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Review

Neurobiology of decision-making: Quo vadis?

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Abstract

Decision-making is an important aspect of daily life. Moreover, dysfunctions of decision-making play a critical role in a number of neuropsychiatric disorders. Several important research groups have contributed a diverse set of approaches to study decision-making and its underlying neurobiology. Insights from these studies may provide important directions for future research in this area.

Theme: Decision-making
Topic: Cognition

Keywords: Decision-making; Neurobiology; Neuropsychiatric disorder

Contents

1. Introduction

Decision-making fundamentally refers to the process of making choices or reaching conclusions. One can conceptualize decision-making in a wide variety of situations, which range from the selection of a simple act, such as initiating a finger movement, to the selection of a complex action, such as which bonds to buy in the stock market. In this special issue, a number of research groups provide intriguing insights into the blossoming field of the neurobiology of decision-making, but also highlight some of the important unsolved problems. The goal of this overview is to identify common ground among these researchers, embed the current findings into a more general framework addressing important aspects of decision-making research, and identify issues that will need to be addressed in future research.

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Conceptually, decision-making can be divided both temporally and functionally into partially distinct processes: (1) the assessment and formation of preferences among possible options; (2) the selection and execution of an action; and (3) the experience or evaluation of an outcome. During the first stage, individuals attribute value to the available options and select one of them. During the second stage, individuals initiate, perform, and complete an action according to the preferences established during the first stage. To successfully complete this stage, a range of action-related processes occurs, such as the sequencing of actions, the inhibition of competing actions, and the appropriate timing of actions. During stage three, individuals generate and process a signal, which is related to the difference between expected and experienced outcomes. This signal provides a means of linking actions to outcomes, and is key to adjusting the values during the first stage of the next decision-making. Finally, decision-making is an iterative process, such that the current stage of decision-making is influenced by the history of preceding stages and directly influences the subsequent stages of processing.

2. Dimensions of decision-making

There are at least five critical dimensions that can have profound effects on how individuals make decisions. First, decision-making is often associated with uncertainty, either explicitly described as the probability of an outcome associated with an action, or implicit as past experienced associations of an action with an outcome. Trepel et al. [66] argue that one must carefully consider the complex transformation of probabilities into decision weights, which influence the degree to which one option is preferred over another. Similarly, Shiv et al. [61] show that these probabilities are not necessarily perceived in a linear fashion. Second, each option in a decision-making situation has a certain value, which is derived from the possible reward or punishment associated with the outcome of that option. Ursu shows that this value may fundamentally be processed relative to the alternative option. Thus, the reference point, which defines the most preferred option in a decision-making situation, may not be constant as suggest by traditional utility theories but may vary according to the available alternatives [40]. Third, decision-making takes place over time; in other words, past actions and outcomes affect the future assessment of options available. Yarkoni et al. [69] show that individuals may process options over several different time scales. In many daily decision-making situations, individuals do not know explicitly how likely it is that a given option will have a desirable or undesirable outcome, but instead have acquired positive or negative values associated with options because of prior experiences with the selected choice. Fourth, many decision-making situations take place between individuals or between groups of individuals. Thus, options are evaluated not only according to the positive and negative values of the decision-maker, but also in regards to the effects of the decision on other individuals or groups. These possible consequences may have profound effects on the value attributed to an option. Haselhuhn and Mellers [25] show that one must carefully consider the trade-offs between self-interest, the individual component, and fairness, the group-specific component of decision-making. Fifth, although traditional choice psychology has sought to discover generic decision-making rules and laws, there is extensive behavioral evidence that decision-making is highly dependent on context—to the extent that some investigators have questioned whether there is such a thing as a generic decision-making situation. Several groups [26,61,68] show that contextual characteristics of the task or the task situation have profound influence on behavior or neural substrate activation.

Attribute level refers to the specific quantitative or qualitative degree of an option dimension such as the price of an apartment or the degree of nightlife in a vacation resort [27]. The attribute levels of the dimensions for each option in a decision-making situation do not contribute linearly to the degree of preference of one option over another. This seemingly obvious statement can have profound consequences for the interpretation of the experimental results. For example, as Huckfeldt elaborates, subjects show a quicker selection of an option when there is a stronger association in long-term memory, which increases the level of accessibility. This theme is also briefly mentioned in Trepel's article, which attempts to identify the basic components of a decision-making situation (acts [options], states, and consequences). Nevertheless, the characteristics of options or acts are based on complex processes that tend to conglomerate attributes not necessarily in a cognitively rational manner (as hypothesized in system I, see below) but also in an associative affective way (as conceptualized in what is referred to as system II).

