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Studies of SUD and MDD's effect on decision-making based on the drift diffusion model

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Abstract. Major Depressive Disorder (MDD) and Substance Use Disorder (SUD) have been major medical concerns across the globe in the past century. These mental disorders are posited to arise from cognitive dysfunctions in the brain and have a critical influence on decision-making and emotional regulation in patients. Therefore, in-depth investigation into decision-making, a crucial composition of the cognitive system, can help uncover the fundamental mechanism of MDD and SUD and their relationship. By reviewing and contrasting decision-making studies of MDD and SUD through Drift Diffusion Models, this paper found that MDD and SUD reflect similar defects and impacts within the decision-making system. To conclude, though MDD and SUD are often seen as two completely unrelated and even contrasting mental conditions, this result suggests that they might be two sides of the same coin.

Keywords: Decision-making, Drift Diffusion Model, Depression, Addiction

1. Introduction

Ever since the dawn of human civilization, humans have been wondering how our minds, souls, and cognitive abilities operate. With the advancement of medical technology and knowledge of the human body in modern times, scientists can finally advance these areas previously unimaginable to be objectified and quantified. One of the most crucial cognitive functions is the decision-making process, carried out in every aspect of our lives. With the thought that by studying the special phenomenon (diseases), we can gain better insight into the decision-making system and solve major medical issue across the globe, scientists began to focus on conditions within the brain that seems to directly alter one's behavior and thinking, including Major Depressive Disorder (MDD) and Substance Use Disorder (SUD). This paper aims to briefly overview how MDD and SUD affect its victims' decision-making and behavior and answer the relation between MDD and SUD through the scope of the Drift Diffusion Model (DDM).

This paper proposes two opposite hypotheses of the relation between DDM and SUD's impact on decision-making. Are they two sides of the same coin? Or just two different coins? The first hypothesis believes MDD and SUD are simply two different coins: MDD is the deficient stimulation in the decision system, causing the patient to lose interest in all activities; SUD is the excessive stimulation of the decision-making system, causing the patient to be completely addicted to something. The Second hypothesis believes MDD and SUD are two sides of the same coin: MDD causes its patients to lose interest in all activities through direct alteration of the cost and reward system, through dysfunction of substances within the neural system, such as dopamine, which controls the weight being put on rewards;

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SUD cause similar behavioral impact because of the repetitive high-level stimulations-intakes of drug-unreachable under normal condition, causing the decision-making system to believe that the drug intaking level stimulations are the normal level, therefore raising the bar for the decision-approved for all activities, in the end resulting in the loses of interest in activities other than drug.

This study bridges the gap between behavior and decision-making through the Drift Diffusion Model. The Drift Diffusion Model (DDM) is a model commonly used by scientists to describe the decision-making process. It was first proposed by Ratcliff and his colleagues in 1978 [1] and further elaborated and summarized in his review paper in 2008 [2] It presented the decision-making process as an accumulation of evidence over time. The y-axis represents the progress of evidence accumulation, and the x-axis represents time. The DDM models a two-choice situation, and each of the two sides represents a choice. The reaction time (RT) is the total time of decision. It consists of the time for the decision-making message to be inputted(u), the time for the decision-making process(d), and the time for the final decision to be outputted(w). The RT can be varied due to the requirement sent from other brain areas, depending on whether fast or accurate decisions are required. The time other than the decision-making process time is called the non-decision time (Ter). The drift rate(v) is the effectiveness of each evidence accumulation, which is determined by the quality of the evidence. The boundary separation(a) is the range of the diffusion model. It represents the amount of evidence required for a decision to be reached. The starting point(z) represents the bias of the subject. Subjects without bias should start at point y=0. The drift-diffusion model has the sticky boundary property, in which the evidence accumulation line would stick to the side upon reaching a decision boundary (see Figure 1).

