

Effects Of Parkinson's Disease on Choice Under Risk and Uncertainty

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Parkinson's Disease is a progressive central nervous system disorder affecting motor control and cognitive functions due to loss of dopamine-producing neurons. Although the impacts of Parkinson's Disease on cognition have been extensively studied, less attention has been made to its impact on decision making. This manuscript reviews existing literature to summarize Parkinson's patients' deficits in financial decision making especially in the face of risk and uncertainty, focusing on behavioral and physiological measures including choice, response time, and skin conductance. Testing Parkinson's patients with the Iowa Gambling Task, Game of Dice Task, and Experiential Discounting Task, revealed that these individuals have a tendency toward impulsive decisions, preferring immediate rewards despite long-term disadvantages and higher risks. These findings were in the context of financial decisions, weighing options related to winning or losing large sums of money. Using data collected during these three tasks, it is concluded that patients are more strongly affected by larger and sooner rewards, and lack the ability to make educated predictions. Exclusion criteria included papers that did not mention decision-making tasks, left out variations of dopaminergic medication administered to participants, or used animals rather than humans for cognitive study. From the neuronal point of view, dopamine depletion in Parkinson's Disease affects brain regions crucial for executive functions, influencing tasks requiring complex decision-making strategies. Based on these findings from 43 total studies, it is argued that in order to improve quality of life and battle challenges like decreased autonomy and emotional instability, personalized interventions are required.

Keywords: Neuroscience; Cognitive Psychology; Parkinson's Disease; Decision-making; Impulsivity; Dopamine agonist treatment; Gambling tasks; Financial discounting

Introduction

Parkinson's Disease (PD) is a progressive disorder that affects the central nervous system and parts of the body controlled by the nerves. The prevalence of PD has doubled over the past 25 years, as in 2019 over 8.5 million individuals were living with PD, an increase of 100% since 2000 (World Health Organization, 2023)¹. This disease is due to a loss of neurons that produce dopamine, a neurotransmitter critical for different cognitive functions. Progression of PD tends to cause individuals to lose physical autonomy in relation to motor functions. As their motor control deteriorates, patients have to rely heavily on family members or medical staff for simple actions like standing, picking and holding things up, and walking which can create a large amount of frustration. Thus, the ability to make sound decisions becomes vital for them in preserving a sense of independence. Unfortunately, PD also has a damaging impact on emotional well-being, causing patients to experience higher levels of anxiety, depression, more common emotional outbursts, and even personality changes, all of which can have a negative impact on their decision-making abilities (Sotgiu & Rusconi, 2013)². Moreover, in addition to daily tasks, patients' impaired ability to make financial decisions could further increase the burden to the family. It is crucial for patients to maintain financial

stability as they age, and decisions under risk typically involve large quantities of money. These decisions may also end up affecting long-term wellbeing for PD patients, and can negatively impact their overall financial standing, or life in retirement. By studying financial decisions specifically, future research can understand how to support patient's decisions better in the future. To address a patient's challenges, several strategies can be implemented. These include specialized financial advisors, new ways of framing and learning to motivate better choices, and dopaminergic medications (although those can have negative side effects as well).

Although the impacts of PD on cognition have been extensively studied, its effects on decision making are less well-understood. These impacts include impairments in decision-making processes which greatly influence the independence and wellbeing of a patient. Creating a larger sense of autonomy to guide patients in high-risk financial situations calls for greater attention to the issue. In this study, previous literature on PD-related decision-making deficits under risk and uncertainty will be analyzed, using behavioral and physiological measures such as choice, response time, and skin conductance. Additionally, a gap in the literature will be addressed by focusing on patients' impairment in making financial decisions. These financial decisions include using currency, paying bills, manag-

ing a checkbook, making investments, and exercising financial judgment. The application of such financial concepts typically requires theoretical knowledge along with arithmetic skills and processing speed. However, the development of PD dementia (PDD) often causes patients to lose those abilities, thus causing them to struggle with the decision-making process. In order to make financial decisions, skills including, arithmetic, speed processing, and memory are required, which are all impaired in PDD.

The focus will be on the Iowa Gambling Task (IGT), Game of Dice Task (GDT), and Experiential Discounting Task (EDT), as well as intertemporal choices to explain financial decision-making in PD patients. The IGT and GDT are commonly used to assess the ability to evaluate risk, learn from feedback, and track risky and ambiguous choices made, whereas the EDT is used to measure financial discounting after delays and as an index of impulsive behavior (Reynolds & Schiffbauer, 2004)³. These tasks are really important in discussing how people make monetary decisions as they are simulations of real-world scenarios, have been linked to specific areas in the brain, and provide quantitative measures. Additionally, analysis of the same tasks also allows for more consistency across studies. While there are several other tasks being used like the Columbia Card Task (CCT) and Balloon Analogue Risk Task (BART), the main three that will be discussed are the IGT, GDT, and EDT. Furthermore, much research has been done on intertemporal choice which is the phenomenon of choosing between smaller, more immediate, rewards and larger, later on, rewards. Studies have demonstrated that individuals with PD exhibit a tendency towards impulsive decisions and have had a preference for immediate rewards over delayed but larger rewards. Not all patients have issues with temporal decision making, but most lack the cognitive stability to infer what choices are advantageous to make, specifically shown in the IGT and GDT explained previously. Other methods used include stimulation of the subthalamic nucleus (STN) which will be explained later. Overall, patients were given choices between financial options and researchers measured patterns in brain activity in the basal ganglia and limbic-orbitofrontal-striatal loop. Ultimately, using findings from a wide range of studies on reward processing, different types of financial decision-making, and other cognitive deficits, possible mitigations to improve decision making in PD patients will be provided.

