

Reward-Based Decision-Making in Depression or At-Risk Population

Yiyan Lin *

Department of Psychological & Brain Sciences, Boston University, Boston, Massachusetts, United States

* Corresponding Author Email: lin29@bu.edu

Abstract. This paper discussed the recent studies on the behavioral and neural patterns of individuals with depression and those with familial risk in reward-based decision-making. Current theories for depression and reward-based decision-making were presented so that they can pave the way for investigation of the interaction between the two under scrutiny. The paper argues that depression influences individuals' aspects of reward-based decision-making, including thinking strategies, flexibility, reward perceptions, and motivation. At-risk populations inherited the same patterns. According to the empirical studies from recent years, results mainly support the argument. Both clinical and at-risk groups have conservative thinking strategies, inflexibility in demanding situations, and lower perceived reward salience. Furthermore, at-risk populations can obtain the same reward amount even though their neural signals indicate a diminishing reward salience. Future studies, such as longitudinal studies to scrutinize the effect of depression on clinical and at-risk populations, should seek insight into the long-term impact. Moreover, in the future, more studies should investigate the critical period for at-risk populations adopting inflexible thinking patterns so that clinicians can prevent depression in time.

Keywords: reward-based decision-making; depression; cognitive psychology; reward salience.

1. Introduction

This review first offers the contemporary trending definitions and understandings of depression and decision-making before diving into the presentation of studies regarding the interaction between these two factors. Depression is a mood disorder with high prevalence worldwide that alters individual values, perspectives, and behaviors. The clinicians diagnose depression through criteria including low motivation, anhedonia, diminished motor ability, and cognitive impairment [1]. Moreover, having parents with depressive symptoms or diagnoses may be a factor that increases the risk of developing depressive symptoms in the child. Those who have parents with depressive symptoms would be more at risk of having depressive symptoms. Decision-making is a part of executive functions within cognition. It is the cognitive process of intelligent beings choosing one option over the others after appraising each option according to their knowledge, experiences, or logic [2]. Reward-based decision-making involves the presence of rewards and individual judgment of the value of each option. Specifically, reward-based decision-making is usually associated with gambling or cost-reward tasks. Since depression impairs the cognitive process, investigating the interplay between depression and reward-based decision-making should offer invaluable insights into the prevention period for at-risk populations and intervention approaches for individuals with depressive symptoms. A correlation between reward-based decision-making and depression could help clinicians and families take precautions or provide adequate help. Depression has long been the focus of researchers and correlates with many risk factors, such as genetic makeup, social support systems, and unhealthy thinking patterns.

Studies found that the impairment of interpersonal processes is a factor in chronic and recurring depression. Hames et al. found that individuals with depressive symptoms or diagnoses have impaired social communication, distorted self-perception, interpersonal dependency (excessive reassurance-seeking and negative feedback-seeking), and insecure attachment style [1]. All of those could act as



an indicator of depression. These vulnerable factors influence relationships negatively. They may elicit social rejections, which then could initiate a downward spiral. The insecure attachment style functions as a risk factor through the interplay with depression and sociotropy. Current treatments for depression, such as interpersonal psychotherapy and behavioral activation, aim at restoring social ability to help individuals regain a healthy social dynamic. Interpersonal psychotherapy focuses on improving social skills to form and sustain meaningful social relationships. Behavioral activation enhances the individual's positive experience and helps them act consistently according to their values and beliefs. The cognitive behavioral analysis system of psychotherapy not only restores relationships but also helps to establish a helpful approach to reaching goals, which is effective in treating chronic depression.