The review by Trepel et al. [66] emphasizes an important issue that has not been widely addressed in the literature on the neurobiology of decision-making. Specifically, investigators typically manipulate reward or punishment probability or magnitude without explicitly taking into account the long established behavioral biases in these situations. For example, a 50% chance of winning $1 is not the same as a 25% chance of winning $2 even though the expected value of both options is the same. It has long been recognized that human beings transform both probability and reward or punishment magnitude in characteristic ways to evaluate different options. It would be useful to take into account these transformations when conducting future neuroimaging studies with these types of paradigms. Moreover, these investigators also emphasize that framing effects are likely to have strong influences on the processing characteristics of particular tasks, which will make it more difficult to establish a neural substrate that could be called a "generic decision-making" system.

Over 200 years ago, Bernoulli [5] recognized that people's evaluation of potential outcomes is based on a subjective value and differs from the simple mathematical product of probability and outcome magnitude. He proposed that the psychological function underlying the evaluation of the magnitude of an outcome is concave, that is, that the difference between $200 and $400 is evaluated as larger than the difference between $1200 and $1400. The concavity of the value function in the gain domain is paralleled by a convexity in the loss domain (i.e., losing $400 versus $200 is more aversive than $1400 versus $1200). In addition to subjective effects on the magnitude of the value function, individuals also show subjective weighing of the probability of an outcome. It has long been recognized that a change from impossibility, for example, "the earth is not going to get hit by an asteroid", to possibility, for example, "the earth may get hit by an asteroid", or from possibility to certainty has a bigger impact than a change from a somewhat probable to a more probable outcome [15]. In practical terms, people tend to value a reduction of a probability proportionally much less than the complete elimination of a probability, for example, individuals typically do not buy car insurance for half price that would only cover them on odd days [63].

Context-specific effects in decision-making situations: it is widely assumed that because of the limited processing resources of the brain, complex sets of stimuli are systematically simplified or "edited", which helps to establish rules. Editing includes principles of combination, that is, probabilities of equal outcomes are added; simplification, that is, non-essential differences are neglected; cancellation, that is, elements common to both gambles are cancelled; and segregation, that is, complex gambles are separated into risky and riskless components. In addition to these editing processes, other context-specific decision-making effects have been reported. Specifically, one of the most basic finding in decision-making processes is the "concreteness principle" [62]. If an individual is asked to decide on the relative preference (on a scale from "like very much" to "don't like at all") between different ski vacation packages that are characterized by the "quality of the snow" and the price of the hotel, individuals tend to overweigh the quality of the snow attribute. In contrast, if subjects are asked to estimate the maximum price they would be willing to pay for the different ski vacation packages, they tend to overweigh the price of the hotel attribute. Tversky [67] argued long ago that people compare available options on each attribute individually rather than evaluating the option as a whole, which leads to the emphasis on some attributes and the neglect of others. In particular, when two options have attributes that are very similar, such as two cars with equally powerful engines, then these attributes are ignored when one arrives at a final decision.

Background contrast refers to the observation that previous experience profoundly influences which dimension to emphasize when determining the degree of preference of a particular option. For example, people are more likely to select a cheaper tire, that is, select according to price rather than quality, when they were previously asked to select between two tires which differed little in price but a lot in their associated warranty [60]. In contrast, individuals who had previously been exposed to small differences in warranty and a large price difference were more likely to select the tire with the longer warranty. Ursu and Carter [68] show in their study that background contrast may be a special case of a counterfactual thinking, that is, the evaluation of the selected option within the context of the alternatives.

The degree of preference for an option and the resulting selection of an action in a decision-making situation depend strongly on the specific constellation of attributes. For example, in situations when competing attributes of available options are "too close to call", for example, two apartments that cost $290 versus $350 a month and are associated with a 25-min versus a 5-min commute, individuals do not necessarily select the option that would maximize the outcome (select the $290 apartment) but, instead, often choose to search for alternatives with more variable attributes (e.g., asked to see other options with varying commuting times). Moreover, the introduction of a competing alternative increases the delay to make a decision, for example, people are less likely to buy a t-shirt, even if it is on sale, when at the same time another t-shirt is on sale, relative to the situation when only one t-shirt is on sale [59]. Finally, adding an option with an extreme value on one attribute can have two effects on decision-making. It can increase the preference for an option with a medium value of the same attribute (compromise) or it can reduce the attractiveness of an option, which has a less attractive attribute (polarization). For example, introducing a high-quality/high-priced camera as a third option for two mid-quality/mid-priced cameras increases the preference for the cameras with the median price. However, introducing a low-quality/low-priced item tends to increase the preference for a high-quality/high-priced item.

