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Disrupted reward processing in Parkinson's disease and its relationship with dopamine state and neuropsychiatric syndromes: a systematic review and meta-analysis

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ABSTRACT

Background Neuropsychiatric symptoms are common in Parkinson's disease (PD) and predict poorer outcomes. Reward processing dysfunction is a candidate mechanism for the development of psychiatric symptoms including depression and impulse control disorders (ICDs). We aimed to determine whether reward processing is impaired in PD and its relationship with neuropsychiatric syndromes and dopamine replacement therapy.

Methods The Ovid MEDLINE/PubMed, Embase and PsycInfo databases were searched for articles published up to 5 November 2020. Studies reporting reward processing task performance by patients with PD and healthy controls were included. Summary statistics comparing reward processing between groups were converted to standardised mean difference (SMD) scores and meta-analysed using a random effects model.

Results We identified 55 studies containing 2578 participants (1638 PD and 940 healthy controls). Studies assessing three subcomponent categories of reward processing tasks were included: option valuation (n=12), reinforcement learning (n=37) and reward response vigour (n=6). Across all studies, patients with PD on medication exhibited a small-to-medium impairment versus healthy controls (SMD=0.34; 95% CI 0.14 to 0.53), with greater impairments observed off dopaminergic medication in within-subjects designs (SMD=0.43, 95% CI 0.29 to 0.57). Within-subjects subcomponent analysis revealed impaired processing off medication on option valuation (SMD=0.57, 95% CI 0.39 to 0.75) and reward response vigour (SMD=0.36, 95% CI 0.13 to 0.59) tasks. However, the opposite applied for reinforcement learning, which relative to healthy controls was impaired on-medication (SMD=0.45, 95% CI 0.25 to 0.65) but not off-medication (SMD=0.28, 95% CI −0.03 to 0.59). ICD was the only neuropsychiatric syndrome with sufficient studies (n=13) for meta-analysis, but no significant impairment was identified compared tonon-ICD patients (SMD=−0.02, 95% CI −0.43 to 0.39).

Conclusion Reward processing disruption in PD differs according to subcomponent and dopamine medication state, and warrants further study as a potential treatment target and mechanism underlying associated neuropsychiatric syndromes.

INTRODUCTION

Parkinson's disease (PD) is the fastest growing neurological disorder globally,[1] with estimated annual societal costs comparable to those of dementia.[2] Traditionally conceptualised as a movement disorder, non-motor symptoms, including disruptions to mood, cognition and motivation, are common and have a greater negative impact on health-related quality of life than motor symptoms.[3] Neuropsychiatric syndromes are common in PD (see table 1). One-third of patients experience depression,[4] up to one-half experience apathy[5] and impulse control disorders (ICDs) associated with dopaminergic medication occur in up to one-quarter.[6] Currently, there is a lack of understanding of the mechanisms underlying psychiatric symptoms in PD and this represents a barrier to the development of more effective treatments.[7]

Reward processing describes how reinforcement-related perceptions guide goal-directed behaviours.[8] Impaired reward processing is a prominent transdiagnostic feature of several mental health disorders such as depression[8] and represents a useful framework for understanding symptoms associated with motivation. The National Institute of Mental Health's Research Domain Criteria identifies reward processing as one of six major domains underpinning human functioning and psychopathology.[9] Dopamine has a well-established role in both reward and motivational pathways.[10] Evidence from dopamine depletion studies has not supported the hypothesis that dopamine mediates hedonic responses ('liking'), but has revealed a crucial role in motivated behaviours toward desired goals ('wanting').[11]

PD is caused by dopaminergic cell death and consequently is a model of striatal and dopamine dysfunction.[12] The striatum is reciprocally connected with prefrontal areas as well as other parts of the basal ganglia and midbrain, forming frontostriatal circuits involved in the initiation and control of motor, cognitive and emotional function. These pathways also constitute part of the brain's reward circuit, responsible for modulating reward-related behaviour and learning.[13] Psychiatric syndromes in PD (see table 1) are thought to reflect dysfunction of non-motor frontostriatal circuitry; for example, ICDs are believed to develop through

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Table 1 . Current understanding of the role of reward processing in neuropsychiatric symptoms & syndromes in PD.

Common PD neuropsychiatric symptoms and syndromes	Prevalence in PD	Relationship with reward processing
Apathy—loss or reduction of motivation compared with an individual's previous state.	40%[s1]	Apathy and anhedonia are disorders of motivation. Effort-based decision making for reward, the process of how a potential benefit/reward for performing an activity is evaluated with respect to the cost in effort required to attain it, is believed to be a key reward processing mechanism underlying both symptoms.[s3]
Anhedonia—consistently diminished interest or pleasure in almost all daily activities.	46%[s2]	
Depression—clinical syndrome with core symptoms of persistent low mood and anhedonia.	20%–30%[s4, s5]	Disrupted reward processing is understood to be a key cognitive mechanism underlying depressive symptoms. Patients with depression have been shown to have impaired option valuation, reinforcement learning and reward bias versus healthy controls.[s6]
Anxiety—often co-morbid with depression, symptoms include persistent tension, worry and feelings of apprehension.	25%[s7]	Individuals with anxiety are less sensitive to rewards depending on certainty, preferring less profitable but more predictable options over riskier more rewarding outcomes.[s8]
Impulse control disorder (ICD)—development of harmful risk-taking and impulsive behaviours. Can include pathological gambling, hypersexuality and sudden episodes of aggression (intermittent explosive disorder).	25%–30%[s3]	ICD has been proposed to be secondary to dopamine agonists and Parkinson's pathology sensitising patients to reward.[s9] Increased reward sensitivity is suggested to then lead to immediate reward seeking behaviours and impulsivity.
Dopamine dysregulation syndrome—complication of PD treatment characterised by addictive behaviour and excessive use of dopaminergic medication.	3%–4%[s10]	The reward deficiency theory of addiction posits that patients have a deficit in recruiting/hypoactivation of striatal reward pathways, leading to compensatory addictive behaviours such as drug seeking. Striatal hypoactivation during reward anticipation has been found in individuals with addiction.[s11]
Psychosis—used to describe range of hallucinations and delusions.	Visual:[s12] 22%–38% Auditory:[s12] 20% Delusions:[s12] 5%	Abnormal reward processing driven by elevated ventral striatal dopamine levels is hypothesised to underlie psychotic symptoms. Hypoactivation of the ventral striatum during reward anticipation has been reported in psychosis. [s13]

See online supplement for references.
PD, Parkinson's disease.

aberrant reward processing, due to an interaction between the disrupted reward processing circuitry underlying PD and dopamine agonist treatment.[14]

Over the past two decades, studies of reward processing in PD have typically used behavioural tasks assessing three subcomponent processes[8]: (1) option valuation, the process by which individuals evaluate reward-related options when given explicit information about those options (eg, reward, cost and probability); (2) reward response vigour, which reflects the speed or strength with which an individual executes an action to obtain a reward; (3) reinforcement learning, which describes the process by which an individual uses feedback to change their future behaviour. To date, there has been one meta-analysis of Iowa gambling task performance in PD, which reported significantly impaired reward learning.[15] However, the degree and pattern of impairments on other reward processing tasks in PD and any relationship with dopaminergic state and psychiatric symptoms remain unclear.

Here we report the first systematic review and meta-analysis of reward processing behaviour in PD and its relationship with dopamine replacement therapy and associated neuropsychiatric syndromes. Our aims were: (1) to clarify the nature and extent of differences across reward processing subcomponents between PD and healthy groups; (2) to test the role of dopamine state (on or off medication) in reward processing in PD; (3) to investigate any differences in reward processing in patients with PD with and without neuropsychiatric syndromes.

METHOD

Systematic review

The Ovid MEDLINE/PubMed, Embase, and PsycInfo databases were searched for articles published between 1 January 1946 and 5 November 2020 inclusive, with titles or abstracts containing the terms: Parkins* and (reward* or motivat* or incentiv* or effort* or deci*) and (psychiatric or neuropsychiatric or depress* or psychosis or delus* or impuls* or mood or anxiety or apathy or anhedonia or hallucin*). Inclusion criteria were as follows: (1) case-control design; (2) included a group with PD without dementia or deep brain stimulation (DBS) (studies including participants with dementia or DBS withing the PD group were excluded); (3) participants were at least 18 years old; (4) participants performed a reward-processing task; (5) task rewards were explicit, that is, money, points, water or food (we did not include studies that used outcomes that could be considered purely informational or social feedback, eg, happy/sad faces or variants of correct/incorrect, to ensure specificity); (6) studies reported data on a behavioural measure of reward processing that could be converted to a case-control standardised mean difference (SMD) score. If this was not reported, data were requested from the authors. Articles were independently assessed by HC and AJB, using a rating tool based on the Newcastle-Ottawa scale[16] for assessing the quality of non-randomised studies (online supplement). Conflicts in quality assessment rating were resolved through in-person discussion.

Meta-analysis

Behavioural measures from each study were categorised as measuring option valuation, reward response vigour or reinforcement learning, and converted to an SMD score and an associated SE (see online supplemental material for equations).[17]

Within the option valuation and reward response vigour subcategories, a positive SMD represents a greater or faster response to reward by the control than the PD group, respectively. A positive SMD within the reinforcement learning subcategory represents faster use of feedback to maximise reward by the control group than the PD group.

Meta-analysis was conducted if four or more studies were present within a reward processing subcategory for patients with PD compared with healthy controls, PD with and without a psychiatric symptom, or PD on-medication compared with off-medication (within-subjects designs only).

Meta-analysis was performed using the R statistical programming language and the packages metafor and metaviz, using random effects models. Heterogeneity was analysed using the approximate proportion of total variability (I^2).

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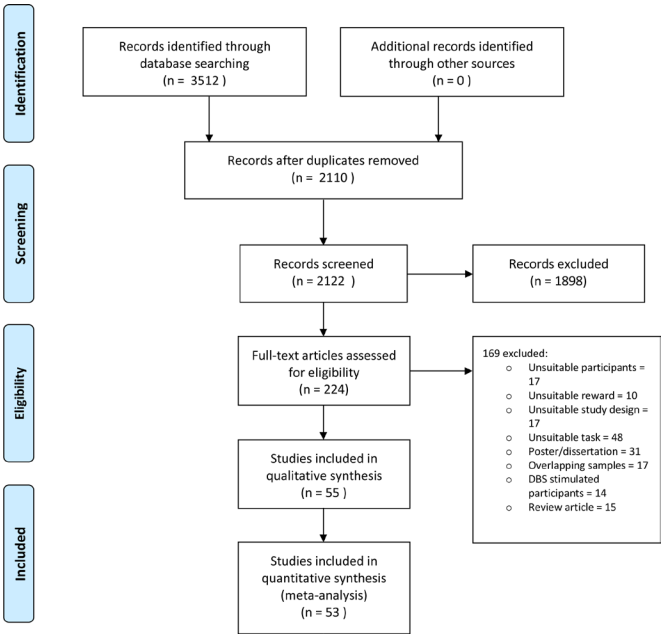

Figure 1 PRISMA flow diagram of study selection and inclusion. DBS, deep brain stimulation; PRISMA, Preferred Reporting Items for Systematic Reviews and Meta-Analyses.

