *39*, 333-339.

Shinogle, J., Norris, D. F., Park, D., Volberg, R. A., Haynes, D., & Stokan, E. (2011). *Gambling prevalence in Maryland: A baseline analysis*. Baltimore: Maryland Institute for Policy Analysis and Research.

Singh, V., & Khan, A. (2012). Decision making in the reward and punishment variants of the Iowa gambling task: Evidence of "foresight" or "framing"? *Frontiers in Neuroscience*, *6*, Article 107.

Sinz, H., Zamarian, L., Benke, T., Wenning, G. K., & Delazer, M. (2008). Impact of ambiguity and risk on decision making in mild Alzheimer's disease. *Neuropsychologia*, *46*, 2043-2055.

Skvortsova, V., Palminteri, S., & Pessiglione, M. (2014). Learning to minimize efforts versus maximizing rewards: Computational principles and neural correlates. *Journal of Neuroscience*, *34*, 15621-15630.

Stocco, A., Fum, D., & Napoli, A. (2009). Dissociable processes underlying decisions in the Iowa Gambling Task: A new integrative framework. *Behavioral and Brain Functions*, *5*(1), Article 1.

Suhr, J., & Hammers, D. (2010). Who fails the Iowa Gambling Test (IGT)? Personality, neuropsychological, and near-infrared spectroscopy findings in healthy young controls. *Archives of Clinical Neuropsychology*, *25*, 293-302.

Takahashi, T., Takagishi, H., Nishinaka, H., Makino, T., & Fukui, H. (2014). Neuroeconomics of psychopathy: Risk taking in probability discounting of gain and loss predicts psychopathy. *Neuroendocrinology Letters*, *35*, 510-517.

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*, 1276-1286.

Toplak, M. E., Jain, U., & Tannock, R. (2005). Executive and motivational processes in adolescents with attention-deficit-hyperactivity disorder (ADHD). *Behavioral and Brain Functions*, *1*(1), Article 8.

Toplak, M. E., Sorge, G. B., Benoit, A., West, R. F., & Stanovich, K. E. (2010). Decision-making and cognitive abilities: A review of associations between Iowa Gambling Task performance, executive functions, and intelligence. *Clinical Psychology Review*, *30*, 562-581.

Van den Bos, R., Homberg, J., & de Visser, L. (2013). A critical review of sex differences in decision-making tasks: Focus on the Iowa Gambling Task. *Behavioural Brain Research*, *238*, 95-108.

Van den Bos, R., Koot, S., & de Visser, L. (2014). A rodent version of the Iowa Gambling Task: 7 years of progress. *Frontiers in Psychology*, *5*, Article 203.

van Holst, R. J., van den Brink, W., Veltman, D. J., & Goudriaan, A. E. (2010). Why gamblers fail to win: A review of cognitive and neuroimaging findings in pathological gambling. *Neuroscience & Biobehavioral Reviews*, *34*, 87-107.

Verdejo-García, A., Rivas-Pérez, C., Vilar-López, R., & Pérez-García, M. (2007). Strategic self-regulation, decision-making and emotion processing in poly-substance abusers in their first year of abstinence. *Drug and Alcohol Dependence*, *86*, 139-146.

Wandschneider, B., Centeno, M., Vollmar, C., Stretton, J., O'muircheartaigh, J., Thompson, P. J., . . . Richardson, M. P. (2013). Risk-taking behavior in juvenile myoclonic epilepsy. *Epilepsia*, *54*, 2158-2165.

Welte, J. W., Barnes, G. M., Wieczorek, W. F., Tidwell, M. C., & Parker, J. (2002). Gambling participation in the US—Results from a national survey. *Journal of Gambling Studies*, *18*, 313-337.

Xiao, L., Wood, S. M., Denburg, N. L., Moreno, G. L., Hernandez, M., & Bechara, A. (2013). Is there a recovery of decision-making function after frontal lobe damage? A study using alternative versions of the Iowa Gambling Task. *Journal of Clinical and Experimental Neuropsychology*, *35*, 518-529.

Yechiam, E., Busemeyer, J. R., Stout, J. C., & Bechara, A. (2005). Using cognitive models to map relations between neuropsychological disorders and human decision-making deficits. *Psychological Science*, *16*, 973-978.