Lastly, in reference to Kahneman's distinction between decision utility and experienced utility, Trepel et al. [66] emphasize that what one expects to observe and its corresponding emotional impact may differ significantly from what one eventually when an outcome is presented experiences and the subsequent emotional impact of that outcome. This distinction is consistent with the notion that decision-making occurs in different and possibly separable stages (assessment, action selection, and outcome processing). Moreover, this observation also calls into question whether decision-making in situations with hypothetical outcomes is similar to decision-making when the individual experiences subsequently the effects of the selected option. For example, one could ask a subject to choose between two gambles with or without presenting an actual outcome. Whereas the former can be formulated to explicitly address effects of explicit reward or punishment probability or magnitude on the assessment of preferences for an option, the latter may be required to examine the integration of preceding stages of decision-making on subsequent decision-making situations. This calls for more systematic research into comparing the role of neural substrates when decisions are made without presenting an outcome versus when individuals are asked to select from a range of available options within the context of experiencing explicit reward or punishment associated with these options.

A sophisticated experimental approach to determine the influence of control mechanisms versus inhibitory processes is suggested by Yarkoni et al. [69]. In their formulation, self-control is defined as the ability to use internal representations of long-term future outcomes to bias and constrain their decision-making behavior. These investigators also emphasize the fact that in many decision-making situations, values, goals, and probabilities are "moving targets", that is, are not constant over time but are in fact sensitively influenced by the prior choices that the person has made. This approach mirrors that of dynamic decision-making theories. Specifically, Busemeyer and Townsend [7,51] propose decision field theory to capture the deliberation process that occurs with conflicting values. The theory predicts the feeling of pleasure we may have about an important decision when the action is far away, and the later dread we feel when the action is imminent, for example, accepting to give an important talk at a scientific conference. Decision field theory also predicts preference reversals as a function of time pressure, violations of stochastic dominance, and the inverse relationship between decision time and choice proportions. Yarkoni et al. [69] show that neural substrates important for temporal processing are engaged in sustained neural activity when processing rewards that change over many trials versus those that change over few. These authors also highlight that decision-making takes place over several temporal domains and that one needs to establish a paradigm to examine these different phenomena simultaneously.

3. Emotion and decision-making

William James linked decision-making, the process of deliberating until an action takes place, to emotion [28]. Emotions have significant effects on decision-making processes both during the assessment and outcome stage of decision-making. For example, positive affect during the assessment stage can result in greater variety seeking [29], overestimation of the likelihood of favorable and underestimation of the likelihood of unfavorable events [43], increased deliberation times [33], and more complex decision-making strategies [38]. In comparison, negative affect during this stage can narrow the search for response alternatives [18], speed response selection, and reduce the use of different sources of information [36].

Some investigators have suggested that two fundamentally different systems underlie decision-making [17], which work in parallel but may arrive at conflicting decisions. One system, which is thought to be evolutionarily older, fast, mostly automatic, and hence not very accessible to conscious awareness and control, uses primarily similarity and associative processing [70]. The other system is based on algorithms and rules, for example, the probability calculus, Bayesian updating, formal logic, is slower, effortful, and requires awareness and conscious control. For example, uncertain and threatening cues associated with action options can trigger affective responses (e.g., fear, dread, anxiety) and have profound influences on the decision-making process. Therefore, several investigators have proposed that decision-making in the presence of risk could be conceptualized as a general feeling state [34] rather than defined by the properties of the decision-making situation. Some investigators have even argued that people predominantly use an affect heuristic when making a decision [20,45], that is, individuals base their decision on an "affect pool", which contains all the positive and negative tags consciously or unconsciously associated with the action options. Several empirical findings have been cited to support this view.