Funnel plot asymmetry was assessed using visual inspection of a contour-enhanced funnel plot and the Egger test.

RESULTS

We initially identified 2122 studies, excluded 1898 of these by title/abstract and retrieved the remaining 224 full papers (figure 1). Data from 55 studies containing 2578 participants (1638 PD, 940 healthy controls) were analysed (see Preferred Reporting Items for Systematic Reviews and Meta-Analyses diagram in figure 1); two studies could not be used in the quantitative analysis due to a lack of reported summary statistics. The median number of patients per study was 24 (IQR 16), median participant age was 63.3 years (IQR 7.5) and median duration of PD was 7.0 years (IQR 4.5).

Meta-analysis across all reward processing subcomponent categories (see online supplemental table 4) identified a small-to-medium reward processing impairment in patients with PD both on-medication (SMD=0.34; 95% CI 0.14 to 0.53) and off-medication (SMD=0.40; 95% CI 0.19 to 0.62), compared with healthy controls (figure 2A, B). Within-subjects comparison of reward processing between on-medication and off-medication states was possible in 14 studies (see online supplemental table 6), revealing relatively impaired reward processing off-medication, with a medium effect size (SMD=0.43, 95% CI 0.29 to 0.57; figure 3A).

ICD was the most studied and only neuropsychiatric syndrome with sufficient studies (n=13) for meta-analysis (see online supplemental table 5). No significant impairment (see figure 3B) was identified in reward processing in patients with PD with ICD compared to patients with non-ICD (SMD=−0.02, 95% CI −0.43 to 0.39).

Overall interstudy heterogeneity was substantial (I^2=57.48%), and the median power of included studies and R-index was low (online supplemental figure 1), median power=36%; R index=28%). Analysis of funnel plot asymmetry using Egger's regression line did not meet statistical significance (p=0.32) and was likely a consequence of high heterogeneity and small sample size of included studies (see online supplemental figure 1).

Quality assessment and risk of bias analysis using a modified Newcastle-Ottawa scale (see online supplemental table 7) found the majority of included studies used a validated assessment tool for diagnosis of PD (65.5%), and accounted for PD severity (94.5%) and medication status (90.9%). However, almost half of included studies gave no description of how healthy controls were selected (42.2%) or clearly defined controls as having no past psychopathology (42.2%).

Option valuation

We identified 12 studies containing 347 patients with PD and 278 healthy participants that used option valuation tasks (online supplemental table 1). The mean age of participants was 62.9 (±4.6) years, and mean duration of illness was 7.5 (±2.8) years. Effort-based decision-making tasks (three studies) and the game of dice task (three studies) were most commonly used. Four studies reported psychiatric medication use in participants, three of which included participants taking antidepressant medications.

Meta-analysis of studies comparing option valuation in patients with PD compared with healthy controls showed lower reward weighting in PD, which was moderated by dopamine

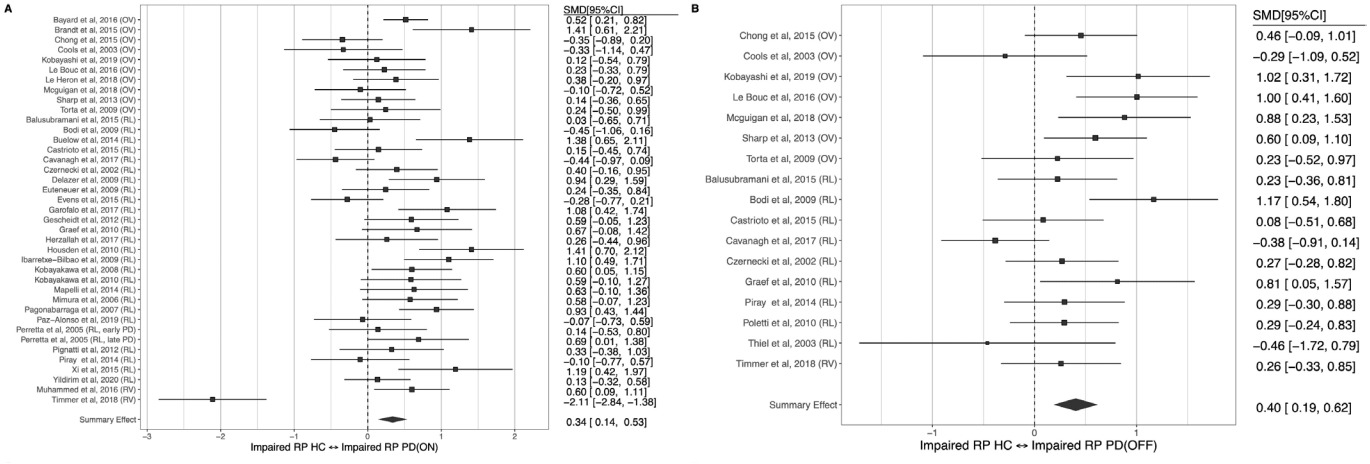

Figure 2 Forest plot of reward processing (RP) in (A) PD ON versus healthy controls (HC), (B) PD OFF versus HC. PD, Parkinson's disease; SMD, standardised mean difference.

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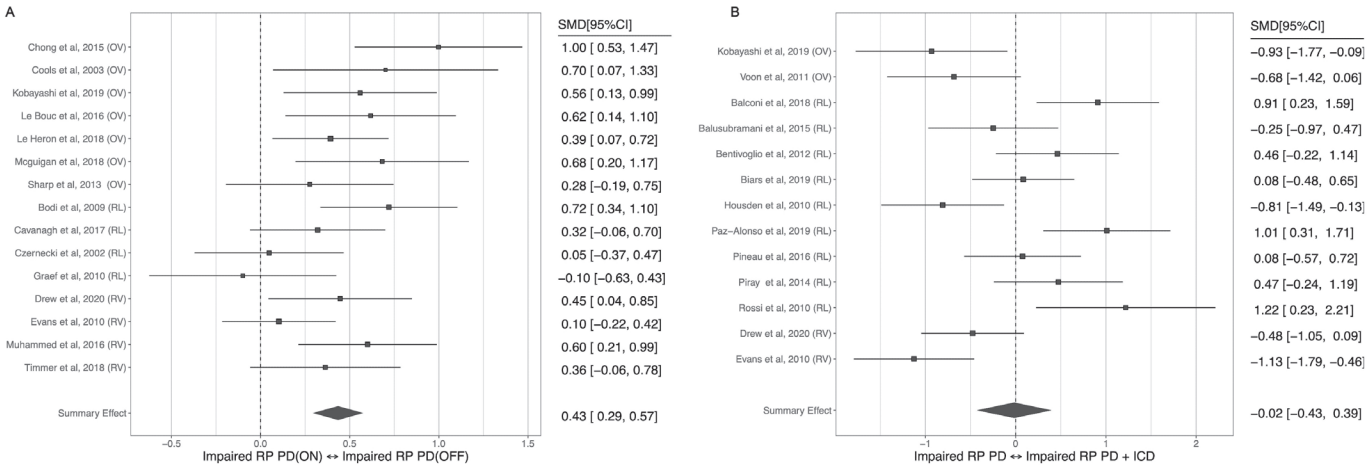

Figure 3 Forest plot of reward processing (RP) in (A) PD ON versus OFF dopamine state, (B) PD with and without impulse control disorder (ICD). PD, Parkinson's disease; SMD, standardised mean difference.

medication (figure 4A, B). Patients on-medication did not differ significantly from healthy controls (SMD=0.22, 95% CI −0.04 to 0.49), but off-medication there was a medium-to-large impairment (SMD=0.60, 95% CI 0.30 to 0.89). Within-subjects comparison confirmed lower reward weighting off-medication, with a medium-to-large effect (SMD=0.57, 95% CI 0.39 to 0.75; figure 4C).

Four studies compared option valuation in patients with PD with and without neuropsychiatric syndromes. Three of these studies[18–20] compared option valuation in patients with PD with and without ICD, with mixed findings. One study[19] using an economic choice task reported lower reward weighting in ICD, while the other two studies[18 20] using gambling tasks found no difference[18] and increased reward weighting,[20] respectively.

One study[21] investigating the effect of apathy on option valuation reported lower acceptance of offers of reward obtained through physical exertion. This pattern of impairment in apathy was found to be dissociable from the effects of dopamine. Apathy was characterised by rejection of predominantly low reward offers, while dopamine state increased choices of high effort, high reward offers.

In summary, option valuation impairment in PD is dopamine dependent, with lower reward weighting off dopaminergic medication. Too few studies have investigated option valuation in patients with PD with neuropsychiatric syndromes to draw meaningful conclusions.

Reinforcement learning

We identified 37 studies containing 1059 patients with PD and 593 healthy controls that used reinforcement learning tasks (online supplemental table 2). The majority of studies (20/37)

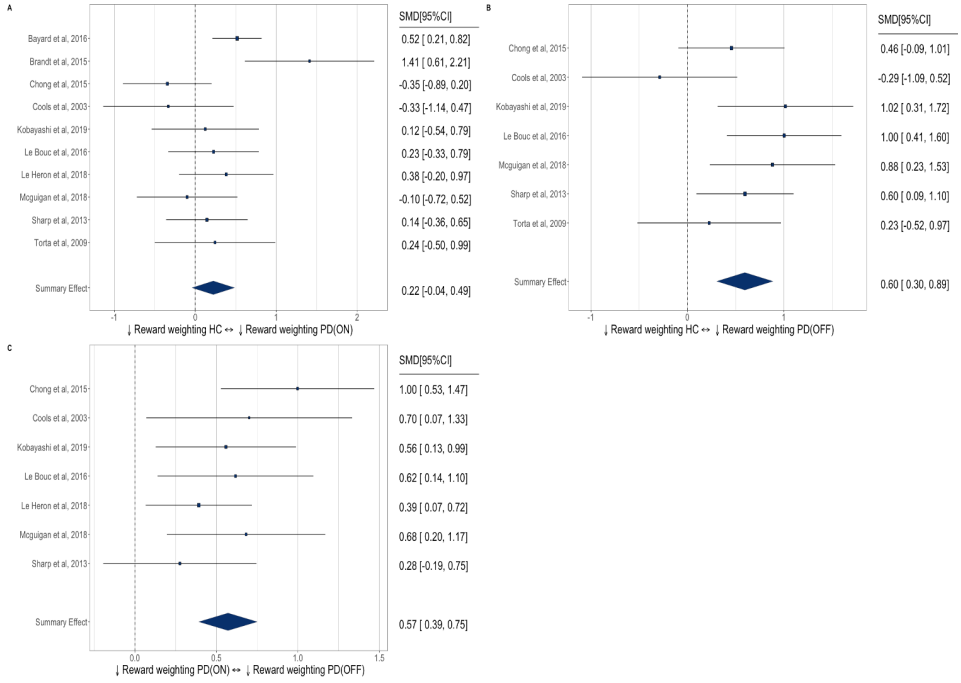

Figure 4 Forest plot of option valuation in: (A) PD ON versus healthy controls, (B) PD OFF versus healthy controls, (C) PD ON versus OFF dopamine state. HC, healthy controls; PD, Parkinson's disease; SMD, standardised mean difference.