In making a decision, an individual has to rely on their executive functions, value systems, and memory. The decision-making was initially proposed to be domain-specific, especially constrained to the activities in the anterior cingula cortex and orbitofrontal cortex. However, distinct from the previous modular approach and the feedforward network, Hunt and Hayden recently proposed a distributed, hierarchical, and recurrent model based on connectionism and computer science models to explain the mechanism of producing a choice within reward-based decision-making [2]. Specifically, this model posits that decision-making is an emergent product of neurons weighing the values of each offer. The model interprets this mechanism as the collective efforts of networks. All neural components within the cortical regions contribute to various aspects of presented options so that, through mutual inhibition, awareness can arrive at a final choice. According to the model, all three dimensions interconnect to produce the emergent property: a choice algorithm based on values. Hunt and Hayden challenged the past modular explanation by presenting recent studies that found neural activities that form local circuits to function in a network manner during the computation of decision-making throughout the cortical regions. The regions of interest scholars thought to correlate primarily with decision-making, such as the prefrontal cortex, activated along with their adjacent areas during the decision-making process. The recurrent property accounts for the behaviors that involve the applications of past experiences and the anticipation of future consequences across species. Furthermore, the hierarchical property imitates the mechanism of cognition processes, supplementing the other two aspects of the model. With hierarchical recurrent neural networks, solid options can convert into abstract concepts and form a unified value scale to influence the final choice along with the additional temporal information from memory. Overall, Hunt and Hayden's model implied that reward-based decision-making is under the influence of individual experience, thinking patterns, and, most importantly, the value an individual assigns to the options.

In short, recent studies on depression, especially chronic depression, found that depression correlated with interpersonal skills, attachment styles, and cognition of values and self-perception. Studies on decision-making found that the distributed, hierarchical, and recurrent models fit the decision-making process, which utilizes information from values systems, memory, and personal response style. Since depression impairs both cognition and motivation, it is more than likely that reward-based decision-making is under the influence of the disorder. Moreover, since depression theory suggests that interpersonal relationships influence depression, it can be inferred that the decision-making ability of the at-risk population with familiar risks would also diminish. With research on the reward-based decision-making of individuals with depressive symptoms or diagnoses and those with familiar risks, researchers can investigate whether the impairment in reward-based decision-making can be an indicator of depression pre-onset. If such a relationship existed, then the treatment period and prevention methods of depression, especially for the at-risk groups, could improve efficiently and drastically. In the following sections, this paper will discuss the main regards altered in reward-based decision-making under the effect of depression or familial risk for depression, including thinking strategies, perceptions of rewards, and motivation in both interested populations.

2. Different Aspects of Reward-Based Decision-Making in Depression

2.1. Thinking Strategies, Flexibility, and Rewards in Depression

One of the decision-making aspects that depression influences is thinking strategies: individuals with depressive symptoms and diagnosis tend to have a conservative thinking style that prevents them from adapting to the environment rapidly. Studies have examined the speed of the decision process within a reward-based context to find a pattern. Lawlor et al. analyzed the drift rate (speed of evidence accumulation) and reaction time of Major Depressive Disorder patients (MDD group) and the controls during the Probabilistic Reward Task (PRT) [3]. The PRT presented a picture of a face without a mouth and then a picture of a face with a mouth. The task was for the participants to choose if the mouth they saw was long or short. Rewards were rich or lean rewards. A correct choice in the rich stimuli trial would earn the participant three times more rewards than in the lean trial. Thus, the participants would develop response bias and their reaction time would shorten in theory. However, after Lawlor et al. compared the reaction time and cumulative reward total between the MDD and the control group, they found that the MDD group earned fewer reward totals and had a slower reaction time than the control group. Other than that, their drift rate also predicted their cumulative reward totals. The researchers indicated that a slower decision-making process might account for the observation that the MDD group needed more evidence to register a response bias and the overall poorer performance in the tasks. Their results agree with the abovementioned view that MDD patients adopt more conservative thinking strategies. Not only that, the results show that a reserved thinking style keeps individuals away from updating their understanding of the situation. It could get in the way of obtaining positive consequences in situations and induce a negative spiral.