Using this approach, it is concluded that PD leads to heightened processing of reward and impulsive behavior in individuals. Patients tend to be strongly affected by bigger and immediate rewards, and lack the ability to infer things in the long run. Due to the presence of these cognitive changes, such as impaired executive functions and decision-making abilities, there is an increasing need to develop personalized interventions aimed at enhancing advantageous decision-making capabilities specifically for PD patients. To achieve that, it is critical for researchers to gain a detailed understanding of how PD patients make deci-

sions as it paves the way for developing strategies to improve patients' quality of lives and disease management.

Results and Discussion

Decisions Under Uncertainty

Decisions made under uncertainty are situations when one does not know the potential outcomes prior to their actions. Patients with PD often find themselves in these situations, just as any healthy control would. A commonly used task to mimic ambiguous decision making, whether it be daily functions of living, financial, or medical, is the IGT. The IGT requires emotional, cognitive, and executive skills. The individual must have punishment and reward sensitivity, focus, attention, inference skills, control of impulsivity and recklessness, in order to achieve accumulated earnings (Colautti et al., 2021)⁴. Memory could also be involved with the IGT and PD patients lack the ability to form stable associations between choices and feedback, so they are more insensitive. The IGT is believed to measure decision-making under uncertainty as achieving the goal of gaining more money requires one to use feedback to decipher which decks are advantageous and disadvantageous (Gleichgerrcht et al., 2010)⁵. In the IGT, participants choose from four decks of cards, each card revealing hidden gains and losses, given implied rules. The goal is to accumulate money over 100 choices with having two decks advantageous due to small wins and losses with a net gain, and the other two being disadvantageous due to occasional high wins but larger losses overall. In healthy participants, they tend to choose cards randomly at the start but adapt to favor the advantageous decks as the task progresses and they recognize patterns. Colautti et al. (2021)⁴ explains that researchers analyze this task to track decision-making under ambiguity and under risk later on. These researchers also found that participants show a preference for safer decks even before they realize the deck characteristics. In order to complete the IGT successfully, a higher level of decision-making skills, impulse control, and sensitivity to various rewards and punishments are crucial. Additionally, the same study revealed that skin conductance responses show that people subconsciously recognize risk and have physiological responses to the potential for high losses despite potential gains. These may include an increased heart rate or sweat. Gleichgerrcht et al. (2010)⁵, found that while healthy controls leaned towards choosing cards from advantageous decks after about 40 card choices, PD patients consistently chose cards from the disadvantageous decks. Due to lesions in the ventromedial and orbitofrontal prefrontal cortex, there are deficits in memory, intelligence, and the ability to infer things over time. One thing to note is that individuals may have just preferred the disadvantageous decks, knowing the difference between them. Gleichgerrcht et al. (2010)⁵, further suggested that impairments on the IGT reflect damage done to the amygdala,

proved by PD patients demonstrating lower skin conductance responses than healthy controls throughout IGT participation. To add on, a few studies have talked about PDD, as patients with PDD are more affected by risk compared to those without, but both groups are affected by uncertainty.

On the contrary, many studies in the past have found that PD patients are primarily focused on managing risks rather than dealing with uncertainty or ambiguity (Czernecki et al., 2002; Mimura, Oeda, & Kawamura, 2006; Stout, Rodawalt, & Siemers, 2001; Thiel et al., 2003; Colautti et al., 2021)^{4,6,7}. In a more recent study Colautti et al. (2023)⁸, took into account all previous studies that found no significant impairments in decision-making under uncertainty. Additionally, the importance of executive functions in decision making is discussed to further demonstrate PD patients' difficulty to see long-term gains or losses and a preference to choose riskier options as shown in the GDT. In this study, there were 21 non-demented and non depressed patients with PD, all in the early stages of dementia. To further develop the idea that impairments related to uncertainty may not be significant, in the earlier progressive stages of PD, the limbic loop is not strongly affected (Euteneuer et al., 2009)⁹. While it may not be significantly impacted at first, the limbic loop connects the orbital frontal cortex to the ventral striatum, and striatal dopamine transmission is important for reward processing in probabilistic tasks, such as the IGT. In later stages of PD, the limbic loop is disturbed, which is the leading factor behind cognitive decline and PDD. Overall, for decision making under uncertainty, there are very mixed results as some studies are in line with finding an impact on decisions, whilst others find differences in choices insignificant. The controversial and contradicting findings cannot only be explained by using differences in measures from methodology, materials or procedures as these factors can be limiting (Colautti et al., 2021)⁴. One of the factors that might have affected the results concerns PD treatments, especially dopamine agonists. Based on these conflicting findings, it is unclear how PD affects financial decisions under uncertainty, however other information is now known. Impairments in decision-making may stem from the stage at which a patient is at having PD. Depending on this progression, patients become more likely to have PDD, quicker cognitive decline, and an increased frequency in making disadvantageous choices. This knowledge calls for future research to explore decision-making under ambiguity while taking into account the effect of treatments, disease progression, and methodological differences.