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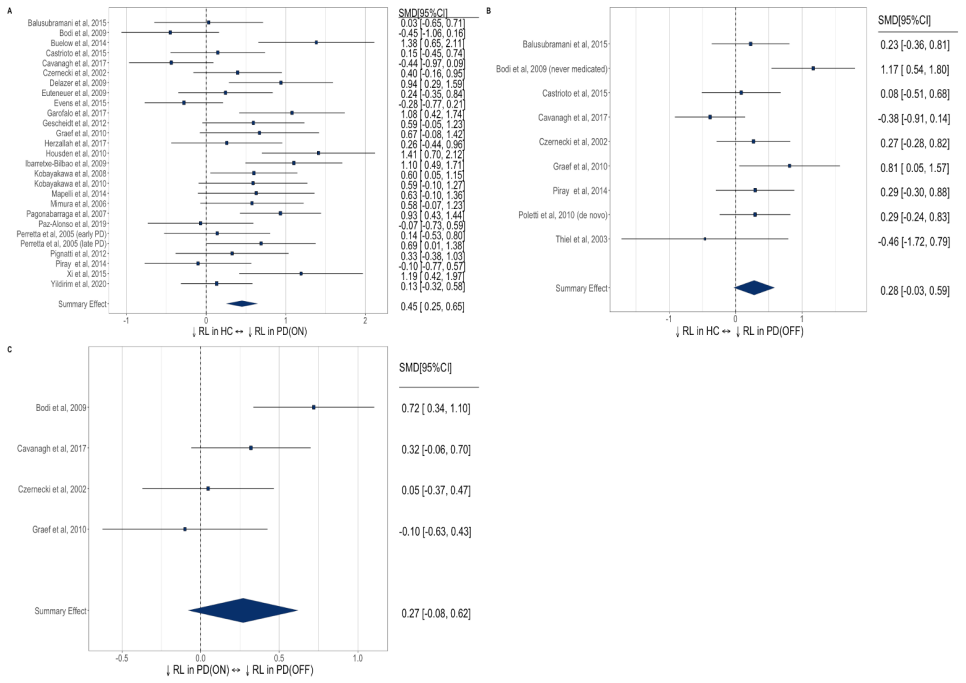

Figure 5 Forest plot of reinforcement learning (RL) in: (A) PD ON versus healthy controls, (B) PD OFF versus healthy controls, (C) PD ON versus OFF dopamine state. HC, healthy controls; PD, Parkinson's disease; SMD, standardised mean difference.

used the Iowa gambling task. Ten studies reported psychiatric medication use, of which three included participants taking antidepressant medication.

Reinforcement learning was slowed in patients with PD on-medication versus healthy controls (figure 5A, B) with a medium effect size (SMD=0.45, 95% CI 0.25 to 0.65). Interestingly, there was no significant group difference off-medication (SMD=0.28, 95% CI −0.03 to 0.59). Comparison of reinforcement learning comparing on-medication and off-medication within-subjects (figure 5Cc) was possible in four studies, which did not detect a significant effect (SMD=0.27, 95% CI −0.08 to 0.62); however, we note that this analysis is likely underpowered due to the small number of included studies.

Sixteen studies investigated reinforcement learning in patients with PD with and without neuropsychiatric symptoms (online supplemental table 2), with the majority (11/16) examining ICD. Meta-analysis of nine studies (online supplemental figure 2) found no significant difference between patients with PD with ICD and non-ICD PD patients (SMD=0.32, 95% CI −0.09 to 0.73).

Two studies[22 23] examined reinforcement learning in patients with PD with major depressive disorder. Both[22 23] reported impaired reinforcement learning in depressed patients with PD compared with non-depressed patients with PD. One[23] also compared reinforcement learning in depressed patients with PD with depressed participants without PD. A similar pattern of impairment in learning from positive feedback was identified in the two groups, suggesting that reinforcement learning impairment may not be specific to depression in PD.[9]

Two studies[24 25] examined the role of apathy in reward learning. Both used the Iowa gambling task but reported conflicting findings: one found significant impairment[25] but the other reported better reinforcement learning in patients with PD with apathy,[24] compared with those without.

In summary, and in stark contrast to studies of option valuation, reinforcement learning is particularly impaired in PD in the on-medication state. There was no significant impairment in reinforcement learning in patients with PD with ICD compared with those without ICD. Too few studies have investigated reinforcement learning in patients with PD with other neuropsychiatric syndromes to draw meaningful conclusions.

Reward response vigour

We identified seven studies containing 232 patients with PD and 69 healthy controls that investigated reward response vigour in PD (online supplemental table 3). Insufficient studies were identified to allow meta-analysis of reward response vigour in PD compared with healthy controls. Of the three studies[26–28] that reported reward response vigour in PD and healthy controls, results were mixed, with studies reporting lower,[26] greater[27] and no difference[28] in patients with PD compared with healthy volunteers.

Meta-analysis of the effect of dopamine state on reward response vigour in four studies (figure 6) identified a small-to-medium increase in reward response vigour on-medication (SMD=0.36, 95% CI 0.13 to 0.59).

Six studies investigated reward response vigour in patients with PD with and without neuropsychiatric syndromes (online supplemental table 3). Two studies[27 29] examined apathy, one using a rewarded saccadic eye movement task,[27] the other a rewarded spatial search task[29]; both reported no significant group differences. Similarly, no significant difference in reward response vigour was found in two studies comparing patients with ICD and patients with non-ICD,[30 31] and two investigating depression in PD.[28]

In summary, relatively few studies have investigated reward response vigour in PD, and findings are mixed. Reward response vigour in PD was reduced in the off-medication compared with the on-medication state. Too few studies have investigated reward response vigour in patients with PD with neuropsychiatric syndromes to draw meaningful conclusions.

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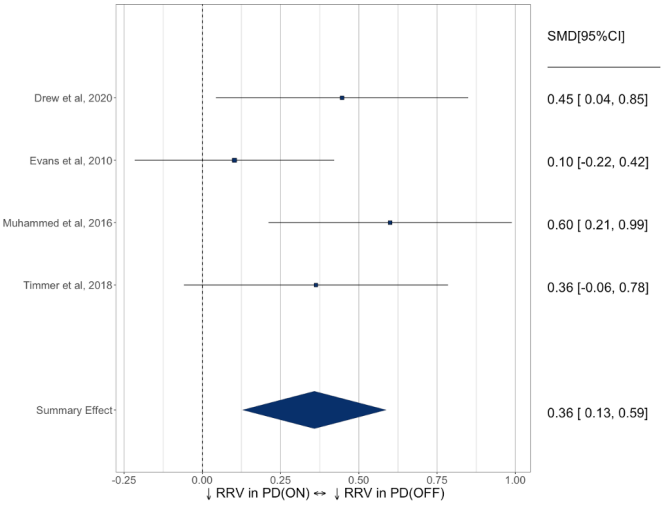

Figure 6 Forest plot of reward response vigour (RRV) in PD ON versus OFF dopamine state. PD, Parkinson's disease; SMD, standardised mean difference.

DISCUSSION

This is the first systematic review and meta-analysis of reward processing in PD, associated neuropsychiatric syndromes and the influence of dopaminergic medication. Across all 55 studies, including different subcomponents of reward processing, we found patients with PD to have small-to-medium reward processing impairments relative to healthy participant groups. The degree of impairment in reward processing is similar to that reported in major depressive disorder, a condition where dysfunctional reward processing is a leading aetiological candidate mechanism for 'interest-activity' symptoms, such as anhedonia.[8] We also identified potentially important differences between reward processing subcomponent categories and the effect of dopamine state.

The option valuation subcategory exhibited the largest impairment in PD which was dopamine dependent, with markedly reduced reward weighting in patients with PD off dopaminergic medication. This finding is supported by animal[11] and human experimental studies[32] which show impaired valuation following dopamine depletion. Dopamine antagonists such as antipsychotic drugs also reduce preference for high-effort/high-reward options,[11] suggesting that dopamine transmission is crucial in cost-benefit decision making. Dopaminergic pathways in the brain reward circuit including the anterior cingulate cortex and basal ganglia are believed to be central in choosing and executing effortful action.[5] Option valuation is a component of effort-based decision making and represents a framework for understanding apathy and anhedonia, both common motivational disorders in PD and depression.[5] However, no study to date has investigated option valuation in depression in PD, and the only study[21] to examine apathy found dissociable effects of dopamine and apathy on decision making, indicating impairment may not only be secondary to dopamine depletion.

In direct contrast to the pattern identified in the option valuation subcategory, reinforcement learning was moderately impaired in PD when patients were on dopamine medication, with no significant difference detected when off medication. This is surprising given decades of evidence that dopaminergic pathways from the midbrain are crucial for reward learning.[33] However, recent studies applying cell-type specific monitoring and manipulation of distinct neuronal populations in the striatum have suggested that heterogenous signals in dopaminergic neurons support specific types of learning.[34] For example, differentially regulated mechanisms of dopamine release in the basal ganglia underlie distinct functions.[35] Reward learning is believed to be facilitated by dopamine cell spiking encoding reward prediction errors, whereas gradual increase in dopamine release mirrors reward expectation.[35] Reinforcement learning is therefore believed to be dependent on phasic rather than tonic dopamine signalling. Wave-like spatiotemporal dopamine dynamics in the dorsal striatum have also been implicated in encoding reward prediction errors to facilitate learning.[36] It remains unclear what effect exogenous dopamine in PD has on the dynamics of striatal dopamine signalling. Studies of associative learning in healthy subjects have found that dopamine agonists can impair learning by inhibiting phasic dopamine signalling.[37] Therefore, one possible interpretation is that dopamine medication may remediate control of reward expectation and motivation within the striatum, but impair the broadcast burst signals required to promote learning.[35] However, this requires testing in future studies.

Distinct types of reinforcement learning model used during task performance may also play a crucial role.[38] 'Model-free' learning describes learning through direct experience rather than through constructing an internal model of the environment in order to develop a complex map of cues and actions which lead to reward.[38] Most studies included in our review used model free reinforcement learning tasks. Evidence suggests that these two types of reinforcement learning processes are mechanistically distinct, and differentially dependent on dopamine reward prediction errors.[38]

The reward response vigour subcategory showed a significant small-to-moderate impairment in the off-medication compared with the on-medication state in patients with PD. However, relatively few studies were identified and reaction times may be vulnerable to attentional confounds. Though several studies reported reaction times during tasks, reward-related speeding (ie, the difference between rewarded and non-reward conditions) was infrequently measured, without which slower reaction times would likely only reflect bradykinesia associated with PD.