The role of emotions is highlighted in the article by Shiv et al. [61]. These investigators utilized a simple investment task to examine the role of losses versus gains in individuals with substance use disorder. These subjects were more likely to invest than healthy comparison subjects even when faced the possibility of a loss. Moreover, it appeared that these subjects respond differently to feedback. Whereas normal participants were more likely to withdraw from selecting a risky option particularly after a loss, substance use individuals showed high levels of risky responses after a prior loss or gain. These investigators emphasize the multifactorial nature of these differences, which could be attributable to attenuated loss outcome processing, decreased ability to view future negative consequences, and inability to inhibit attractiveness of immediate reward.

4. Physiological responses and decision-making

Emotions have been defined as evolved adaptive process to improve survival, characterized by and perceived as distinctive and automated physiological responses [28], with the function to judge or appraise events in our environment along immediate, non-reflective dimensions of pleasantness, control, certainty, responsibility, effort [64] and to create a state of readiness to act [22]. Thus, measuring physiological responsivity during decision-making situations may be a useful approach to examine the effects of emotions on decision-making. A major contribution is that of Damasio [13], who proposed the somatic marker theory. This theory posits that every stimulus is associated with an affective weight that is coded automatically and generates changes in the autonomic nervous system (i.e., heart rate, blood pressure, skin conductance). These autonomic changes constitute the somatic markers, which inform brain systems of the affective weight, particularly emotional intensity, of stimuli. A key component of their theory is the interaction between body and brain in computing advantageous versus disadvantageous action selection. In particular, somatic markers may represent primary (body generated) or secondary (brain generated) signals that associated value and meaning to options in a decision-making situation. Along similar lines of reasoning, some investigators have proposed a "risk-as-feelings" hypothesis, which highlights the role of affect experienced at the moment of decision making [34], consistent with the emerging view that the anterior cingulate and the anterior insula may be critical for the integration of afferent interoceptive information about impending external stimuli and internal emotional states [10,11]. According to these and other related models, brain-generated body-feeling states may be critical determinants for the evaluation of different options during decision-making situations and result in establishing a value system based on these body-feeling states. The study by Cohen et al. [9] points toward the critical role of the anterior cingulate cortex in a network of structures that are important for processing interoceptive stimuli.

At this stage, it is not clear whether the observed changes in body state are primary or secondary. Specifically, is an acceleration or deceleration of the heart, a primary event aimed to alert brain areas to the significance of an impending stimulus or action selection situation or does the brain initiate body state changes to prepare the individual for these events? Ultimately, these questions can only be resolved by sophisticated psychophysiological neuroimaging experiments. Moreover, selective pharmacological manipulation of peripheral body states, for example, administration of beta-blockers that do not cross the blood–brain barrier, may begin to address the causal connections between the body and the brain in a decision-making situation.

Intriguingly, Crone et al. [12] show in a set of experiments that heart rate changes can be linked specifically to outcome variability, a measure of risk in a decision-making situation. Specifically, it appears that heart-rate changes are related to the ability to make a decision, which is contextually dependent, that is, varies according to what could have happened. Therefore, peripheral body states may provide a means of alerting to events that are important for adjusting future performance.

5. Neural substrates underlying decision-making

The neural processes and computations that may underlie the adjustment of the value system over time has been under intense investigation and several theoretical models [16,23,57,65] have been proposed to explain how response selection takes place in a decision-making situation.

These neural systems theoretical models have in common a connection between specific brain systems and processes underlying the adjustment of the value system. For example, in the Log-likelihood model [57] a Bayesian-like process [48] is proposed to modify probabilities of hypotheses according to perceived stimuli [23], which is thought to occur in the parietal cortex [47,58]. In comparison, the Prediction Error, or Temporal Difference model [56,65] focuses on monoaminergic neurons in general, which appear to broadcast prediction errors, that is, the difference between the expected and observed reward, as global teaching signals to different areas of the brain [55], and dopamine neurons in particular, which generate a short-latency, phasic reward signal [54]. The temporal difference model originally provided a neurally based conceptualization of stimulus–reward processing. This model has also been used to account for changes in the stimulus–reward relationships in decision-making situations [16]. Moreover, BOLD fMRI activation changes were found to be consistent with predictions by the temporal difference model in ventral striatum and orbitofrontal cortex during acquisition of appetitive conditioned stimuli [44] and in the striatum during the expectancy violation of positive and negative stimuli [39].