It is also crucial to note that there are limitations to using the IGT for studies relating to decision-making under ambiguity. Researchers have questioned if participants have emotional bias towards punishments if they are less frequent, regardless of the high value of losses. There are concerns regarding decision-making being impaired, as participants have unexpectedly chosen bad decks more frequently despite large cost even without

a PD diagnosis. The IGT is also driven by “hot decision making” and strong emotions, compared to just data-oriented cost decisions. Patients rely on emotional processes which interrupt the findings and can introduce misinterpretations due to their bias. Finally, because the IGT is in a practice simulation setting, participants may have done previous similar experiments so they have bias and already know how the games work. These findings were all found across Aram et al. (2019)¹⁰, Huizenga et al. (2023)¹¹, and Webb et al. (2014)¹².

Decisions Under Risk

Decisions made under risk are situations where one is unable to fully control the outcomes or consequences of such an action but knows or is given the probability of those outcomes for each alternative. When it comes to financial decision-making, this includes choices related to investments in the stock market, equities, and gambling. The following studies use the GDT as well as the second part of the IGT. “Studies have shown that successful performance on the GDT requires functioning of the ventromedial prefrontal and dorsolateral prefrontal cortices (DLPFC) as well as executive functions” (Gleichgerricht et al., 2010)⁵. Executive functions include anticipation, judgment, reasoning, long-term and working memory which are mental processes crucial to normal daily life. These executive functions are thought to be linked to both risky and ambiguous decision-making, but more strongly related to risk, due to the circuitry in the “DLPFC” (Gleichgerricht et al., 2010; Euteneuer et al., 2009)^{5,9}. When tasks such as the GDT require individuals to evaluate and weigh strategies to make the right choice, and categorize stimuli, the success rate is strongly linked to executive test scores. Overall, this means that better performance rates on decision-making tasks under risks are associated with higher scores on tests for executive functions. The GDT analyzes preference to risk by presenting dice rolling scenarios to participants, where they can choose to roll to receive potential gains or losses (in money). Each roll is associated with levels of risk and probability, which is provided to the participants. These range from high-probability but low gains to low probability but larger possible gains, allowing researchers to calculate risk preference whether they tend to lean towards risky options, or steer clear of them. Researchers should be aware that the GDT is not useful for adolescents, and is limited to only measuring decision-making under risk, not ambiguity (Deisenhammer et al., 2018; Donati et al., 2018)^{13,14}. In both the GDT and IGT, data was collected by finding net and total scores and “subtracting the number of risky choices from the number of non-risky choices” (Euteneuer et al., 2009)⁹. In addition to using these tasks to demonstrate patterns in decision-making, researchers have compared patients “on” and “off” dopaminergic medication. Research indicates that when patients with PD are “off” dopaminergic medication, they usually show results similar to healthy controls, which proves

that cognitive deficits are “strongly influenced by dopaminergic stimulation of orbitofrontal striatal circuits” (Euteneuer et al., 2009)⁹. Moving onto some of the broader findings. The first study to observe decision making in PD in both ambiguous situations with implicit rules and risky situations with explicit rules was by Euteneuer et al. (2009)⁹. They hypothesized that PD patients without dementia and depression will show stronger impairments of decision-making in risky situations. Indeed, their findings supported this hypothesis as the performance of PD patients was found to be significantly impaired. Brand et al. (2006)¹⁵ found that PD patients with poor performance on the GDT demonstrated both deficits in executive functions and a diminished response to negative feedback. Despite studies being relatively older, the majority of the included studies using the GDT has found a link between the number of risky choices and elements of executive function, especially skills like categorization, adapting to new rules of the task, and mental flexibility (Euteneuer et al., 2009)⁹. In a more recent study, Colautti et al. (2023)⁸, found that consistent with previous literature, PD patients preferred riskier options. This behavior is characterized by reduced probabilities to achieve higher wins no matter the higher probability of significant losses. Not only does the GDT apply here, but decisions under risk may also connect to decisions under uncertainty, making the IGT relevant. Some studies have mentioned the emotional states behind making risky decisions under ambiguous circumstances. Schiebener and Brand (2015)¹⁶, have pointed out that decision-making involves processes influenced by cognitive processes and the prospect of emotional reward, or, punishment.

Additionally, the positive link between executive function and success on the IGT suggests that the DLPFC is key for effective decision-making in the face of uncertainty. In the later, second half of the task, decision-making under clear risk allows participants to assess whether a deck has a positive or negative impact for them, and forces them to be the ones to choose the risky option when selecting a deck (Colautti et al., 2021; Gleichgerrcht et al., 2010)^{4,5}. Colautti et al. (2021)⁴ found that PD patients exhibit a mild to moderate increase in their want for rewards, and tended to become emotionally insensitive to losing money. Participants with PD focused only on how to gain money and completely ignored losses, demonstrating a lack in the ability to evaluate risk. During the later portion of the IGT, patients repeatedly choose riskier options, even if they recognized the failure in that strategy. When put side by side with healthy individuals, PD patients made “wrong”, risky decisions throughout the entire game showing their lack of instinct to avoid them. As a result of this, PD patients were unsuccessful and had little amounts of money once they completed the task. In terms of brain regions, “vmPFC patients failed to understand and predict long-term consequences based on previous consequences or feedback, and DLPFC patients failed to have a consistent behavior keeping the goal of the task in mind” (Colautti et al.,

2021)⁴. These are known as reversal learning deficits and executive difficulties (Izquierdo et al., 2017; Dirnberger & Jahanshahi, 2013)^{17,18}. Executive functions are most highly impaired in early stage PD patients, reflected by the papers finding those results. It is also important to note that Colautti et al. (2021)⁴ was not clear on whether PD patients showed a shift to choosing disadvantageous to choosing beneficial ones or created an attitude that avoided risk, which was seen in healthy patients. In conclusion, as demonstrated in two different tasks, patients with PD have a tendency to make risky decisions, even if they are aware of it.