Despite PD being a model for dopamine dysfunction, current treatments of common neuropsychiatric syndromes in PD such as depression do not differ from depression in patients with other long-term conditions[39] and have limited efficacy.[40] Symptoms of anxiety and depression in patients with PD with motor fluctuations can be more common and severe in the off-dopamine state,[41] suggesting depression in PD may be related to dopaminergic deficit and have a specific aetiology. Our findings suggest PD is characterised by a specific pattern of impairment in reward processing which is dopamine dependent and potentially could be a causal mechanism underlying neuropsychiatric symptoms such as depression. Although ICDwas not significantly associated with reward processing impairment statistical power was limited, and few studies have investigated reward processing in other PD-associated neuropsychiatric syndromes. Further understanding of how impairment in reward processing is associated with specific neuropsychiatric manifestations of PD is needed to understand the underlying mechanisms of these disabling syndromes and develop more targeted and effective treatments.

LIMITATIONS

We categorised reward processing into three subcomponent categories, however there are several ways to measure function in each category which grouped diverse processes. For example,

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the option valuation subcategory included studies measuring risk taking and decisions to exert effort, resulting in meta-analysis of heterogeneous measures. A minority of studies reported psychiatric medication use in participants. Evidence suggests antidepressant medication may partly exert its effect via modulating reward processing[42] which could have confounded results. Though we measured and compared the effect of dopamine medication state on task performance, the medication regime and proportion of patients on dopamine agonist treatment as opposed to levodopa was reported in less than half of included studies (22/55). Different PD medications are disproportionately associated with dopamine-related psychiatric conditions such as ICD,[6] and distinct regimes could potentially impact reward processing variably. The majority of studies investigating reward processing in PD-associated neuropsychiatric syndromes used patients with PD without the syndrome as a control group. Only one study[23] investigating depression in PD used a control group of patients with depression without PD. In order to establish whether patterns of reward processing impairments are specific to PD-associated neuropsychiatric syndromes and not a common feature of psychiatric symptoms more generally, further studies of this type are needed. Finally, our systematic review and meta-analysis examined the findings of case-control studies which are unable to inform us of the causal relationship between reward processing impairment, PD and its associated neuropsychiatric syndromes. Longitudinal studies are needed to answer these questions and understand how reward processing changes develop as PD advances. Our analyses of the impact of dopamine medication were derived from studies conducted using within-subjects experimental comparisons, and therefore we can be more confident of a causal role. However, the effects of being off-medication in a patient who usually takes dopamine-boosting drugs, including heightened anxiety and physical discomfort, could plausibly affect task performance. A minority of studies (22/55) measured motor symptom severity in both on and off states, and only four studies measured differences in anxiety symptoms in both states.

CONCLUSIONS

PD is associated with a small-to-medium level of reward processing impairment overall, with variable degrees of impairment across subcomponent reward processing categories. Reward processing is dependent on dopamine state with greater impairment in option valuation and reward response vigour when patients are off dopaminergic medication, but surprisingly faster reinforcement learning. Other than reinforcement learning in ICD, few studies have investigated the relationship between reward processing and PD associated neuropsychiatric syndromes. Further research, including longitudinal studies are needed to conclude whether specific patterns of impairment in reward processing have a causal relationship with neuropsychiatric syndromes in PD.

Correction notice This article has been corrected since it was published online first. The caption of figure 3 has been updated.

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Contributors HC, JPR and RH contributed to study concept and design. HC and AJB contributed to quality assessment of studies. HC, AJB and JPR contributed to acquisition of data. HC and JPR contributed to analysis and interpretation of data. HC contributed to drafting of manuscript. All authors critically revised successive drafts of the paper and approved the final version. HC accepts responsibility as guarantor for the overall content of the study.

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Patient consent for publication Not applicable.

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Provenance and peer review Not commissioned; externally peer reviewed.

Data availability statement All data relevant to the study are included in the article or uploaded as supplementary information.

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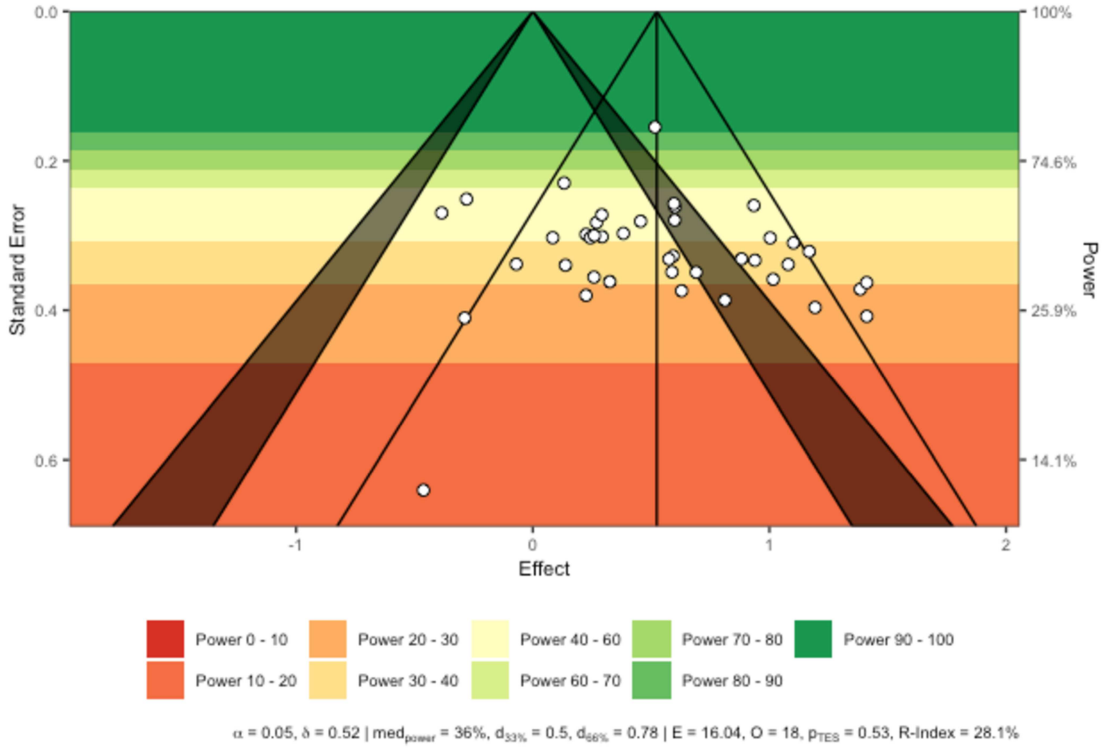
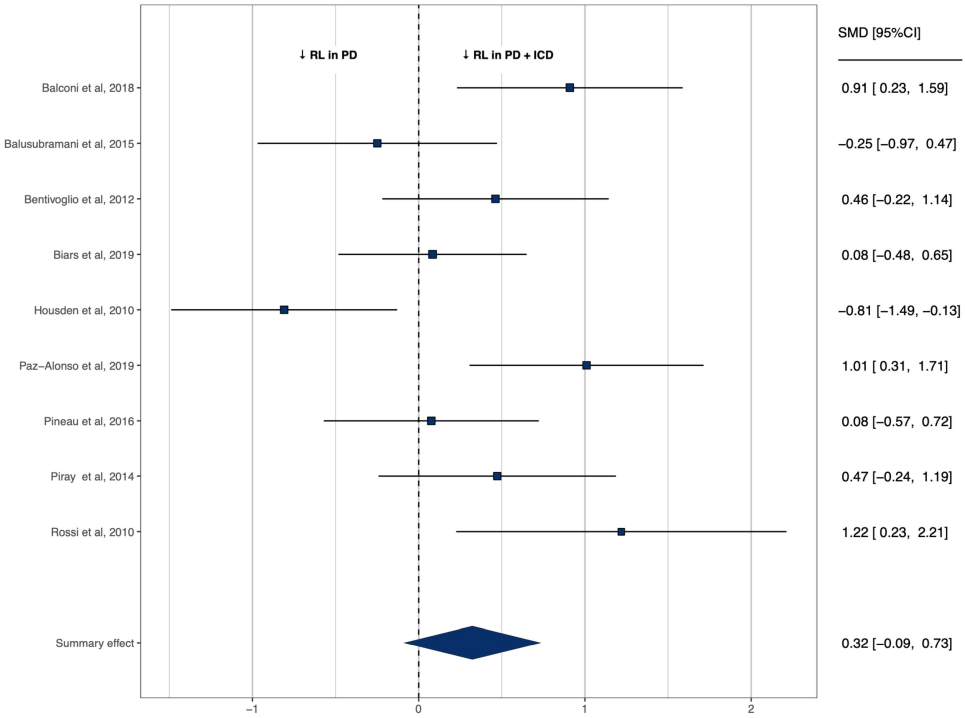
Supplement figure 1. Contour-Enhanced Funnel Plot of all studies Parkinson's versus healthy controls



Supplement figure 2. Forest plot of reinforcement learning (RL) in Parkinson's patients with and without Impulse Control Disorder (ICD)



Formulae used to convert study measures into Cohen's ds and associated variances.

The following formulae were used to convert study measures into Cohen's ds and associated variances **between subjects:**

$$d = \frac{M_1 - M_2}{SD_{pooled}}$$

Equation 1. Cohen's d from Means and Standard Deviations of 2 samples. d is Cohen's d, M1 is the mean of one sample M2 is the mean of the other sample, SDpooled is the pooled standard deviation of the two samples (please see below.)

$$SD_{pooled} = \sqrt{(N_1 - 1)SD_1^2 + (N_2 - 1)SD_2^2}$$

Equation 2. Pooled standard deviation of 2 samples. SDpooled is the pooled standard deviation of the two samples, N1 is the size of one sample N2 is the size of the other sample, SD1 is the standard deviation of one sample, SD2 is the standard deviation of the other sample.

$$d = \frac{t}{\sqrt{\frac{1}{\frac{1}{N_1} + \frac{1}{N_2}}}}$$

Equation 3. Cohen's d from t-statistic. d is Cohen's d, N1 is the size of one sample N2 is the size of the other sample, t is the t-statistic

$$d = \frac{F}{\sqrt{\frac{1}{\frac{1}{N_1} + \frac{1}{N_2}}}}$$

Equation 4. Cohen's d from F-statistic. d is Cohen's d, N1 is the size of one sample N2 is the size of the other sample, F is the F-statistic.

$$Var_d = \frac{N_1 + N_2}{N_1 \times N_2} + \frac{d^2}{2(N_1 + N_2)}$$

Equation 5. Variance on Cohen's d for between subjects. Vard is the Variance on Cohen's d, N1 is the size of one sample N2 is the size of the other sample, d is Cohen's d.