Using neuroimaging studies or brain lesion patients and decision-making paradigms, several investigators have shown that structures important for the processing of reward [32], punishment [3], positive and negative moods [46], as well as self-relevant processing [53] are also active in decision-making situations. Therefore, it is important to consider at what stage and to what extend emotions play a role during decision-making. If one divides decision-making into the three stages outlined in the introduction, that is, assessing the situation and the weight of each available option, selecting and completing an action according to optimal option, and experience the consequences of the outcome, one can argue that emotions can play different roles during different stages of decision-making. For example, anticipation or expectation of outcomes associated with each available option may play a critical role during the first stage of decision-making, which is consistent with the findings by Ursu and Carter [68]. It appears that individuals continuously form predictions about the future, which are updated with new information (see, for recent example, Ref. [50]). If one assumes that emotions are the consciously perceived feelings [14], indicating change in impending reward or punishment, one should not be surprised to find significant emotional responses during the assessment stage of decision-making. Similarly, during the action phase of the decision-making process, particularly when temporally extended, one could conceivably find that the degree of effort associated with action selection can generate feelings that are highly relevant for the completion of the selected choice. Lastly, it is obvious that outcomes can provoke strong emotions. It will be particularly interesting to examine whether the outcomes experienced following a decision-making situation show similar characteristics as the experience of expected rewards or punishments. In particular, it will be important to determine whether populations with psychiatric disorders as studied by Shiv, Fishbein and Goudriaan show stage-specific emotional impairments.

One may propose that neural substrates, which are observed to be active during decision-making, could play three different roles. First, these neural substrates could serve to employ generic cognitive and affective components during the decision-making process. For example, Braver asserts the point that many of the activation patterns observed during a temporally-extended decision-making task involve neural substrates that have commonly been identified with cognitive functions comprising cognitive or executive control, error monitoring, and working memory. Second, one may argue that certain neural substrates are specifically involved in decision-making relevant processes. For example, Trepel argues that valuation, an important component in establishing expected utility of a given option, could be linked to posterior parietal cortex activation and not simply reflect different degrees of attentional processing. Similarly, Cohen shows differential activation during high-risk vs. low-risk decisions in right orbitofrontal, dorsolateral, temporal and parietal cortex, as well as anterior cingulate and ventral striatum. Moreover, this author argues that the ACC specifically processes decision to choose a highly uncertain large reward. In this context, it is interesting to mention that prospect theory specifically argues that the nonlinearity of the probability weighing is directly related to a risk-averse/prone decision-making pattern. Future investigation will need to show whether there is a relationship between the ACC and the degree of nonlinearity within the context of prospect theory. Third, one may argue that processes that are associated with but not necessarily central to the decision-making operation activate neural substrates. For example, Yarkoni shows that task-related activation patterns were related to state-dependent changes in task condition but argued that some of these neural substrates may simply be due to perceptual processing and specific task characteristic. Similarly, Trepel highlights the importance of considering framing effects, which may be due to contextually biased brain representations of the options available to the decision-maker.

Can we link choice theories to brain activation patterns? This is a difficult but important question to address because it may enable us to make predictions within a framework of an existing theory rather than gathering isolated behavioral and neuroimaging findings without identifying the mechanics that connects them. In their contribution, Trepel et al. [66] review key findings from traditional choice psychology and suggest that one may be able to associate activation patterns in distinct neural substrate to peculiar decision-making phenomena. For example, is the anterior cingulate activation related to the S-shaped probability weighing function, the nonlinear value function, or the fourfold pattern of risk-seeking and risk-aversion?

6. Individual differences and clinical populations

Traditional choice psychology has sought to identify generic decision-making patterns, that is, behaviors that deviate from a normative explanation in a systematic manner and can be observed in almost all individuals [30,35]. In comparison, less attention has been paid to individual differences, that is, whether personality or temperamental characteristics are associated with different choice behaviors. In several of the current studies, investigators show significant individual differences in choice behaviors. For example, Haselhuhn and Mellers show that although the majority of individuals cooperated for strategic reasons, that is, the weighing between expected pleasure and the likelihood of rejection, others appear to be driven by a tradeoff between greed and fairness or by more pleasure from fair payoffs than from large payoffs. These findings suggest that decision-making patterns are highly influenced by the manner in which the individual process the conditions in which a decision has to be made. These differences may be due to the degree to which individuals project their own emotions onto others. In this context, error monitoring may also be different for individuals with different personality characteristics. For example, Crone makes the point that highly anxious individuals may have a hypersensitive performance monitoring system.