Ecological Validity of the IGT and GDT

Using simulated laboratory decision-making tasks can capture certain aspects of risk preferences, however their predictive power may be limited to specific contexts. A study conducted in 2016, Verschoor et al., collected a sample of farmers in the rural region of eastern Uganda, and compared their farming strategies and willingness to take risks associated with higher expected profit in agriculture. Some farmers answered a hypothetical investment question and some participated in an actual investment game. It was found that self-reported risk was more accurate. The results of this experiment were that farmers who took risks in the hypothetical experiment were more likely to buy fertilizer (considered a simple choice) but the task did not predict bigger financial moves like switching from subsistence to market based farming (complex choice). However, when the farmers self-reported their willingness to take big risks in a questionnaire, the findings correlated with fertilizer purchase and moving towards market farming (Verschoor et al., 2016)¹⁹. Overall, controlled settings are good for basic isolated decisions but not big-picture decisions with many factors involved. This is because participants often take more risks in hypothetical situations compared to real-life situations.

Furthermore, behavioral tasks show lower reliability and validity in their findings compared to questionnaires which stems from how complex risk attitudes are. Risk sensitivity can vary significantly and may involve responses to external stimuli, which alter the results. It is also hard to repeat and replicate the conditions for each round of the IGT and GDT because a subject tested twice with the same behavioral task at different time points will not necessarily display the same phenotype (Palminteri & Chevallier, 2018)²⁰. Future models should combine repeated online testing with computational models or standard questionnaires. To fully ensure ecological validity, researchers can track real financial spending through online budgeting apps, patient and family interviews, virtual reality simulations, and virtual, but real, stock market investing.

Intertemporal Choice and Impulsivity

Intertemporal decision making is “the process of weighing and choosing outcomes that occur at different points in time” (Yang et al., 2021)²¹. This means short-term vs. long-term rewards, now or later. The main studies that will be discussed in this section use different types of intertemporal choice tasks, including the Experiential Discounting Task (EDT), as well as comparing how participants view sums of money after some period of time. Additionally, all of these studies discuss the impact of dopaminergic medication in relation to impulse control disorders (ICDs) in chronological order. This allows readers to see how research has changed over time and what literature exists out there. Below is a table of the main types of medications currently used to treat PD and their potential side effects (team, 2024; Isaacson et al., 2023)^{22,23}.

This research is important because PD patient’s decision-making abilities are strongly affected by different types of medications. Despite currently available options, there is no drug that can improve patients decision-making and also treat motor symptoms simultaneously. There is a crucial need for research in this region in order to treat PD using neuroprotective drugs that do not cause negative cognitive side effects like pathological gambling. Disease modifying drugs also must be researched, rather than just symptom controlling. The papers studying different receptors of dopamine agonists focus on patients with early-stage PD as well, calling for more research to be done for late-stage patients.

The following papers also consistently mention the concept of patients “on” or “off” medication states and how it affects decision-making. “On” time is when a patient’s symptoms are well controlled, and “off” time concur in between or before medication period where patients experience pain and clouded minds (Coping with “On/Off” Changes, 2025). In order to reduce symptoms in the off times and maximize the length of on without more medication, regular aerobic exercise can be done. Additionally, ICDs are more common with dopamine agonists in comparison to levodopa, however a single treatment of L-dopa does not disturb the total financial valuation process. Dopamine agonists increased the rate of learning from positive outcomes (ie. gaining more money), but in the “on” stage where symptoms were controlled, they did not learn from negative feedback (Oh et al., 2024)²⁴. This means that while the symptoms are controlled, impulsivity may be increased as patients don’t recognize the losses they are suffering and can continue to make identical decisions. The last important thing when talking about on and off periods, is that as the disease progresses, medication dosage is adjusted to obtain optimal symptom control where the off period (the benefit from parkinson disease medications wears off and symptoms reemerge), or minimize the adverse effects of medication. Some later progression stages require more medication for example, whereas early stages of PD prefer the

lowest dose that is still effective to minimize risk (Demailly et al., 2024)²⁵. Also, with increasing age and physical decline, there is decreased conversion of L-dopa into dopamine, so it becomes less effective.

Firstly, Milenkova et al. (2011)²⁶ discussed dopaminergic medication related ICDs and their role in influencing greater impulsive choice and discounting of delayed rewards. While there are definitely changes in the study’s results because of medication, there are challenges of isolating medication effects from disease progression. It is difficult to determine whether observed changes are due to the drug or underlying disease progression because levodopa alleviates patient symptoms temporarily. Symptoms can also fluctuate with or without medication due to environmental or genetic factors, leading to increased variability in responses to medications. Finally, studies often lack pre-medication symptoms because when diagnosed with PD, patients take medications almost immediately, ruling out testing how they were before levodopa or dopamine agonists. However, Milenkova et al. (2011)²⁶ found that PD patients also had faster reaction times in higher conflicts worsened by executive dysfunction which is linked to ICDs. Psychostimulants increase the release of dopamine which causes fluctuations in impulsive behavior, so this study specifically researched impulsive choice in PD patients with ICDs compared to PD controls both on and off dopamine agonists and normal participants, using the EDT. The many situations and groups of individuals provides various data and allows for researchers to identify what variables carry the strongest impact on PD. The EDT is an intertemporal choice task using real-time coin machine feedback to show changes in discounting and to naturally model context in decision making. Instead of just imagining consequences, the EDT involves participants directly experiencing the consequences of their choices in rewards and waiting times. The subjects experienced choosing rewards at specified times throughout the test in 4 session blocks with time delays. Using this task, previous studies have compared the results of wanting to wait and devaluing rewards over time when participants were sleep-deprived and non-sleep-deprived. It was found that discounting and impulsive choice was significantly steeper on the EDT when participants were sleep deprived. Furthermore, Reynolds & Schiffbauer (2004)³, found that “sleep deprivation reduces accuracy of the timing of prior events [...] and fatigue increase[s] risk-taking and behavioral disinhibition” (Reynolds & Schiffbauer, 2004)³. PD (with ICDs) patients and PD controls were tested on and off DA on the EDT while normal patients were tested once on the EDT and were medication free. Based on their results, Milenkova et al. (2011)²⁶ found that PD controls had slower reaction times compared to patients with ICDs (PDI) patients and normal volunteers and further, on medication PDI patients had slower reaction times for choices they had to make immediately. Finally, PDI patients on DA have impaired spatial working memory compared to PD controls on DA. All of these results demonstrate that being