The impact of depression on decision-making extends to the aspect of flexibility. Depression shapes a reserved thinking style and instigates rigid decision strategies in demanding reward-based scenarios. Harlé et al. conducted a study that explored the behavioral patterns and neural mechanisms of adolescents afflicted by depression when confronted with obstacles during the reward-obtaining process [4]. In the behavioral task, both the MDD and control groups were tasked to predict if the number on the card was above or below five and to give their answers by pressing the buttons. The participants encountered random low and high reward trials and button malfunction (obstruction) or normal (unobstructed) conditions. Harlé et al. also tracked whether the participants would shift strategy after the previous trial and the neural responses through functional magnetic resonance imaging (fMRI). During the obstructed block, the MDD group was found to prefer to shift more during a low-stake situation, and the participants with higher depression severity would choose to alter strategies more. Additionally, the fMRI scans revealed more activation in the ventromedial prefrontal cortex, caudate, and putamen in the MDD group. Hyperactivity in these brain regions is associated with conservative decision patterns, impairment in coping with negative stimuli, and an inflexible response. Harlé et al. proposed that these results suggest that the MDD group expressed reduced motivation and flexibility in the obstructed trials. Moreover, the reasons behind those patterns may be a perceived lack of control over the malfunctions and a subdued reaction toward rewards. Such results support the perspective that individuals grappling with depression tend to exhibit an inflexible response style under high-stakes and high-reward situations. Inflexibility in current-day society means a slow updating rate, which could lead to failure to keep up with the fast-changing information world and create a frustrating situation for patients. Once frustrating situations happen frequently, patients may experience rumination and poor self-esteem.

However, the rigidity of cognitive patterns and conservative thinking styles only appear when the individuals affected by depression are in demanding situations. Rutledge et al. looked at the behavioral patterns of patients with moderate MDD in non-learning situations [5]. Specifically, they focused on whether depression correlates negatively with dopaminergic Reward Prediction Errors (RPE) through functional neural imaging in simple tasks. RPE is a neural signal that occurs when the response from reality does not match the expected outcome. Past studies generally find a correlation between RPE and depression in reinforcing learning. Therefore, the researchers arranged behavioral

tasks without involving learning to isolate the variables. Participants of the fMRI group performed a probabilistic reward task that required participants to choose between two lotteries and then reveal the result. The other group, the smartphone group with a larger sample, participated in a Risky Decision Task (RDT). RDT offers safe and risky choices for participants to obtain a momentary reward.

Moreover, an even chance of two outcomes will appear within the risky option. The RDT study participants reported their happiness level after every two to three trials. Rutledge et al. found no attenuation effect from depression on RPE in both behavioral and neural aspects in fMRI and RDT studies. However, they suggest that these results indicate that the MDD group has a standard capacity to perceive emotional impact. Other than that, they also propose that the past findings of attenuated RPE in the MDD group during learning tasks could be attributed to impairment in the environment evaluation. These findings corroborate that depression affects individuals' decision-making patterns, primarily in high-demand situations. As presented above with these empirical studies, individuals with depressive symptoms are more likely to possess conservative and inflexible strategies within demanding reward-based decision-making scenarios.

2.2. Motivation and Reward-Based Decision-Making

Another major aspect that depression casts its influence upon is motivation. Motivation is the underlying force that encourages people to exert effort to earn rewards or results. In other words, motivation is the key component behind human reasoning within reward-based decision-making. Depression is known to diminish motivation; therefore, it also negatively impacts the motivation aspect in reward-based decision-making. Yang et al. studied the relationship between two types of anhedonia and the motivation level of patients with MDD in two studies [6]. Both studies use a modified Effort Expenditure for Rewards Task (EEfRT), depression assessments, and the Assessments of pleasure experience and anhedonia. Yang et al. anticipated finding a correlation between anhedonia and impairment in decision-making. The researchers employed the EEfRT to measure the willingness of participants to exert effort to gain rewards. Within the EEfRT, the participants, subsyndromally depressed (SD) and non-depressed (ND) groups, needed to choose between low-cost/low-reward (LC/LR) and high-cost/high-reward (HC/HR) tasks. The EEfRT revealed the probability of winning the reward in the HC/HR condition before choice. The second study replicated the first study, except for containing three groups: first episode (FE), remitted, and control group. Yang et al. found that the SD group in the first study and the FE group in the second study would choose fewer HC/HR tasks, but the remitted group behaved the same as the control group. Moreover, they discovered that anticipatory anhedonia correlated with impairment in motivation in the first study, while anticipatory and consummatory anhedonia predicted lower HC/HR in the FE group. These findings support the perspective above and further indicate that anhedonia is specifically related to the lack of motivation for individuals with depressive symptoms during demanding reward-based decision-making. Additionally, to address a bonus point, the finding regarding the relatively normal reward-seeking behaviors of the remitted group may bespeak a potential restoration of typical motivation and reward-seeking behaviors.