The following formulae were used to convert study measures into Cohen's ds and associated variances **within subjects:**

$$d = \frac{M_d}{SD_d}$$

Equation 6. Cohen's d from Means and Standard Deviations from within subjects sample. Where M_d is the mean change and SD_d is the SD of the change scores
(equal to $SD_d = \sqrt{SD_1^2 + SD_2^2 - 2 \times r \times SD_1 SD_2}$).

$$d = \frac{t}{\sqrt{N}}$$

Equation 7. Cohen's d from t-statistic for within subjects results. d is Cohen's d, N is the sample size, t is the t-statistic

$$d = \sqrt{\frac{F}{N}}$$

Equation 8. Cohen's d from F-statistic. d is Cohen's d, N is the sample size, F is the F-statistic.

$$Var[d] = \frac{1}{n} + \frac{d^2}{2n}$$

Equation 9. Variance on Cohen's d for within subjects, n is the size of the sample.

Supplement table 1. Option Valuation study characteristics and participant demographics.

Option valuation in Parkinson's vs Healthy Controls				Age (years)			Disease duration (years)		UPDRS		Cognition			Depression		
Study	Task	Group	n	Mean	SD	% female	Mean	SD	Mean	SD	Cognitive measure	Mean	SD	Depression measure	Mean	SD
Bayard, 2016	Game of dice task	PD	78	67.49	8.16	35	7	.	24	(5-80)	MMSE	28.1	1.93	BDI	12.5	7.38
		HC	96	67.95	6.75	32	-	-	-	-		28.46	1.38		10.04	11.76
Brandt, 2015	Game of dice task	PD	15	64.78	8.09	46.66	.	.	14.43	10.14	MoCA	26.87	1.69	GDS-15	3.33	3.54
		HC	15	62.39	10.04	40	-	-	-	-		27.6	1.43		1.33	1.18
Chong, 2015	Effort based decision making task	PD	26	66.6	6.8	34.6	.	.	21.6	11.7	MoCA	28.2	1.3	DASS	2	2.23
		HC	26	66.2	6.4	42.3	-	-	-	-		28.2	1.7		1.5	1.84
Cools, 2003	Decision making gambling task	PD	12	64.6	1.5	58.33	6.5	1.4	30.9	6.8	MMSE	29.5	0.15	BDI	7.7	1.1
		HC	12	.	.	.	-	-	-	-		.	.		.	.
Kobayashi, 2019	Economic choice task	PD	15	63	6.58	40	6.93	6.2	39	14.6	MMSE	28.3	1.76	.	.	.
		HC	21	60	6.69	57.1	-	-	-	-		28.7	1.99		.	.
Le Bouc, 2016	Incentivised grip force choice task	PD	24	60.2	1.6	29.17	11.4	1.3	11.7	1.7	MMSE	27.3	1.3	MADRS	5.9	1
		HC	25	57	2.1	52	-	-	-	-		.	.		2.9	0.7
Le Heron, 2018	Effort based decision making task	PD	39	67.8	7.6	19.04	.	.	29.5	9.9	ACE	91.1	7.9	BDI	14.3	7.7
		HC	32	68.9	6.9	40.6	-	-	-	-		95.6	3.8		3.8	3.7
Mcguigan, 2018	Cognitive effort task	PD	20	67.1	9.1	40	5.4	4.9	27.3	18.1	MoCA	27.7	1.92	BDI	9.5	4.98
		HC	20	61.1	13.6	40	-	-	-	-		28.1	1.37		3.55	4.13
Torta, 2009	Cambridge gamble task	PD	15	58.4	6.9	13.33	13.2	3.2	16.52	7.5	MMSE	28.2	1.5	BDI	10	6.6
		HC	13	58.2	5.7	15.38	-	-	-	-		.	.		.	.
Sharp, 2013	Vancouver gambling task (modified)	PD	18	65.47	9.17	27.78	5.59	4.04	20.65	6.91	MOCA	27.94	1.14	BDI	6.06	3.78
		HC	18	66.76	5.83	50	-	-	-			28.85	1.32		5.18	3.57
Option valuation in Parkinson's with psychiatric syndrome vs without				**Age (years)**			**Disease duration (years)**		**UPDRS**		**Cognition**			**Depression**		
Study	**Task**	**Group**	**n**	**Mean**	**SD**	**% female**	**Mean**	**SD**	**Mean**	**SD**	**Cognitive measure**	**Mean**	**SD**	**Depression measure**	**Mean**	**SD**
Haagensen, 2020	Game of dice task	PD	13	61.4	9.7	46.15	4.5	2	22.8	6.9	MoCA	28.7	1.3	BDI	7	5
		ICD	13	59.4	10.9	38.46	6.5	3.6	22.6	6		28.7	0.9		7.4	6.5
Kobayashi, 2019	Economic choice task	PD	15	63	6.58	40	6.93	6.2	39	14.6	MMSE	28.3	1.76	.	.	.
		ICD	10	63.1	9.68	40	8.4	2.99	49.9	26.3		28.3	1.77	.	.	.
Le Heron, 2018	Effort based decision	PD	18	68.2	6.5	44.44	.	.	27.1	13.2	ACE	93.5	5	BDI	11	7
		Apathy	21	67.5	8.5	19.05	.	.	29.5	9.9		89.4	9.4		17.1	7.4

Voon, 2011	Gambling task	PD	14	54.5	12.5	71.4	.	.	.	.	.	.	.	.	.	.	.
		ICD	14	51.5	8.3	71.4	.	.	.	.	.	.	.	.	.	.	.

PD = Parkinson's disease, HC = healthy controls, ICD = Impulse control disorder, SD = standard deviation, IQR = interquartile range, '.' = not reported, '-' = not applicable, UPDRS = Unified Parkinson's Disease Rating Scale, MMSE = Mini-mental state examination, MoCA = Montreal cognitive assessment, ACE = Addenbrooke's cognitive examination, BDI = Beck depression inventory, DASS = Depression, Anxiety and Stress Scale, GDS = Geriatric depression scale, MADRS = Montgomery-Asberg Depression Rating Scale

Supplement table 2. Reinforcement Learning study characteristics and participant demographics.

Reinforcement learning in Parkinson's vs Healthy Controls				Age (years)			Disease duration (years)		UPDRS		Cognition			Depression		
Study	**Task**	**Group**	**n**	**Mean**	**SD or (IQR)**	**% female**	**Mean**	**SD or (IQR)**	**Mean**	**SD or (IQR)**	**Measure**	**Mean**	**SD or (IQR)**	**Measure**	**Mean**	**SD or (IQR)**
Castrioto, 2015	IGT	PD	20	53.2	6.6	45	10.3	3.8	12.3	6.1	MDRS	137.6	4.2	.	.	.
		HC	24	54.9	7.6	62.5	-	-	-	-		140.7	2.4		.	.
Balusubramani, 2015	Probabilistic rewarded categorisation learning task	PD	30	.	.	18.75	9.5	.	.	.	MMSE	.	.	BDI	.	.
		HC	20	.	.	13.04	-	-	-	-					.	.
Bodi, 2009	Probabilistic classification task	PD	22	44.8	5.2	30.77	0.266	0.166	27.5	6.1	.	.	.	HAM-D	4.2	1.4
		HC	20	45.3	8.5	25	-	-	-	-		.	.		.	.
Buelow, 2014	IGT	PD	24	68.04	7.86	45.8	.	.	29.89	13.14	MMSE	28.33	1.63	GDS	2.5	1.91
		HC	14	69.62	6.36	53.85	-	-	-	-		29.31	1.11		1.15	1.57
Cavanagh, 2017	Cost of conflict task	PD	28	69.75	8.59	39.28	5.54	4.18			MMSE	28.64	1.06	BDI	7.64	5.23
		HC	28	69.21	9.23	39.28	-	-	-	-		28.82	1.02		4.93	4.69
Czernecki, 2002	IGT	PD	23	57.6	2.1	60.87	14.9	1.2	12.4	2	MDRS	139.1	0.8	MADRS	8.3	1.4
		HC	28	58.1	1.7	35.71	-	-	-	-		141.1	0.3		6.2	0.8
Delazer, 2009	IGT	PD	20	68.5	5.9	25	5.25	6.38	17.6	8.7	MMSE	27.8	1.9	HADS	6.6	3.2
		HC	20	71.3	3.5	85	-	-	-	-		29.8	0.4		.	.
Euteneuer, 2009	IGT	PD	21	67.6	7.31	67	7.14	6.06	17.7	9.2	MMSE	29	1.1	BDI	3.9	2.12
		HC	23	64.4	8.56	48						29.65	0.65		0.83	1.3
Evens, 2015	IGT	PD	32	65.12	8.25	25	7.38	4.33	16.58	7.36	MMSE	29.25	0.98	MADRS	4.33	3.68
		HC	32	65.53	5.94	31	-	-	-	-		29.34	0.83		1.59	2.19
Garofalo, 2017	Instrumental conditioning task	PD	17	63.29	9.94	50	16.42	28.77	.	.	MMSE	28.41	1.37	BDI	12.66	7.83
		HC	24	61.91	5.83	44	-	-	-	-		28.94	1.54		8.88	4.94
Gescheidt, 2012	IGT	PD	19 (early onset)	50.32	8.74	25	11.32	6.42	14.6	8.7	MMSE	29.37	0.96	MADRS	.	.
		HC	20	49.95	9.03	26.3	-	-	-	-		29.7	0.47		.	.
Graef, 2010		PD	15	65.27	8.14	40	4.3	4	19.64	7.7	MMSE	29	1	BDI	6.93	5.55