Medication Type	Stage Usage/Patient Age	Function	Common Side Effects	Adverse Side Effects
Levodopa/Carbidopa	Early in low dosages	Converts to dopamine and prevents breakdown before reaching the brain	Nausea, dizziness, dry mouth, drowsiness	Dyskinesia, motor fluctuations, hallucinations, orthostatic hypotension
Dopamine Agonists	Early and late	Mimic dopamine by stimulating dopamine receptors	Nausea, dizziness, fatigue, leg swelling, sleep attacks	Impulse control disorders, hallucinations, depression
MAO-B Inhibitors	Early and mild symptoms	Inhibits MAO-B enzyme, reduces dopamine breakdown	Insomnia, nausea, dizziness, headache, rashes	Orthostatic hypotension
COMT Inhibitors	Early and mild symptoms	Prevents breakdown of levodopa	Diarrhea, nausea, orange urine	Dyskinesia, liver toxicity
Anticholinergics	Under 70 years old	Reduces acetylcholine activity to help with tremors	Dry mouth, blurred vision, constipation, confusion	Cognitive impairment, hallucination

Table 1 Overview of Parkinson’s Disease Medications

on DA is associated with greater choice impulsivity when these patients already had ICDs, which could be side effects of the medication. These findings tie into what medication has to do with symptoms and what conditions may have pre existed in the patient. A later study published in 2009 compared PD patients with and without ICDs and also on and off dopamine agonist medication (Voon et al., 2009)²⁷. In line with the findings of the previous study, patients showed significantly steeper discounting than healthy controls independent of medication status and PD patients without ICDs nevertheless tend to make more impulsive decisions. PD patients who were treated with dopamine agonists and L-dopa, tended to give less attention to future rewards compared to controls, but PD patients “on” and “off” medication did not show a difference in their discounting rate. As an example of discounting, \$100 may be worth only \$60 after a delay of 50 days for PD patients, compared to \$80 for control participants. This study overall found that PD patients who do not suffer from pathological gambling and ICDs discount rewards later on more steeply than healthy controls, but not as steeply as pathological gamblers (Milenkova et al., 2011; Voon et al., 2009)^{26,27}. Furthermore, a study published one year later found that patients with ICDs had greater issues with working memory compared to those without, pointing to impaired executive functions (Simioni et al., 2012)²⁸. Executive functions are linked to all types of impaired decision making, and specifically impulsivity, especially in early stage PD, as there is the greatest amount of dopamine depletion (Poletti & Bonuccelli, 2012; Colautti et al., 2021)^{4,29}. The importance of this is that even PD patients without pathological gambling showed impulsivity which can severely harm them financially in their lifetimes. Finally, a 2017 study by Foerde et al. (2016)³⁰ tested early stage PD patients with a lack of dopamine in the striatum, and added on the ex-

tra layer of being on and off dopaminergic medication. Both the striatum and ventromedial and lateral prefrontal cortex are key to understanding decision-making processes involving delayed rewards. Participants completed every task twice and the task-taking sessions were separated by some time and the new task had different amounts of money. During this “break”, “a neuropsychological test battery and an unrelated task were completed. [In the first task] participants used a computer mouse to select the sooner smaller or larger, later reward [and the second was] to rate the attractiveness of various monetary options on a visual analog scale” (Foerde et al., 2016)³⁰. There was a third task that involved selecting options in different rows, but overall, researchers found patients on medication being more inclined to choose options that offered future rewards, demonstrating that their medicated “status affected time sensitivity in valuation” (Foerde et al., 2016)³⁰. This renewed valuation shows how patients were less likely to decrease their desire for future rewards due to time and were more willing to wait it out, compared to patients without medication. Simply put, shown through patterns of choice, there were greater likelihoods of choosing larger later rewards instead of smaller sooner ones.