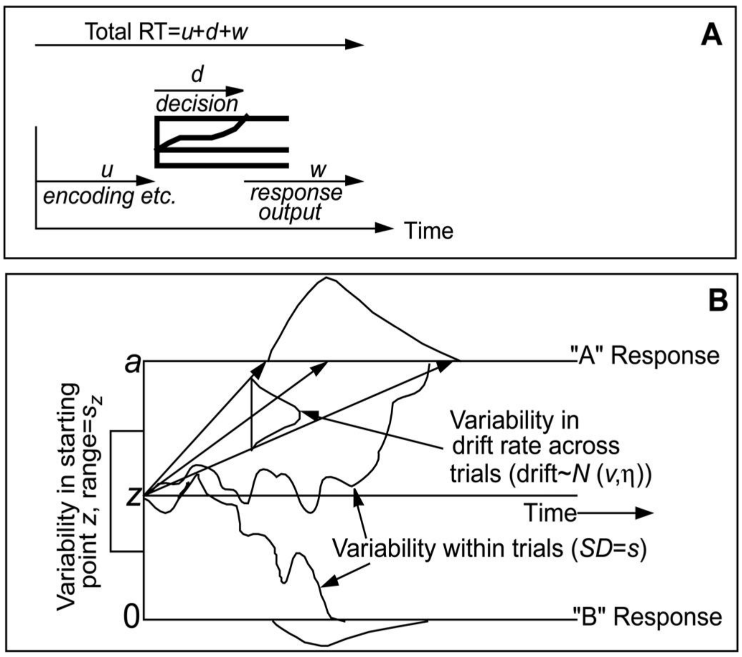

Figure 1. Drift Diffusion Model.

The upper part of the figure represents the total reaction time, compositing of encoding time (u), decision time (d), and response output time (w). The second part of the figure demonstrates the concept of drift rate (v), variability in the starting point (z), and variability within trials.

There are many advantages to using the Drift Diffusion Model compared to comprehending the decision-making system raw. DDM would be a straightforward and comprehendible way to explain the decision-making process even to those who have little knowledge about the decision-making system. DDM provides a more detailed analysis of the decision-making process and allows researchers to identify the source of the fluctuation quickly. Without it, only results such as “the variation in RT in teenagers are larger than average" are available. Nevertheless, with the help of DDM, researchers can go into detail and find out if the separation boundary is shorter, the drift rate is higher, etc. The Drift Diffusion Model also allows thorough utilization of the data collected from the trial. It has strong predictive power and can build a clear connection between behavioral action and decision-making.

2. Depression

2.1. Primer on Depression

Major depressive disorder (MDD), in short, depression, is a mental illness that causes persistent feelings of sadness and hollowness and a lack of interest in almost all activities. MDD patients are found to make decisions to avoid anxiety at a rate much higher than mentally healthy people. As it has become more and more widespread in recent years, it receives more and more attention from doctors and scientists. Two major factors that cause depression are loneliness and stress, which are common in the current information era. By studying the decision-making process of patients with major depressive disorder with DDM, scientists can develop better psychotherapy and drugs.

Just to clarify, this study will not cover anhedonia, dysphoria, the emotion of depression, etc. Unlike MDD, they are considered symptoms and do not have a direct impact on the decision-making system.

2.2. Behavioral Impacts of Depression

A Study was done by Dahlia and his colleagues in 2020 to find out the specific impact of depression on behavior decision-making [3] 128 people participated in the experiments, 64 individuals with depression and 64 without. This study uses BDI to distinguish patients with major depressive disorder and the severity of it. Both sides have similar composition in demographic settings. They set up 9 experiments to test multiple aspects of decision-making. The experiments are Risk Tolerance Task, Ambiguity tolerance task, Delay discounting task, Persistence, or willingness to wait, (WTW) task, Reward learning task, Punishment learning task, Ultimatum game: proposer, Ultimatum game: responder, and Prediction problems. Out of these experiments, patients with major depressive disorder show significantly worse performance in reward learning, punishment learning, persistence or willingness to wait tasks, and prediction problems. Therefore, they concluded that the most impacted aspects of individuals with depression are the future expectations and willingness to wait. Depressed individuals have a low willingness to wait and always expect poor results from situations, which causes their ability to learn from reward tasks and punishment tasks to weaken. They show weaker biases even after going through a reward task (in which one response is much more rewarded than the other) than the control. A study done by Wen-Hua and his colleagues has also shown similar results [4].