	Probabilistic reversal learning task	HC	16	67.75	4.55	37.5	-	-	-	-		28.64	1.15		5.31	2.98
Herzallah, 2017	Rewarded categorisation task	PD	17	59.4	12.6	11.76	5.24	4	28.6	14.6	MMSE	28.5	1.1	BDI	8.3	5.2
		HC	15	54.3	12.3	33.33	-	-	-	-		29.3	0.7		6.7	5.3
Housden, 2010	Rewarded salience attribution test	PD	18	67.7	5.5	38.89	12.9	8.3	20	6.6	MMSE	28.6	2.1	BDI	12.9	9.9
		HC	20	65.5	6	33.33	-	-	-	-		29.4	0.8		11.3	6.9
Ibarretxe-Bilbao, 2009	IGT	PD	24	56.13	8.5	33	3.06	1.6	14.67	3.5	MMSE	29.63	0.5	BDI	.	.
		HC	24	57.58	8.9	33	-	-	-	-		29.83	0.4			
Kobayakawa, 2008	IGT	PD	34	69.9	8.9	64.7	6.4	3.4	.	.	MMSE	28	2.2	SDS	36.1	8.9
		HC	22	67.6	6.9	40.9	-	-	-	-		28.8	1.6		29.1	6
Kobayakawa, 2010	IGT	PD	14	68.9	8	50	5.6	2.7	.	.	MMSE	28.2	1.9	SDS	32.9	7.8
		HC	22	67.6	6.9	69.2	-	-	-	-		28.8	1.6		29.1	6
Mapelli, 2014	IGT	PD	15	61.4	9.6	25	4.8	3.4	8.9	4	MMSE	28.3	1.2	BDI	Excluded if >14	
		HC	15	60.7	9.8	26.7	-	-	-	-		27.86	1.5		.	.
Mimura, 2006	IGT	PD	18	68.9	7	72.2	.	.	.	.	MMSE	27.8	1.9	ZSRD	39.4	6.9
		HC	20	.	.	70	-	-	-	-		29.1	1.5		30.5	6
Pagonabarraga, 2007	IGT	PD	35	67.2	8	37.2	8.4	5	21.2	8	MDRS	133	6	.	.	.
		HC	31	70.2	10	47.7	-	-	-	-		136	5		.	.
Paz-Alonso, 2019	IGT	PD	17	61	8.7	11.8	7	(4-10)	25.9	8.2	.	.	.	HADS-D	2.2	2.6
		HC	18	63	9.7	16.7	-	-	-	-		.	.		1.9	1.3
Perretta, 2005	IGT	PD (late stage)	16	77.7	6	50	.	.	27.2	1.3	MMSE	Excluded if <27	.	BDI	12.7	1.5
		PD (early stage)	16	72.4	2.3	43.75	.	.	11.3	1.1					6.9	0.7
		HC	19	72.6	8.28	42.1	-	-	-	-					5.2	0.8
Pignatti, 2012	IGT	PD	15	64.27	10.5	.	.	.	.	.	MMSE	28.31	1.11	.	.	.
		HC	16	41.56	13.9	.	-	-	-	-					.	.
Piray, 2014	Rewarded categorisation task	PD	40	63.33	3.98	23.07	9.72	2.64	19.6	6.42	MMSE	27	0.93	BDI	8	1.69
		HC	20	66.45	4.7	35	-	-	-	-		27.65	1.18		7.75	1.97
Poletti, 2010	IGT	PD (off)	24	64.9	5.8	27	0 (de novo)		14.3	8.1	MMSE	28.8	2	GDS	4.7	3.3
		HC	25	65.4	2.2	44						28.5	1.8		2.8	1.4
Thiel, 2003	IGT	PD	5	62.6	12.5	40	8	2.55	20.6	6.47	MMSE	.28.4	2.07	.	.	.
		HC	5	44.2	21.3	20	-	-	-	-						
Xi, 2015	IGT	PD	15	60.73	11.7	53	4.33	5.05	15.87	8.96	MMSE	27.6	4.63	HAMD	4.67	1.29

		HC	15	56.33	14.5	60	-	-	-	-		29.4	1.12		3.8	1.37
Yildirim, 2020	IGT	PD	39	65.9	7.3	21	7.8	4.3	11.6	6.1	MMSE	.	.	.	.	.
		HC	37	64.4	8	24	-	-	-	-		.	.		.	.
Reinforcement learning in Parkinson's with psychiatric syndrome vs without				**Age**			**Disease duration (years)**		**UPDRS**		**Cognition**				**Depression**	
Study	**Task**	**Group**	**n**	**Mean**	**SD or (IQR)**	**% female**	**Mean**	**SD or (IQR)**	**Mean**	**SD or (IQR)**	**Measure**	**Mean**	**SD or (IQR)**	**Depression measure**	**Mean**	**SD or (IQR)**
Balconi, 2018	IGT	PD	20	63.9	7.1	15	.	.	13	9.3	.	.	.	BDI	11.3	6
		PG	17	60.7	6.1	17.65	.	.	17	7.8		.	.		15.9	9.1
Balusubramani, 2015	Rewarded categorisation task	PD	14	.	.	21.4	8.35	.	.	.	MMSE	.	.	BDI	.	.
		ICD	16	.	.	12.5	9.56	.								
Bentivoglio, 2012	IGT	PD	17	63.94	9.2	35.29	7.3	4.4	22.5	6.9	MMSE	28.6	1.4	HAM-D	5.6	4.1
		ICD	17	62	10.1	17.65	6.9	3.8	23.8	11		28.4	1.6		7.5	6.3
Biars, 2019	IGT	PD	24	60.5	7.8	12.5	11.9	7.1	37.2	14.8	DRS	136.5	5.9	BDI	8.5	5.3
		ICD	24	61.2	8.3	12.5	13.2	7.1	21.6	9.9		138	3.5		11.2	6.8
Buelow, 2014	IGT	PD	14	69	6.19	57.14	.	.	29.62	6.85	MMSE	28.71	1.38	GDS	2.14	1.41
		Apathy	10	66.7	9.96	30	.	.	29.89	13.14		27.8	1.87		3	2.45
Garofalo, 2017	Instrumental conditioning task	PD	17	63.29	9.94	44	10.94	10.38	.	.	MMSE	28.94	1.54	BDI	8.88	4.94
		Psychosis	12	60.83	6.6	50	16.42	28.77	.	.		28.41	1.37		12.66	7.83
Herzallah, 2017	Rewarded categorisation task	PD	17	59.4	12.6	11.76	5.24	4	.	.	MMSE	28.5	1.1	BDI	8.3	5.2
		MDD	13	55.2	11.9	69.2	4.84	3.7	28.6	14.6		27.5	1.8		26.9	7.7
Housden, 2010	Rewarded salience attribution test	PD	18	67.7	5.5	33.33	12.9	8.3	21.3	0.4	MMSE	29.4	0.8	BDI	11.3	6.9
		ICD	18	62.3	7.6	38.89	13.9	9	20	6.6		28.6	2.1		12.9	9.9
Martinez-Horta, 2013	IGT	PD	17	65.06	4.85	.	5.38	4.25	18	4.61	MMSE	28.94	1.24	HADS	3.88	3.6
		Apathy	17	68.25	6.06	.	6.75	4.93	18.65	5.8		28.55	1.23		5.65	2.92
Paz-Alonso, 2019	IGT	PD	17	61	8.7	11.8	7	(4-10)	25.9	8.2	.	.	.	HADS	2.2	2.6
		ICD	18	62.3	7.6	11.1	8	(5.1-10)	22.31	6.6		.	.		3.1	2.4
Pineau, 2016	IGT (adapted)	PD	20	55	(40-62)	35	5.5	(4-12)	8.5	(0-34)	MDRS	139	(131-143)	.	.	
		ICD	17	55	(37-65)	17.64	7	(2-10)	7	(0-23)		140	(133-144)		.	.
Piray, 2014	Rewarded categorisation task	PD	40	63.33	3.98	25.9	8.87	3.14	19.6	6.42	MMSE	27	0.93	BDI	8	1.69
		ICD	16	64.38	3.32	11.1	9.63	2.45	19	5.32		27.19	1.11		6.75	1.69
Poletti, 2011	IGT	PD	12	63.92	7.17	16.66	.	.	.	.	MMSE	28.72	2.41	GDS-15	3.33	2.34
		Alexithymia	12	66.17	5.2	41.66	.	.	.	.		28.49	1.94		6.33	3.89
Rossi, 2010	IGT	PD	13	65.1	3.8	23	.	.	14.7	6.7	MMSE	.	.	MADRS	14.1	7.9

		PG	7	61.4	6.9	14	.	.	17	9.1		Excluded if <24	.		17.1	6.5
Sáez-Francàs, 2014	IGT	PD	56	62.64	9.06	32.14	4.31	3.65	18.41	5.82	MMSE	.	.	HAM-D	3.64	3.37
		Fatigue	33	61.73	9.85	39.4	4.94	3.44	20.85	6.31		Excluded if <26	.		8.64	7.06
Timmer, 2017	Rewarded task-switching paradigm	PD	22	61.1	7.6	36.4	.	.	21.9	6.8	MMSE	28.6	1.2	BDI	4.3	2.3
		MDD	19	58.4	5.3	36.8	.	.	.	.		28.5	1.3		8.7	5

PD = Parkinson's disease, HC = healthy controls, IGT = Iowa Gambling Task, ICD = Impulse control disorder, MDD = Major depressive disorder, SD = standard deviation, IQR = interquartile range, '.' = not reported, '**-**' = not applicable, UPDRS = Unified Parkinson's Disease Rating Scale, MMSE = Mini-mental state examination, MoCA = Montreal cognitive assessment, MDRS = Mattis dementia rating scale, BDI = Beck depression inventory, HAM-D = Hamilton depression rating scale, HADS = Hospital anxiety and depression scale ZSRD = Zung Self-Rating Depression scale, DASS = Depression, Anxiety and Stress Scale, GDS = Geriatric depression scale, MADRS = Montgomery-Asberg Depression Rating Scale, SDS = Self-rated depression scale

Supplement table 3. Response Vigor and Reward Bias study characteristics and participant demographics.

Response vigor in Parkinson's vs Healthy Controls				**Age**			**Disease duration**		**UPDRS**		**Cognition**			**Depression**		
Study	**Task**	**Group**	**n**	**Mean**	**SD**	**% female**	**Mean**	**SD**	**Mean**	**SD**	**Cognitive measure**	**Mean**	**SD**	**Depression measure**	**Mean**	**SD**
Muhammed, 2016	Speed of gaze shifting task	PD	16	67.3	6.4	.	3.2	2.2	19.4	9.8	MoCA	27.8	2.3	BDI	11.7	5.5
		HC	31	65.9	5.6	.	-	-	-	-		28.2	1.6		15.2	7.8
Renfroe, 2016	Rewarded speed of response to specific visual stimuli	PD	18	66	7.99	22.2	8.39	4.57	26	9.55	.	.	.	BDI	7.82	4.85
		HC	15	70	6.94	40	-	-	-	-		.	.		1.8	2.44
Timmer, 2018	Stroop-like incentive task switching	PD	23	61	7.4	39.13	4.5	2.2	21.8	6.7	MMSE	28.5	1.3	BDI	4.1	2.3
		HC	23	60.9	5.9	39.13	-	-	-	-		28.8	1.2		3.1	2.1
Response vigor in Parkinson's with psychiatric syndrome vs without				**Age**			**Disease duration**		**UPDRS**		**Cognition**			**Depression**		
Study	**Task**	**Group**	**n**	**Mean**	**SD**	**% female**	**Mean**	**SD**	**Mean**	**SD**	**Cognitive measure**	**Mean**	**SD**	**Depression measure**	**Mean**	**SD**
Drew, 2020	Speed of gaze shifting task	PD	26	67.19	5.92	26.9	4.87	4.09	18.62	9.38	MoCA	27.77	1.95	BDI	13	7.1
		ICD	23	63.7	7.56	47.82	8.71	4.25	24.22	16.94		27.39	2.55		12.26	5.84
Evans, 2010	Card arranging reward responsivity test	PD	20	59.5	7.9	.	13.6	8	19.2	2.5	MMSE	29.1	(27-30)	GDS	9	4.9
		DDS	20	55.4	7.6	.	14	5.7	22.7	2.5		29	(24-30)		17.6	6.4
Lawrence, 2011	Spatial search task	PD	10	59.6	6.4	.	.	.	25.6	11	MMPD	25.6	11	GDS	4.7	2
		Apathy	10	61.7	6.1	.	.	.	28.2	11.4		29.3	2.8		8.2	3.5
Muhammed, 2016	Speed of gaze shifting task	PD	16	65.9	5.6	.	6.8	4.6	18.4	2.6	MoCA	28.2	1.6	BDI	11.7	5.5
		Apathy	14	67.3	6.4	.	3.2	2.2	20.4	2.4		27.8	2.3		15.2	7.8
Timmer, 2018	Stroop-like incentive task switching	PD	23	61	7.4	39.13	4.5	2.2	21.8	6.7	MMSE	28.5	1.3	BDI	4.1	2.3
		Depression	22	58.4	5.7	36.36	5	3.5	23.1	9.6		28.4	1.4		9.6	6.1