While the previous 2009 study found no difference in medication states, another paper, Figner et al. (2010)³¹ found that patients had reduced discounting in the high dopaminergic state as well. It can be concluded that dopamine promotes behaviors that encourage farsighted choices and predictions about future rewards “by simulating paths to future outcomes” (Foerde et al., 2016)³⁰. When connecting back to ICDs, two studies found no difference between PD patients and controls (Simioni et al., 2012; Foerde et al., 2016)^{28,30} whilst one study did find differences in discounting, which is increased impulsivity regardless of medication status (Milenkova et al., 2011)²⁶. Milenkova et

al. (2011)²⁶ found that “contrary to [their] expectations, PD patients “on” and “off” medication did not show a difference in the [temporal] discounting rate” or impulsivity. Patients that were taken off dopaminergic medication tended to value some specific outcomes a little less but did not vary significantly from healthy controls who had never been on medication. The contradictory findings are due to a few factors. Milenkova et al. (2011)²⁶ and Voon et al. (2009)²⁷ studied patients without ICDs and randomly tested them on or off medication. In comparison Figner only looked at the left, not right, lateral prefrontal cortex, meaning their methods varied. Additionally, Siminioni looked at PD patients with mild-moderate conditions, and did a baseline follow up 1.5-3 years later. This follow up did not demonstrate that disease progression affected the temporal discounting rate, however this study looked at different brain regions and actually did a follow-up, unlike the other studies. It is crucial to note that different drugs require different doses and quantities throughout the day. Some are more for nausea and dizziness and sleepiness while others are for confusion, sleep attacks and gambling (motor vs cognitive requirements) (Dopamine Agonists — Parkinson’s Foundation, n.d.)³². During early-stage PD, patients are given levodopa, selegiline, ropinirole, and rotigotine due to their tolerability, and later on, pramipexole manages motor fluctuations and dyskinesias. Another unique medication called metformin mitigates disease progression as a whole (Oh et al., 2024)²⁴. Furthermore, discount rates were similar in all three ways of measuring intertemporal choices. If higher discount rates were found in one method, they could also be identified using other methods. For patients who do not already have ICDs, dopamine influences sensitivity to delays when evaluating rewards with larger amounts, but they come later in time. Overall, participants value immediate rewards over delayed ones they discounted, because they believe there is more value in the gains, and less when the delay was ‘unpacked’. When the waiting time is broken down into smaller parts or described in detail, it feels much longer, making delayed gains less desirable (Yang et al., 2021)²¹. Any steep discounting can lead towards improper management of funds, long-term consequences, and higher levels of economic stress for individuals and their families. The findings are mostly uniform as the papers use the same relative dosages for their patients, based on doses recommended by healthcare professionals. Future research should look into more variations of ICDs and their impacts on impulsivity. Knowing this information, personalized treatments and education should be built to protect patients and their decisions.

Existing Treatments and Their Impacts

Critical to the goal of this study, the measured behaviors in the three examined decision-making paradigms are related to each other. Intertemporal choice measures the ability to choose immediate versus delayed outcomes, thus quantifying how peo-

ple value short-term lower rewards or long-term benefits in the future. When individuals prioritize the immediate rewards, they can be considered more impulsive but this impulsivity could emerge from avoiding the risk of distant rewards not being available. Impulsivity leads to increased risk-taking behaviors as individuals are focused on the immediate reward while disregarding the potential consequences. Both of these mentioned factors influence how levels of risk are perceived, and how people manage them, sometimes by putting that risk aside in order to receive the immediate benefits. Ignoring the potential risks to come may lead to serious long-term issues as well. Finally, impairments in all types of decision making are linked to executive dysfunctions. This is summarized by Coullatti et al. where they noticed that impulse impairments in the IGT are related to reward processing and risky choices which are also seen in people who are pathological gamblers (Colautti et al., 2021)⁴. This means that when someone has poor executive functions, they are less able to make rational decisions while assessing risk. Additionally, the connection between similar deficits is quite interesting, as gamblers and neurodegenerative disease patients share cognitive qualities.

On the other hand, the results from testing all of these uncertain or risky situations can be modified by either dopaminergic therapy or deep brain stimulation (DBS) (Acting on Impulse: Parkinson’s Disease Treatments Alter Decision-Making through Two Paths, 2024)³³. It is important to take these into account as these therapies have side effects that impact the patient’s ability to make logical decisions, leading them down a path of compulsive shopping and pathological gambling. Pharmacological approaches, like levodopa, and nonpharmacologic approaches such as physical therapy and exercise may seem to work at first, but overtime, is actually harmful. DBS and levodopa can help individuals with tremors and motor deficits, “worsening symptoms when the medication wears off” (Armstrong & Okun, 2020)¹⁰. PD also has multiple variants with early motor and nonmotor symptoms, poor responses to medication leading to fast progression initially, and as time goes on, mild symptoms. In later stages of PD, there is a positive response to medication with slower disease progression. In terms of motor symptoms as well, medication induced dyskinesias increase in frequency after 10 years of PD progression (Demailly et al., 2024)²⁵. However, ICDs like compulsive gambling, hypersexuality, or shopping seen in PD are when patients are on medication, and intensify a patient’s focus on the hope of receiving rewards from risky choices while dissociating from the potential consequences. Instead of understanding how much money they would have to lose by entering a game, the patients were excited at winning, similar to how in poker, you have to bet money to see the next card and hope it benefits you as a player. Because of a “greater release of dopamine” in pathological gambling, there are “some similarities between PD patients with pathological gambling and patients with chemical addiction”. While there might be

addictions that existed prior to being diagnosed with PD, vulnerable, and early-stage PD patients “receive dopamine agonist treatments to correct their parkinsonism” (Damier, 2015)³⁴ and end up with behaviors similar to addicts which are worse than what they began with (Damier, 2015)³⁴.