The recent emergence studying the neurobiology of decision-making has also been closely associated with the search for decision-making dysfunctions in populations with neurological or psychiatric disorders [6,8,37,41,42,49]. In this sense, decision-making research provides an ideal translational opportunity to test emerging hypotheses in the field of systems neuroscience or psychology in the clinical sciences. However, at this stage, there is no clear framework from which to develop “dysfunctions” of decision-making. For example, we do not know whether specific decision-making related processes, for example, probability, value processing, are dysfunctional in these populations or whether the altered decision-making patterns are a consequence of generic cognitive process dysfunctions. Initial studies by Bechara et al. showed that ventromedial prefrontal lesion patients were able to generate somatic markes but were not able to utilize these markers in guiding them to make the optimal decision [2].

Along similar lines of reasoning Bechara showed that some, but not all, substance using individuals show decision-making dysfunctions that are similar to those observed in ventromedial prefrontal cortex lesion patients [1,4]. Extending this line of research, Fishbein et al. [21] show altered risky decision-making behavior in substance using individuals. These authors show that drug using subjects made more risky choices and were less likely to shift strategies in response to learned contingencies. Moreover, this behavior was associated with less activation in the ventral anterior cingulate cortex. An immediate goal for clarifying the decision-making dysfunctions in substance using individuals is whether they are more attracted by the rewarding consequences, or whether they are less deterred by the potential negative consequences, or whether it is a combination of both. Elucidating this mechanism has direct consequences for treatment. For example, it is the former, one may have to focus on providing competing stimuli that have similarly rewarding outcomes but are associated with less negative consequences. Alternatively, if it is the latter, one may need to focus on stressing the negative consequences in educational interventions and measure its direct emotional impact on individuals at risk.

The study of substance using subjects also highlights the importance of further clarifying decision-making specific versus generic cognitive dysfunctions contributing to decision-making abnormalities. For example, these individuals perform poorly on tasks that are constructed to measure inhibition such as go/nogo or stop tasks [19,31,52]. Thus, failed inhibition of competing actions, however, may also have a profound influence on appropriate decision-making.

Finally, the study by Fishbein et al. highlights the importance of investigating various conceptualization of risk. This study uses a modified Rogers' task to which individuals select a low-probability high reward versus a high-probability low reward option. Nevertheless, this task measures only certain aspects of risk but neglects others. Slovic has shown that risk perception are not only driven by the outcome and the probability of the event but are also powerfully modulated by the perceived dread [63], for example, the risk of a nuclear disaster is perceived as more risky than that of a airplane accident because of the aversive dread stimuli with nuclear disaster. This is consistent with the system I and system II type processing [17], which is briefly alluded to in the review by Trepel et al. [66]. It will be important to conceptualize risk processing and its dysfunction in neuropsychiatric populations within the framework of these types of processes (deliberate, slow, explicit, and cognitive versus associative, fast, implicit, and affective). Moreover, it is unclear how these different systems are represented in the brain and whether selective dysfunctions in system II explain the risk-taking patterns observed in drug-using individuals.

Apart from inhibitory dysfunction, self-regulatory abnormalities have also been proposed as a source of decision-making abnormalities in subjects with disorders of addiction. Goudriaan et al. [24] interpret their findings to reveal that pathological gamblers do not regulate their behavior appropriately, that is, change as a result of negative consequences. These authors argued that the difference between pathological gamblers and healthy comparison subjects may be due to the lack of behavioral flexibility or the urge to regain previous losses. Therefore, an "appropriate" strategy may be employed with an "inappropriate goal". One may argue whether drug-using individual do not show "dysfunctional" decision-making but instead show adaptive decision-making within a dysfunctional framework of assumptions and goals.

7. Conclusions

The papers in this issue show that decision-making is complex, involves both cognitive and affective functions, and plays an important role in individuals with neuropsychiatric disorders. Moreover, some investigators raise the concern that the subjective effects of reward and punishment probability and magnitude are complex. Thus, experimental parameters may need to take into account individually derived weight and value functions. The field seems to be ripe for a close collaboration between psychologists, social scientists, systems and cognitive neuroscientists, as well as clinical psychologists or neuroscientists and clinicians. The development of a taxonomy of decision-making situations, that is, the hierarchical classification of different types of decision-making situations and their associated behavioral phenomena, may also help to constrain what is a very broad construct, which involves a number of different component processes that are likely to rely on different brain systems. Identifying or delineating such taxonomy may also help to better determine what is dysfunctional in subjects who have problems with decision-making.

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