There is also direct evidence proving the MDD's affection for the decision-making system. In the study done in 2018, Fei-Fei and her colleagues provided Psychoradiological, which is an application of radiological imaging on psychiatric conditions, evidence supporting the direct impact of MDD on decision-making neural areas. Through conducting Magnetic resonance imaging (MRI) on patients with MDD, researchers found a significant alteration in brain regions, including Prefrontal Cortex and Hippocampus, which are regions majorly involved in decision-making [5].

2.3. MDD's impact on decision-making

Another study done by Victoria and her colleagues [6] also reconsolidates this result. In their study, they split the participants into two groups. In both groups' the participants would be first shown a face (without a mouth), and then a mouth would be briefly flashed onto it. The participants would have to determine if the mouth is long or short. If the answer is incorrect, no reward will be given. The two responses are tagged as "rich" or "lean." The difference is that the first group would receive three times the reward when choosing the "rich" response and being correct than choosing the "lean" response and being correct. The second group would have no different reward when answering correctly with the rich or lean response. The control group (without MDD) in group one showed a response bias toward the "rich" responses under fast RTs, as expected. The MDD group's response in the fast RTs region is less

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impacted by this difference in reward. No major response bias is shown in slower responses. MDD group also tends to be more cautious, which is shown by the longer reaction time. Although the mean RT for depression in the q=0.100 region is only 5 ms slower than the control, this gap extends to 158 ms in the q=0.995 region (see Figure 2).

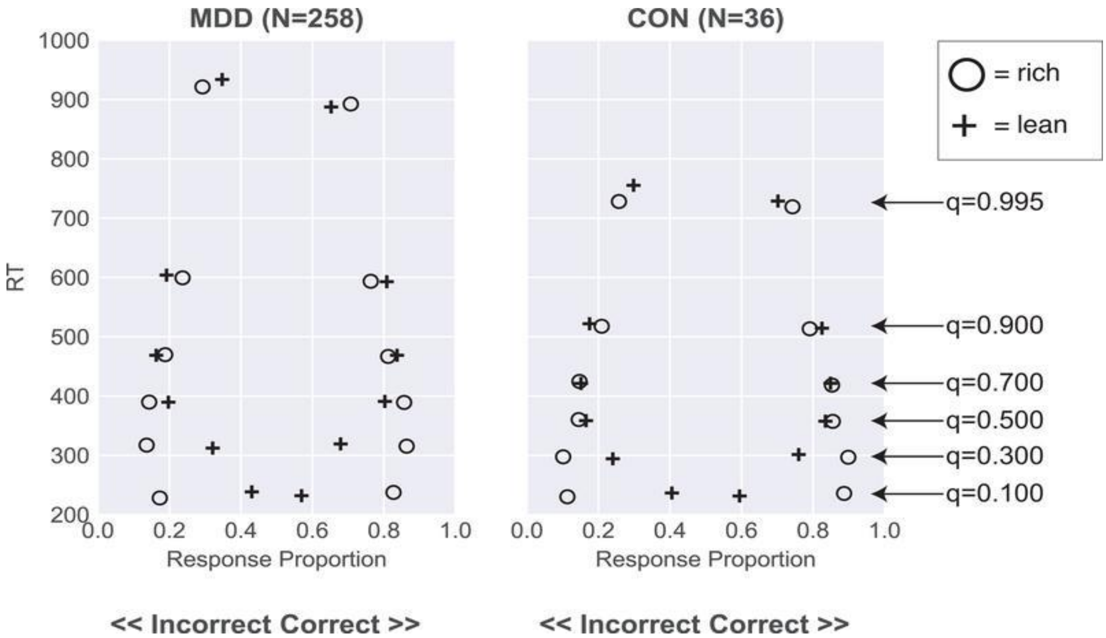

Figure 2. Quantile-probability plots.

HDDM was used in the study to give researchers more detail into the decision-making process. Depressed individuals are shown to have lower drift rates and wider boundary separation, meaning they not only require more evidence to make decisions, but also consider individuals' evidence less significant and reliable. As an easier way of stating it, they are more cautious. No significant difference is shown in starting bias and non-decision (input and output) time.