There are two main types of dopaminergic medications: dopamine agonists and levodopa. Dopamine agonists trick the brain into thinking it’s receiving necessary dopamine, and usually treats motor symptoms and dyskinesia more effectively. Levodopa is more potent and converted into dopamine in the brain, compared to dopamine agonists which mimic the effects of dopamine with any conversion required. Medications like pramipexole, ropinirole, rotigotine, apomorphine injections, which are types of dopamine agonists are effective, however less than levodopa due to the creation of ICDs, leg swelling, hallucinations, and low blood pressure (Dopamine Agonists — Parkinson’s Foundation, n.d.; Choi & Horner, 2023; UpToDate, n.d.; Zhang et al., 2023; Kondo, 2002; Starcke et al., 2011)^{6,32,35–38}. Dopamine agonists can be prescribed through oral doses, injection, or skin patches. Additionally, levodopa has side effects caused by medicines because it is a precursor of dopamine, as dopamine itself cannot pass the blood brain barrier. A combination of levodopa-carbidopa intestinal gel helps with tremor and rigidity, standing, balance and coordination, and also cognitive symptoms. Combined in various concentrations with other compounds (slow-release capsules or tablets taken 2-3 times a day and increased based on tolerance) can improve the medication results and reduce side effects of nausea. There are some present concerns that levodopa speeds up the death of natural dopamine-producing neurons but is not supported by significant evidence. There are many complex effects of dopaminergic medications on cognitive decline, and some gaps in research recruiting exploration of its widespread impact. Dopamine agonists affect working memory in early-stage PD and levodopa enhances positive reinforcement learning but impairs learning from negative feedback by preventing dips in dopamine levels. Both types of medications are associated with significant improvements in motor scores and in all cognitive tasks at the first follow up evaluation, but while improvement in motor scores was maintained, executive functioning, long term memory, and cognitive effects were not sustained. Specifically, apomorphine worsened reaction times in both visual-spatial and visual-object working memory tasks, while levodopa improved accuracy and reaction times in both visual-spatial and visual-object tasks (Poletti & Bonuccelli, 2012)³⁹. Overall, while there are gaps in research about the prolonged use of these medicinal therapies on cognitive domains, each medication affects different brain circuits and improves memory for certain, but usually limited, periods of time.

Moving onto subthalamic DBS, Damier (2015)³⁴ and Colautti et al. (2023)⁸, found that this treatment adds another layer of complexity. It may increase bias and impulsivity when

the risk is high, and in these situations, patients on stimulation could not stop themselves from making fast decisions. When they were not on stimulation, patients slowed down and took time to analyze their options, but due to higher dopamine levels with DBS they struggled. These findings present the role of the STN in supporting better judgment in high stake situations, and shows how stimulation actually causes rash decisions, rather than slowing PD. If we understand the harms of STN DBS we can reduce the risk of harmful behaviors and protect patients. While STN stimulation relieves patients’ motor symptoms, it worsens cognitive ones. According to Weintraub & Zaghoul, (2013)⁴⁰, “[t]he most consistent cognitive effect reported with STN stimulation is a decline in verbal fluency, with affective changes including depression and hypomania” with higher likelihoods of suicidal behavior. According to a study conducted in 2019 with patients currently undertaking STN-DBS, the ability of STN DBS to impact more complex areas of patterns in choice is unclear, but it seems to reduce impulsivity slightly (Paliwal et al., 2019)⁴¹. Later on in the research, it was shown that the impulsivity of PD patients is influenced by their perception of ambiguity or “environmental volatility” (Paliwal et al., 2019)⁴¹. Seinstra et al. (2016)⁴², followed up with finding that patients who received DBS to their STN showed no difference in impulsive decisions compared to people who did not receive the treatment. This controversy is due to external factors, as DBS is considered after already taking years of medications. Because DBS is a later step of treatment, previous medication status can affect its effectiveness or work together with medication to not increase impulsivity. Additionally, there may be other factors that play a role in developing ICDs because the long-term effects of other PD treatments are not considered. DBS stimulation is usually only for a few months, so there may be studies that differ in their findings due to the length of treatment. Overall, the types of decision making in this study are all intertwined, but one should keep in mind what factors can alter the findings.

The progression of the disease is influenced by a combination of genetic and environmental factors. Following a diagnosis, many individuals experience a good response to medications such as levodopa, and this optimal time frame can last for many years. Over time, however, modifications to medication are often needed and symptoms may intensify (Study Reveals Pivotal Insights into the Progression of Parkinson’s Disease, 2024). In terms of dosages during different stages of disease progression, there are different levels of medication that PD patients take. For early PD, levodopa, dopamine agonist, and MAO-B inhibitors are administered. However, clinicians should not prescribe dopamine agonists at risk for higher medication adverse effects and very old patients or preexisting hallucinations (American Academy of Neurology, 2021)⁴³. As previously mentioned in the impulsivity section, different medication types affect decision-making, and are administered in various doses to ensure symptoms are not worsened.