Despite anhedonia, the perception of blunted reward salience as one of the depressive symptoms also contributes to attenuating motivation within the decision-making context. Klawohn et al. investigated the impact of impairment in the motivation of depressed patients on effort-cost decision-making [7]. The researchers utilized the progressive ratio task to test the behavioral differences and the electroencephalogram (EEG) to measure the neural difference in the P300 signal between the depressive and the control group. P300 signal is a neural potential that occurs when an unusual or infrequent stimulus appears. It is usually associated with stimulus salience. The progressive ratio task is a button-pressing task with a fixed monetary reward and increasing effort by ten more presses than the previous at each level. This study found that the depressed group had a similar breaking point level as the control group. However, the depressed group's neural responses were different: the increase of the P300 signal was drastically slower in the later trials compared to the control group,

meaning the MDD group had less reward reactivity as the required effort increased. The findings buttress the view that with incrementing effort, individuals with depressive symptoms perceive dimmer reward salience, manifesting in diminishing motivation. The decreased motivation then presents itself as reluctance to exert higher effort. Supporting by the empirical evidence, depression impairs the motivation of individuals in reward-based decision-making situations through anhedonia and blunted perception of reward salience.

3. Patterns of Reward-Based Decision Making in Individuals at Familial Risk for Depression

The investigation of the at-risk group inspects three aspects that their patterns of decision-making process may have altered. The first aspect the at-risk group is maladaptive in its decision strategy. Even though they are not diagnosed with depression, they tend to adopt a conservative strategy in risk-taking situations with rewards. Mannie et al. conducted a behavioral task study to determine whether young adults who have parents with depression have altered reward-based risk-taking behaviors [8]. The Cambridge Gambling Task (CGT) was employed to measure risk-taking behaviors. The participants and their parents were assessed for depression, anxiety, and other disorders. In the CGT, the researchers presented ten boxes with five different ratio distributions of red and blue colors. The participants needed to find a yellow token within one of the boxes and to bet a percentage of their total score on their choice according to their confidence level. The scores would be added if they were right and subtracted if not. The participants could be in an ascending or descending condition, meaning that the percentage of their bet would increase or decrease as time passed. The researchers found that the high-risk group had a more conservative betting strategy than the control. The high-risk group would bet with fewer percentages among all trials even though the high-risk group did not differ in overall performance. The result suggests an impaired reward-seeking behavior in the at-risk group, supporting the perspective. Such behavior is related to a conservative thinking pattern, which appears also in individuals with depressive symptoms. A conservative thinking pattern or strategy advocates avoidance of potential failures. In individuals with depressive symptoms, reserved strategy comes from the perception of lack of control. The same explanation could contribute to the conservative behaviors of the at-risk group: parents with depression exhibit conservative patterns for their children to learn, and therefore, the children tend to think prudently. On the good side of conservative patterns, contrary to the overall poor permanence of patients with depression, the at-risk group still earns rewards the same way the control group does.

Despite the apparent strategy alteration, the perception of rewards behind the conservative mindset also plays a prominent role in making choices within reward-based situations. The at-risk group is more likely to perceive the same rewards as not rewarding. Morgan et al. scrutinized the reward-processing ability of children in their middle childhood with depressed parents [9]. Morgan et al. observed the behavioral and neural differences between high-risk and low-risk children in behavioral and neural tasks with a positive social cue in fMRI. The behavioral task was a Progressive Ratio Schedule task. The children were asked to press buttons to gain tokens to obtain a reward during the task. The children's affective symptoms data was from parent reports. In order to observe their neural response in the reward regions, the children were presented with unfamiliar happy, sad, and neutral faces and their mother's happy and neutral faces during fMRI sessions. In the behavioral task, the higher-risk group has parent reports of higher children's depressive symptoms. Moreover, the severity of children's depressive symptoms ratings correlates with less reward-seeking behaviors. In neural observation, high-risk children had lower responses to unfamiliar happy faces than the low-risk children in the dorsal striatum and dorsolateral prefrontal cortex. These findings suggest that children with depressed parents have an altered reward perception from a young age and have fewer neural responses to rewards during high-effort tasks. It supports the view mentioned above and offers insight into the critical period of intervention and prevention for at-risk children. The implication is that forming their mindset and perception may occur early on in childhood.