The study group partially replicated the first experiment to prove that its response can be replicated. The difference between RTs for the depressed individual and healthy ones is longer, but the general conclusion of a depressed individual with lower drift rates, less response bias, and wider boundary separation corresponds to experiment one.

3. Addiction

3.1. Primer on Addiction

Addiction is a much more extreme form of liking, in which the subject will uncontrollably do a thing. They will choose to do it, no matter under what conditions. Addiction has always existed, but is receiving more attention due to the substance use disorder (SUD) problem in modern times. The rising substance use disorder problem in the globe, especially among teenagers, has attracted major attention from society and researchers. It is highly susceptible to teenagers and could impact their still-developing brain the deepest. It is a pressing global issue that could ruin many lives, requiring significant attention.

3.2. SUD's impact on decision-making

A study was done by Alexander and his colleagues in 2021 [7] to study the impact of addiction on decision-making, especially on young adults from the age of 18 to 24. They want to study if lower efficiency of evidence accumulation in the decision-making process (EEA) is an indicator of substance abuse in young adults. The study focuses on the three major types of substance use disorder: alcohol, marijuana, and tobacco. They analyzed data from a function MRI study in the Michigan Longitudinal

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Study (MLS) [8]. They aim toward the data of individuals who perform the baseline go/no go scan between the ages of 18 and 21. They then excluded unclear or extreme data, leaving 143 participants' data. Of the 143 participants, 106 have a history of substance use disorder between the ages of 22 and 26. Researchers sent out a questionnaire aimed to collect the respondents'' drink volume (the number of alcoholic drinks consumed in the past year) and the number of days in the past year(frequency) they have consumed marijuana or smoked cigarettes. The data collection for each addiction is separate. A graph is created to show the deviation of individuals' drink volume, marijuana frequency, and cigarette frequency from the mean value more clearly. A detailed table of the participant's condition and background, including family alcoholic or drug history, race (white or non-white), gender, level of substance use disorder prior to the scan, ADHD, and other medical condition (particularly that impacts decision-making) to better understand and thereby rid finding caused by another variable. All ADHD participants are also asked to cease their intake for 48 hours before the scan.

One important focus of this research is error-related activation. Due to a recent finding that indicates error-related activation activities are distributed across multiple regions of the brain, Alexander and his colleagues decided to use multivariate measures on error-related activation. They used data of regions of interest (ROIs) from their previous study in 2019 [9]. They then remove clusters that are too small (less than 10 voxels) for consideration, with only 8 clusters left. From each cluster's center, a sphere with an 8mm radius is set up, and all activities within that region are recorded. PC1, PC2, and PC3 are each a region of the eight ROIs.

As mentioned above, the main question of this study is if lower efficiency of evidence accumulation (EEA) is a risk factor for substance abuse in emerging adults, and it is commonly interpreted as the drift rates of the DDM. The main covariates of interest in the experiments are drift rates, error-related activation, and the relationship between them. By conducting Bayesian linear regression analyses, the researchers can prove the relationship between drift rates and error-related activation. The relationship between the drift rates and False alarm rates is proven to be quite strong and is present in both go or no-go trials. Therefore, they also concluded that drift rate is a determining factor in both inhibitory (FA) performance and inaccurate performance.

Data from ROIs shows that they are closely correlated with inhibitory performance. Out of these ROIs, Anterior cingulate, L. Insula/IFG, and R. Insula/IFG showed the strongest loading of the false alarms, with a correlation of 0.81, 0.81, and 0.78. Both the anterior cingulate cortex (ACC) and anterior insula are components of the salience network. A single ROIs can explain more than half (51.22%) of the variance, and five ROIs can explain 90% of the variance. Using Frequentist regression analysis, they concluded that the male sex and, all the greater, previous usage of drugs usually bring higher substance use. The RT of the subject is proven to be unrepresentative of their drug usage. The false alarm rates do not show a significant correlation with substance use, neither do the rates of no-go responses. The lower level of error-related activation in the PC1 region (4 out of 8 regions in ROIs) and average drift rates across regions are indicators of substance abuse. Therefore, lower efficiency of evidence accumulation in the decision-making process is a risk factor for a substance use disorder in rising and young adults.