Possible Mitigations

Due to the presence of the aforementioned alteration in cognitive processes, such as impaired executive functions and decision-making abilities, an effective solution is to develop personalized interventions to enhance advantageous decision-making capabilities in PD patients. Many challenges complicate the lives of patients, including a lack of autonomy and the feeling of being trapped, although there are methods to protect patients, optimize care, and improve their quality of life. As motor control is degraded and creates a heavy reliance on the people around them, being able to make appropriate decisions is critical in maintaining some sense of self. Unfortunately, PD also has a damaging impact on emotional well-being, experiencing higher levels of anxiety, depression, more common emotional outbursts, and even personality changes, further complicating their daily lives (Sotgiu & Rusconi, 2013)². These PD symptoms rely on different motor and non-motor fluctuations and responses to dopaminergic drugs, so longitudinal studies offer the researchers the opportunity to analyze changes in the everyday emotional life of PD patients individually. Longitudinal studies track response to medication over time, and show how impulsivity or anxiety may increase (Sotgiu & Rusconi, 2013)². For possible mitigations, specialized financial advisors, new ways of framing and learning to motivate better choices, and dopaminergic medications (although those have negative side effects as well) can be used. Firstly, specialized financial advisors can offer customized guidance to navigate financial decisions effectively. If these advisors could be trained to specifically handle patients with PD and understand how to make the right decisions for them, their financial security can be maintained. In order to achieve this, advisors will have to keep all personal information organized, be more involved with communication within the family of the patient, and understand that the patient themselves may not always be in the right mind to make beneficial decisions. They would also have access to studies and reviews like this one, which provide information on common patterns seen in financial decision-making in PD patients. If specialized advisors were aware of impulsivity, or how dopaminergic medication affects mental clarity, they can adapt their care strategy and ensure patients are cared for properly.

Second, adopting new frameworks for decision-making and implementing motivational strategies can empower patients to make better choices coinciding with their original values and goals. If patients are able to see both advantageous and disadvantageous options in a new light, or one that they can grasp more easily, they may learn how to slow down cognitive deficits themselves. This can be done in palliative care homes or facilities where only neurodegenerative patients reside, so that the staff is trained to handle only those patients. Furthermore, dopamine agonists play a critical role in both motor and cognitive functions, and may help alleviate some motor and few emotional

symptoms. However, as explained previously, the side effects of these medications are extreme, including higher impulsivity and pathological gambling. The goal of this study is to minimize these behaviors, so realistically, medications are not the most effective method. Knowing the side effects of dopaminergic medications allows companies to focus on other preventive or symptom-relieving methods that don't contribute to worsened motor control or hallucinations, for example. There are also strategies that enhance dopamine naturally, such as a diet rich in tyrosine, adequate sleep, regular exercise, or getting natural dopamine in nature or from music. Overall, learning more about financial decisions made under risk and uncertainty and where the brain of a PD patient lacks allows future researchers to provide more support.

This paper analyzed extant literature on the impacts of PD on decision making involving risk and uncertainty. Understanding decision making in these patients allows future research to significantly improve patient's lives and disease management. The main findings across various studies demonstrate that PD influences decision-making processes associated with risk assessment and temporal discounting. Specifically, based on three tasks, it is concluded that the effect of PD on individuals is heightened processing of reward and impulsive behavior compared to the control group. Patients prefer bigger and immediate rewards, lacking the ability to infer which choices are the most advantageous based on feedback, as demonstrated in the IGT. Additionally, most of the literature indicates a relationship in PD patients between making more risky choices and less of a difference in decisions made under uncertainty (more research has to be done). There is also a clear link between choices made under risk and uncertainty, as impulsivity is the factor guiding all of these decisions. Based on these results, additional interventions are needed to prevent PD patients from making decisions that may hurt their retirement, investments, or life savings. These include adjusted care strategies to reduce the impact of cognitive impairments and unstable emotions in PD patients. The goal of this personalized approach is to increase the accuracy and improve the strategy in decision-making in order to maintain autonomy and create better quality lives for individuals living with PD.

Methods

The research was conducted using a systematic literature review of relevant articles in the field of Parkinson's Disease, specifically relating to financial decisions under risk and uncertainty. The goal of the review was to find original research explaining how patients behaved under these circumstances and show development over the years, which contributes to more recent treatments and tests that can be used for future research. The author searched the following databases: PsychNet, Scopus, Google Scholar, PubMed, and the National Institute website.

Literature was used from November 30, 2004 to February 24, 2024. Validity and credibility was assessed by a second review done through peer analysis, citation count, author credentials, and using the 2020 PRISMA Guidelines for reporting systematic reviews. There were two recent articles from Arizona State University and Brown University, that the author found using Google and used to backup results found in professional research papers. Selection criteria included studies that specifically explored the IGT, GDT, and EDT as well as how they displayed impulsive and intertemporal choice. The search strategy involved using keywords including "Parkinson's disease," "decision-making," "financial decisions," "impulsivity," "Iowa Gambling Task," "Game of Dice Task," and "dopaminergic medication", across databases previously mentioned. Additional filters, such as publication date and study quality, were applied to ensure the papers were in the past 20 years and relevant to the topics. The author reviewed each study to focus on the correlation between PD-related cognitive decline and impulsive behavior when put in the frame of financial decisions that elderly people have to make. Exclusion criteria included papers that did not mention decision-making tasks, left out variations of dopaminergic medication administered to participants, or used animals rather than humans for cognitive study. To avoid any issues, findings in studies were cross-referenced and the author's review includes contradicting perspectives to show dynamics in this field of study. Data extraction included analyzing how different decision-making tasks were used in different situations, and what results were found. Any additional tasks or various ways of using dopaminergic medication were compared to show how different studies come up with different results, that may often be contradictory and calls for more studies to be done. Furthermore, impulsivity and likelihood of choosing specific card decks (advantageous vs. disadvantageous) was analyzed in each paper as well.

This literature review builds on the previous findings of these papers by collectively analyzing the data, and explaining the long-term implications of them. By taking papers from reliable and verified sources, readers understand what research has already been done, and what still needs to be explored.

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Author

Zara S. Doshi is a sophomore (Class of 2027) at Millburn High School in Millburn, New Jersey. This paper was inspired by her interest in Behavioral Sciences and neurodegenerative diseases. She hopes that this review article will be a springboard

for conducting original research that investigates personalized interventions for patients.

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