Zeeb, F. D., Baarendse, P. J. J., Vanderschuren, L. J. M. J., & Winstanley, C. A. (2015). Inactivation of the prelimbic or infralimbic cortex impairs decision-making in the rat gambling task. *Psychopharmacology*, *232*, 4481-4491.

Zeeb, F. D., & Winstanley, C. A. (2011). Lesions of the basolateral amygdala and orbitofrontal cortex differentially affect acquisition and performance of a rodent gambling task. *The Journal of Neuroscience*, *31*, 2197-2204.

Zhang, L., Dong, Y., Ji, Y., Tao, R., Chen, X., Ye, J., . . . Wang, K. (2015). Trait-related decision making impairment in obsessive-compulsive disorder: Evidence from decision making under ambiguity but not decision making under risk. *Scientific Reports*, *5*, Article 17312.

Author Biographies

Siamak Aram, PhD, is an assistant professor of Data Sciences at Harrisburg University of Science and Technology. He received a PhD in computer and control engineering from the Polytechnic University of Turin in Italy. He has three years of postdoctoral experience working at the University of Maryland School of Medicine's Clinical and Translational Research Informatics Center (UMB – CTRIC) (in collabroation with Biophotonics Lab (NIH)), and the Energy Efficient High Performance Computing Lab at the University of Maryland (UMBC). Aram continues his research as a Data Scientist focusing on data analysis, deep learning and machine learning for healthcare and environmental applications.

Lauren Levy is the health officer for the Cecil County Health Department in Cecil County, Maryland and holds an adjunct faculty appointment in the Department of Epidemiology and Public Health at the University of Maryland School of Medicine. She received her MPH degree from the Columbia University Mailman School of Public Health and her JD from the University of Maryland Carey School of Law.

Jigar B. Patel, MD, is a neuroradiologist at the VA Maryland Health Care System and an adjunct assistant professor at the University of Maryland School of Medicine. His research interests include imaging informatics, traumatic brain injury, and the impact of carotid stenosis on cognitive function.

Afrouz A. Anderson received her PhD in Biomedical Engineering focusing in biophotonic translational research from the University of California, Davis, and National Institutes of Health and her BS in Electrical Engineering from the University of Maryland, College Park. Her research focuses on application of Near Infrared Spectroscopy to quantify and investigate the brain function and development in toddlers, children and adults with typical development and neurodevelopmental disorders.

Rachel Zaragoza is an MD candidate at the Virginia Commonwealth University School of Medicine. She graduated with her bachelors degree in Cognitive Science at the University of Virginia. Rachel is a former researcher at the National Institute of Health with research interests in psychology and brain imaging.

Hadis Dashtestani is PhD student at University of Maryland Baltimore County. She is performing her PhD project on Section on Translational Biophotonics (STB), National Institute of Health. Her area of interest is Machine Learning and she is currently working on brain modeling through non-invasive imaging techniques such as functional Near Infra-red Spectroscopy (fNIRS) and Electroencephalography (EEG).

Fatima A. Chowdhry, MD, is a medically trained, clinical research scientist. Her interest in research led her to the National Institutes of Health where she was given the opportunity to work in a biophotonics lab, working alongside engineers and physicists. Her focus has mainly been related to neuroscience and oncology including: traumatic brain injury, autism spectrum disorders, urea cycle disorders, Cushing's disease and syndrome.

Amir Gandjbakhche received his BS degree in Electrical Engineering, and PhD in Biomedical Engineering from University of Paris. He is now senior investigator and Chief, Section on Translational Biophotonics. His entire career has been devoted to devising quantitative methodologies and associated instrumentations to bring technologies from the bench to the bedside. His focus has been to design relatively inexpensive, wearable and portable monitoring systems. Working at the NIH has provided him with the opportunity to focus his research on the practical needs of heath care providers. In 2009 , he was the awarded NIH Merit Award. He has been recognized by the NICHD Collaboration Award, peers as a fellow of the two largest professional societies in optics and photonics, SPIE and OSA, the NICHD Mentor Award and NIH innovation Award for his seminal work on Placental oxygenation.

J. Kathleen Tracy is an associate professor of Epidemiology and Public Health in the University of Maryland School of Medicine and the director of Research for the Maryland Center of Excellence on Problem Gambling at the University of Maryland School of Medicine.