Lastly, individuals with familial risk for depression exhibit distinct neural patterns even during the resting state. Belleau et al. focused on the potential effect of maternal depression on early teenagers' reward functioning, specifically regarding their reward responsiveness and neural response [10]. The participants were asked to complete the Probabilistic Reward Task (PRT) and to be examined by fMRI for structural, resting, and at-task states. The PRT procedure replicated that of Lawlor et al.'s research. In their neuroimaging study, the researchers primarily focused on the fractional amplitude of low-frequency fluctuations (fALFF) of both the resting ventral striatal (VS) and the medial prefrontal cortex (mPFC). During the PRT, the high-risk group had diminished response bias even when their depressive severity was at the same level as the control. Additionally, the high-risk group had a typical learning rate yet a lower reward sensitivity. The neural scans revealed that the high-risk group had more fALFF activities in VS and mPFC in the resting state. There is also a negative correlation between mPFC fALFF and response bias. These findings align with the previously mentioned view and deepen researchers' understanding by identifying impairment in reward processing as a premorbid marker for depression in at-risk populations. These findings suggest that even in the absence of performance-related factors, the neural mechanism in at-risk populations differed from the typical neural pattern during a reward-based situation. This discrepancy indicates that the impairment in reward processing may stem from an underlying neural mechanism that needs further investigation. These studies focus on the impairment of decision-making ability in at-risk populations, revealing characteristics such as conservative thinking strategy, blunted reward sensitivity, and atypical neural patterns among individuals with familial risk.

4. Conclusion

In conclusion, both individuals with depressive symptoms and at-risk populations have reserved and cautious thinking styles, attenuated perceptions of rewards, and diminished motivation, supported by the results from both behavioral and neural tasks. These effects, especially the prudent thinking style and inflexibility in mindset, could induce a powerless situation in the current versatile society which is full of saturated information. The attenuated perceptions of rewards could increase the risk for at-risk populations even more, putting them into a demanding society with no motivation to move forward, worsening patients' situations, and leading them into a spiral of rumination and helplessness. These findings imply that the effects of depression on decision-making can be alleviated or effaced. Individuals with depression are more likely to obtain fewer rewards than non-depressive individuals in high-effort situations, but their gains are similar in lower-effort conditions. Remitted individuals with symptoms of anhedonia had an adaptive performance as well. The at-risk group, even with conservative strategies in situations, earns at the same level as the control group. However, as evidenced by the previous study, the neural mechanism of at-risk individuals is observed to be atypical even in rest states. This finding complements the earlier conclusion, indicating that while the clinical and at-risk groups may exhibit behaviors similar to the control group, their inner neural pattern deviates from the typical pattern. This also suggests that observed behaviors may be a manifestation of an impairment in neural working. Therefore, it is imperative for the treatment and prevention to not only address negative behavioral outcomes but also to target and improve the impairment early and from the neural level.

One of the limitations is that the studies used as evidence in this paper are all cross-sectional studies. Therefore, the long-term development of individuals impacted is unclear, particularly in children and adolescents with familial risk. Other than this, the limitations also include the need for more investigation into the underlying explanation behind the decision-making pattern change within the at-risk populations. Future studies should investigate whether it is genetic or environmental. Those limitations advocate for an in-depth longitudinal study of individuals with depressive symptoms and the at-risk group and an etiological study into the background of at-risk populations. Furthermore, it would be beneficial to take a step forward to identify the timeframe for forming thinking strategies in young children with risk. Thus, clinicians and families could pay more attention and offer mindful guidance to children with risk or with traits to prevent a negative spiral and the development of

depression. Not only that, a peak within the thinking patterns of individuals struggling with depression could help them and therapists to understand more about the origin of their rumination or other negative perceptions and to adopt coping strategies and mindfulness to adapt to the fast-changing and demanding society better.

Overall, more investigations should be done to understand better the close relationship between depression and reward-based decision-making in populations with depression and at-risk. In the interim, clinicians could consider impairment of reward responsiveness as a marker for depression in at-risk children. Furthermore, intervention methods should prioritize the improvement of thinking strategies and perceptions of rewards by implementing effort-reward reinforcements and mindfulness practices. Meanwhile, prevention strategies should focus on identifying early-stage indicators, especially at a neural level within the at-risk group. Combining as a whole, these improvements can help those populations function effectively within their environments.

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