PD = Parkinson's disease, HC = healthy controls, ICD = Impulse control disorder, SD = standard deviation, IQR = interquartile range, '.' = not reported, '**-**' = not applicable, UPDRS = Unified Parkinson's Disease Rating Scale, MMSE = Mini-mental state examination, MoCA = Montreal cognitive assessment, MMPD = Mini-mental Parkinson's examination BDI = Beck depression inventory, GDS = Geriatric depression scale

Supplement table 4. Study summary statistics, tasks and measures included in the Meta-Analysis of Parkinson's versus healthy controls.

Reward processing summary statistics for Parkinson's disease patients versus healthy controls													**Tasks and Measures Included in the Meta-Analysis.**	
Author, Year	Category	OFF/ON	N (HC)	N (PD)	t	F	M (HC)	SD (HC)	M (PD)	SD (PD)	d	Vard	Task	Measure
Bayard et al, 2016 (ON)	OV	ON	96	78			6.90	7.65	2.77	8.41	0.52	0.02	Game of dice task	Net score
Chong et al, 2015 (ON)	OV	ON	26	26							-0.35	0.08	Effort based decision making task (apple gathering)	Effort indifference point (mean effect size across stake levels, fig 4)
Chong et al, 2015 (OFF)	OV	OFF	26	26		2.70					0.46	0.08	Effort based decision making task (apple gathering)	Effort indifference point
Brandt et al, 2015 (ON)	OV	ON	15	15			14.93	15.72	-8.67	17.67	1.41	0.17	Game of dice task	Net score (fig 1)
Kobayashi et al, 2019 (ON)	OV	ON	21	15			0.21	0.78	0.30	0.66	0.12	0.11	Economic choice task	Relative risk aversion coefficient (fig 2C, first session)
Kobayashi et al, 2019 (OFF)	OV	OFF	21	15			0.21	0.78	0.97	0.70	1.02	0.13	Economic choice task	Relative risk aversion coefficient (fig 2C, first session)
Le Heron et al, 2018 (ON)	OV	ON	32	18	1.30						0.38	0.09	Effort based decision making task (apple gathering)	Mean difference in proportion of offers accepted
Mcguigan et al, 2018 (ON)	OV	ON	20	20	-0.32						-0.10	0.10	Cognitive effort task	Mean difference in k-value
Mcguigan et al, 2018 (OFF)	OV	OFF	20	20	2.79						0.88	0.11	Cognitive effort task	Mean difference in k-value
Sharp et al, 2013 (ON)	OV	ON	18	18	0.43						0.14	0.07	Vancouver gambling task	Gain phase adjust y intercept
Sharp et al, 2013 (OFF)	OV	OFF	18	18	1.79						0.60	0.07	Vancouver gambling task	Gain phase adjust y intercept
Torta et al, 2009 (ON)	OV	ON	13	15							0.24	0.14	Cambridge gamble task	Average bet (across risk levels)
Torta et al, 2009 (OFF)	OV	OFF	13	15							0.23	0.14	Cambridge gamble task	Average bet (across risk levels)
Cools et al, 2003 (ON)	OV	ON	12	12			54.91	12.09	59.65	16.11	-0.33	0.17	Incentivised decision making task	Mean % bets across ascending & descending conditions
Cools et al, 2003 (OFF)	OV	OFF	12	12			54.91	12.09	58.95	15.73	-0.29	0.17	Incentivised decision making task	Mean % bets across ascending & descending conditions
Le Bouc et al, 2016 (ON)	OV	ON	25	24			80.89	7.75	78.56	12.49	0.23	0.08	Effort based decision making task: Binary choice task	Choice of effort level at the highest stake level. (fig 4D)
Le Bouc et al, 2016 (OFF)	OV	OFF	25	24	3.51						1.00	0.09	Effort based decision making task: Binary choice task	Choice of effort level at the highest stake level. (fig 4D)
Castrioto et al, 2015 (ON)	RL	ON	24	20			4.38	40.22	-1.79	44.72	0.15	0.09	Iowa Gambling Task	Baseline final round mean score. (fig 1A)
Castrioto et al, 2015 (OFF)	RL	OFF	24	20			4.38	40.22	0.98	40.34	0.08	0.09	Iowa Gambling Task	Baseline final round mean score. (fig 1A)
Balusubramani et al, 2015 (ON)	RL	ON	20	14			64.10	84.84	61.54	78.69	0.03	0.12	Probabilistic rewarded categorisation learning task	% Optimality during expected reward (fig 3A)
Balusubramani et al, 2015 (OFF)	RL	OFF	20	26			64.10	84.84	43.07	99.38	0.23	0.09	Probabilistic rewarded categorisation learning task	% Optimality during expected reward (fig 3A)
Bodi et al, 2009 (ON)	RL	Medicated	20	22			81.18	18.43	89.18	17.12	-0.45	0.10	Feedback-based probabilistic classification task	Final block % optimal decisions (fig 2)
Bodi et al, 2009 (Never medicated)	RL	Never medicated	20	26			81.18	18.43	59.53	18.61	1.17	0.10	Feedback-based probabilistic classification task	Final block % optimal decisions (fig 2)
Buelow et al, 2014 (ON)	RL	ON	14	24							1.38	0.14	Iowa Gambling Task	Final block score (authors provided)

Piray et al, 2014 (ON)	RL	ON	20	15			0.12	0.16	0.14	0.20	-0.10	0.12	Probabilistic learning task	Actor's learning rate (fig 6C)
Piray et al, 2014 (OFF)	RL	OFF	20	25			0.12	0.16	0.08	0.13	0.29	0.09	Probabilistic learning task	Actor's learning rate (fig 6C)
Yildirim et al, 2020 (ON)	RL	ON	37	39			0.65	5.72	-0.11	5.77	0.13	0.05	Iowa Gambling Task	Final block mean score (author provided)
Gescheidt et al, 2012 (ON)	RL	ON	20	19			10.30	29.42	-6.00	25.26	0.59	0.11	Iowa Gambling Task	Mean total score
Herzallah et al, 2017 (ON)	RL	ON	15	17			76.49	17.36	72.10	16.62	0.26	0.13	Feedback-based probabilistic classification task	Mean % optimal responses for positive feedback (fig 5A)
Housden et al, 2010 (ON)	RL	ON	20	18			56.50	22.40	27.00	19.10	1.41	0.13	Salience Attribution Test	Visual analogue scale rating for high probability stimuli
Mapelli et al, 2014 (ON)	RL	ON	15	15			9.81	10.19	4.74	5.11	0.63	0.14	Iowa Gambling Task	Final block mean score (fig 1)
Mimura et al, 2006 (ON)	RL	ON	20	18			3.70	7.35	-0.33	6.59	0.58	0.11	Iowa Gambling Task	Final 50 cards mean score
Pagonabarraga et al, 2007 (ON)	RL	ON	31	35			6.10	17.00	-10.80	19.00	0.93	0.07	Iowa Gambling Task	Mean total score
Paz-Alonso et al, 2019 (ON)	RL	ON	18	17			40.60	18.82	41.80	15.38	-0.07	0.11	Iowa Gambling Task	Mean difference % optimal choice, final block. (supplement fig 1)
Garofalo et al, 2017 (ON)	RL	ON	24	17			21.50	5.26	15.15	6.68	1.08	0.11	Instrumental conditioning task	Reward learning index (fig 2B)
Czernecki et al, 2002 (ON)	RL	ON	28	23			8.32	11.06	2.86	16.59	0.40	0.08	Iowa Gambling Task	Final block mean score (fig 1, second session)
Czernecki et al, 2002 (OFF)	RL	OFF	28	23			8.32	11.06	5.36	10.89	0.27	0.08	Iowa Gambling Task	Final block mean score (fig 1, second session)
Graef et al, 2010 (ON)	RL	ON	15	14	1.80		68.49	14.07	60.07	11.08	0.67	0.15	Instrumental learning task	% correct choices with constant reward contingencies
Graef et al, 2010 (OFF)	RL	OFF	15	14	2.19		68.49	14.07	59.05	8.86	0.81	0.15	Instrumental learning task	% correct choices with constant reward contingencies
Thiel et al, 2003 (OFF)	RL	OFF	5	5			53.6	15.8	61.2	17.1	-0.46	0.41	Iowa Gambling Task	Mean number of advantageous cards selected.
Perretta et al, 2005 (late PD)	RL	ON late PD	19	16			7.80	1.31	6.80	1.60	0.69	0.12	Iowa Gambling Task	Mean total score
Perretta et al, 2005 (early PD)	RL	ON early PD	19	16			7.80	1.31	7.60	1.60	0.14	0.12	Iowa Gambling Task	Mean total score
Kobayakawa et al, 2008 (ON)	RL	ON	22	34		4.80	4.90	12.20	-16.00	21.57	0.60	0.08	Iowa Gambling Task	Group difference in choice patterns (advantageous - disadvantageous)
Kobayakawa et al, 2010 (ON)	RL	ON	22	14		2.96					0.59	0.12	Iowa Gambling Task	Group difference in choice patterns (advantageous - disadvantageous)
Poletti et al, 2010 (OFF)	RL	OFF (de novo)	25	30			6.00	6.82	3.07	12.07	0.29	0.07	Iowa Gambling Task	Mean total score
Delazer et al, 2009 (ON)	RL	ON	20	20		8.81					0.94	0.11	Iowa Gambling Task	Group difference in choice patterns (advantageous - disadvantageous)
Euteneuer et al, 2009 (ON)	RL	ON	23	21		0.65					0.24	0.09	Iowa Gambling Task	Group difference in choice patterns (advantageous - disadvantageous)
Ibarretxe-Bilbao et al, 2009 (ON)	RL	ON	24	24		14.56					1.10	0.10	Iowa Gambling Task	Group difference in choice patterns (advantageous - disadvantageous)
Pignatti et al, 2012 (ON)	RL	ON	16	15			12.50	14.87	7.47	16.06	0.33	0.13	Iowa Gambling Task	Total score over the last 50 choices
Evens et al, 2015 (ON)	RL	ON	32	32			-7.31	20.78	-2.09	16.27	-0.28	0.06	Iowa Gambling Task	Mean total score