Deeper studies into the behavioral alternation in SUD patients are also crucial. One such study that does this is "Impulsive decision-making predicts the course of Substance-related and addictive disorders" done by Anja Kräplin and her colleagues [9]. Their study concluded that SUD patients have a much steeper delay discounting, meaning the reward's value would decline sharply with a delay, and lower probability discounting for losses when contrasted with the control group.

4. Discussion

This paper examined how MDD and SUD affect decision-making using DDM. The study found that individuals with MDD have wider decision boundaries and lower drift rates. Besides drug intake, individuals with SUD also have lower drift rates.

Since MDD and SUD share similar patterns in DDM, it demonstrates that MDD and SUD are actually the two sides of the same coin, and share fundamentally similar characteristics in the decision-making system. Both MDD and addiction have similar effects, which, in the end, both decrease the enthusiasm and likeliness of the patient in initiating tasks. SUD can raise the bar of the decision to do any activities other than substance use, as shown in the DDM through the lower drift rates. The hypothesis of how this happens is that as the quality of evidence (pleasure felt) of the substances used is drastically higher than all other activities and is constantly experienced, the decision-making process sets the normally required quality of evidence accumulation to the quality of the substance use, and thereby caused all other normal activities' decision-making to have lower drift rates. SUD has the most widely impact on children and young adults because their brain and cognitive function are still in the process of growth and development, and can easily be drastically altered by outside influences. Depression can possibly be caused by dopamine dysregulation in brain regions that involve decision-making, thereby causing the patient to enter a state of fatigue and detachment from the world. There is a recent study on the dysregulation of dopamine levels related to MDD (Delva & Stanwood, 2021) and how dopamine controls the weight of benefits people put upon it. The direct behavioral representation of MDD is being cautious.

Since both MDD and SUD have similar impacts on the decision-making system, could that possibly signify that the behavioral effects of MDD can also be applied to SUD, and so does the opposite? Are SUD patients also less able to learn from reward and punishment than healthy humans? Both SUD and MDD can be attributed to genetic and environmental impact. But while MDD can be caused purely by genetic disorders, SUD cannot be initiated without the involvement of addictive chemical substances. Therefore preventions of kids and rising adults from contacting addictive substances will be crucial.

The results from the study reviewed in this paper are not completely certain since the results in the decision-making process are calculated by models from behavioral data. It still requires further study to confirm and direct evidence from neuro-activity. There is also no data on the decision-making system of the SUD on the intake of drugs, so the decision impact on that subject is still uncertain. Scientists are also trying to identify the genetic factors that could cause SUD and MDD.

Some brand new approaches to the study of MDD and SUD also appeared, such as approaching them with bibliometric analysis [10,11].

Currently, scientists are still graphing out the brain and exploring how the decision-making system functions. As MDD and SUD are becoming major issues in the new generation, increased research is being done on them and more and more unknowns are becoming known. One day, therapy that "normalized" the decision-making system will become available. This can help millions; this number is increasing daily in this information era where loneliness and anxiety are becoming more and more common. Further research into MDD and SUD from the scope of the decision-making system can significantly help understand the fundamental system of human decision. By contrasting the results of normal and special cases of the decision-making system, scientists can more easily obtain the functionalities of certain neural regions and systems.

5. Conclusion

This paper compares studies about the decision-making impact of MDD and SUD through the scope of DDM. MDD and SUD cause similar effects on the decision-making process under the scope of DDM. MDD and SUD patients have lower drift rates, and MDD also has a broader decision boundary. Their behavioral impact includes lower future expectations, a higher average level of cautiousness, and longer response time. These characteristics weaken patients with these diseases' abilities to learn from reward and punishment. Studies on the impact of remarkable phenomena (diseases) such as MDD and SUD on decision-making can assist scientists in better understanding the decision-making system and help scientists grasp the mechanism of these two conditions and, therefore, better cure them.

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