Xi et al, 2015 (ON)	RL	ON	15	15		10.67					1.19	0.16	Iowa Gambling Task	Group difference in choice patterns (advantageous - disadvantageous)
Cavanagh et al, 2017 (ON)	RL	ON	28	28	-1.64						-0.44	0.07	Cost of conflict task	% selection of most (A) vs least (D) rewarding stimuli
Cavanagh et al, 2017 (OFF)	RL	OFF	28	28	-1.44						-0.38	0.07	Cost of conflict task	% selection of most (A) vs least (D) rewarding stimuli
Muhammed et al, 2016 (ON)	RV	ON	31	30	5.50						0.60	0.07	Rewarded speed of gaze shifting task	Reward sensitivity in peak velocity
Timmer et al, 2018 (ON)	RV	ON	23	23			5.00	4.50	14.40	4.40	-2.11	0.14	Rewarded task switching paradigm	Reward related speeding 'repeat' condition
Timmer et al, 2018 (OFF)	RV	OFF	23	23			5.00	4.50	3.80	4.70	0.26	0.09	Rewarded task switching paradigm	Reward related speeding 'repeat' condition

Supplement table 5. Study summary statistics, tasks and measures included in the Meta-Analysis of Parkinson's with & without psychiatric syndrome

Reward processing summary statistics for Parkinson's disease versus Parkinson's disease plus psychiatric syndrome													**Tasks and Measures Included in the Meta-Analysis.**	
Author, Year	Category	Psychiatric syndrome	N (PD)	N (PD+PSYCH)	t	F	M (PD)	SD (PD)	M (PD +Psych)	SD (PD+Psych)	d	Vard	Task	Measure
Balusubramani et al, 2015 (ON)	RL	ICD	14	16			61.54	78.69	78.97	61.56	-0.25	0.13	Probabilistic reward and punishment learning task	% Optimality during expected reward (fig 3A)
Piray et al, 2014 (ON)	RL	ICD	15	16			0.135	0.198	0.067	0.06	0.47	0.13	Probabilistic learning task	Actor's learning rate (fig 6C)
Housden et al, 2010 (ON)	RL	ICD	18	18			27	19.1	42.7	19.7	-0.81	0.12	Salience Attribution Test	Visual analogue scale rating for high probability stimuli
Biars et al, 2019 (ON)	RL	ICD	24	24			3.5	9.7	2.75	8.2	0.08	0.08	Iowa Gambling Task	Final block score (authors provided)
Balconi et al, 2018 (ON)	RL	PG	20	17		7.60					0.91	0.12	Iowa Gambling Task	Group difference in choice patterns (advantageous - disadvantageous)
Paz-Alonso et al, 2019 (ON)	RL	ICD	17	18			41.80	15.38	27.00	13.94	1.01	0.13	Iowa Gambling Task	Mean difference % optimal choice, final block. (supplement fig 1)
Pineau et al, 2016 (ON)	RL	ICD	20	17			15.00	15.56	14.00	9.63	0.08	0.11	Iowa Gambling Task	Mean number of cards selected from winning deck
Bentivoglio et al, 2012 (ON)	RL	ICD	17	17			8.40	22.10	-4.60	33.10	0.46	0.12	Iowa Gambling Task	Mean total score
Rossi et al, 2010 (ON)	RL	PG	13	7	2.60						1.22	0.26	Iowa Gambling Task	Final block mean net score
Garofalo et al, 2017 (ON)	RL	Psychosis	17	12			15.15	6.68	8.67	8.34	0.88	0.16	Instrumental conditioning task	Reward learning index (fig 2B)
Sáez-Francàs et al, 2014 (ON)	RL	Fatigue	56	33			1.79	14.80	-4.18	11.13	0.44	0.05	Iowa Gambling Task	Final three blocks mean net score
Martinez-Horta et al, 2013 (ON)	RL	Apathy	17	20			-1.82	5.80	4.10	4.80	-1.12	0.13	Iowa Gambling Task	Final block score
Buelow et al, 2014 (ON)	RL	Apathy	14	10			22.12	16.80	-24.00	14.87	2.88	0.34	Iowa Gambling Task	Final block score (authors provided)
Herzallah et al, 2017 (ON)	RL	MDD	17	13			72.10	16.62	49.30	22.14	1.19	0.16	Feedback-based probabilistic classification task	Mean % optimal responses for positive feedback (fig 5A)
Timmer et al, 2017 (ON)	RL	MDD	22	19			0.10	0.06	0.07	0.06	-0.50	0.10	Deterministic reversal learning paradigm	Error rate for expected reward

Poletti et al, 2011 (OFF)	RL	Alexithymia	12	12			4.17	8.37	3.00	6.35	0.16	0.17	Iowa Gambling Task	Final block score
Kobayashi et al, 2019 (ON)	OV	ICD	15	10			0.30	0.66	-0.19	0.17	-0.93	0.18	Economic choice task	Relative risk aversion coefficient (fig 2C, first session)
Le Heron et al, 2018 (ON)	OV	Apathy	18	21	2.33						0.75	0.11	Effort based decision making task (apple gathering)	Mean difference in proportion of offers accepted
Voon et al, 2011 (ON)	OV	ICD	14	14							-0.68	0.14	Gambling task	Proportion of risky choices in gain phase (across risk levels, fig 2A)
Timmer et al, 2018 (ON)	RV	MDD	23	22			14.40	4.40	17.70	3.90	-0.79	0.10	Rewarded task-switching paradigm	Reaction time reward benefit (repeat)
Evans et al, 2010 (ON)	RV	DDS	20	20		12.7					-1.13	0.12	Card arranging reward responsivity objective test	Reward responsivity
Drew et al, 2020 (ON)	RV	ICD	26	23		2.78					-0.48	0.08	Rewarded speed of gaze shifting task	Residual velocity reward sensitivity
Lawrence et al, 2011 (ON)	RV	Apathy	10	10		0.38					0.20	0.28	Rewarded spatial search task	Reward related speeding

Supplement table 6. Study summary statistics, tasks and measures included in the Meta-Analysis of Parkinson's on and off dopaminergic medication

Reward processing summary statistics for Parkinson's disease patients ON vs OFF dopaminergic medication							**Tasks and Measures Included in the Meta-Analysis.**	
Author, Year	Category	N	t	F	d	Vard	Task	Measure
Czernecki et al, 2002	RL	22		0.05	0.048	0.046	Iowa Gambling Task	Number of advantageous minus disadvantageous choices
Graef et al, 2010	RL	14	-0.374		-0.100	0.072	Instrumental learning task	% correct choices with constant reward contingencies
Cavanagh et al, 2017	RL	28		2.87	0.320	0.0375	Value of volition task	% selection of A (90% reward) vs C (70% reward) – B (10% reward) vs D (30% reward) stimuli
Bodi et al, 2009	RL	26		13.47	0.720	0.0385	Feedback-based probabilistic classification task	Pattern of optimal decision selection over time
Chong et al, 2015	OV	26		25.9	0.998	0.058	Effort based decision making task (apple gathering)	Effort indifference point
Kobayashi et al, 2019	OV	24		7.48	0.558	0.048	Economic choice task	Relative risk aversion coefficient
Le Heron et al, 2018	OV	39	2.45		0.392	0.028	Effort based decision making task (apple gathering)	Mean difference in proportion of offers accepted
Mcguigan et al, 2018	OV	20	3.05		0.682	0.062	Cogntiive effort task	Mean difference in k-value
Cools et al, 2003	OV	12		5.9	0.701	0.104	Incentivised decision making task	Difference score of bets places in ascending and descending conditions.
Le Bouc et al, 2016	OV	20	2.76		0.617	0.060	Effort based decision making task: Binary choice task	Choice of effort level at the highest stake level.
Sharp et al, 2013	OV	18	1.17		0.276	0.058	Vancouver gambling task	Adjusted y intercept
Timmer et al, 2018	RV	23		3.031	0.363	0.046	Rewarded task switching paradigm	Reward related speeding 'repeat' condition
Muhammed et al, 2016	RV	30		10.8	0.600	0.039	Rewarded speed of gaze shifting task	Reward sensitivity in peak velocity
Evans et al, 2010	RV	38		0.4	0.103	0.026	Card arranging reward responsivity objective test	Reward responsivity
Drew, 2020	RV	26		5.178	0.446	0.042	Rewarded speed of gaze shifting task	Residual velocity reward sensitivity

Modified version of the Newcastle-Ottawa Scale for Assessing the Quality of Nonrandomized Studies in Meta-Analyses, used to assess potential sources of bias.

Potential sources of bias were assessed using a modified version of the Newcastle-Ottawa Scale for Assessing the Quality of Nonrandomized Studies in Meta-Analyses. The studies are scored on:

1. PD Definition: Is the case definition adequate?

A) Cases were defined as PD according to a validated assessment tool/criteria or by an experienced clinician
B) Cases were defined as PD according to a validated assessment tool/criteria but the method for assessing PD status was not stated.
C) Cases were described as 'clinically' but no further description was given.

2. PD Generality: Was a General sample of cases tested?

A) A General sample of PD was tested.
B) Recruitment of PD cases was restricted to a specific sub-sample (specific age range, hospitalised only etc.)

3. HC Selection: Selection of Controls

A) Controls were selected from the same population as cases
B) Controls were not selected from the same population as cases
C) No description

4. HC Definition: Definition of Controls

A) HC were defined clearly defined as having no current or past psychopathology
B) Controls were not clearly defined as having no current or past psychopathology.

Comparability (Comparability of cases and controls on the basis of the design or analysis)

1. Does the study control for Age: Yes/No/Unclear
2. Does the study control for Gender: Yes/No/Unclear
3. Does the study control for IQ: Yes/No/Unclear
4. Does the study control for Socioeconomic status: Yes/No/Unclear
5. Does the study control for PD severity: Yes/No/Unclear
6. Does the study control for medication status: Yes/No/Unclear

Key: A, B, C
Y = yes, N= no, N/A= Not applicable (such as if no healthy control group in study)

Supplement table 7. Quality rating of included studies

Study quality ratings			Modified version of the Newcastle-Ottawa Scale									
Study	**Year**	**Category**	**PD Definition**	**PD Generality**	**HC Selection**	**HC Definition**	**Age**	**Gender**	**IQ**	**Socioeconomic status**	**PD severity**	**PD medication**
Bayard[1]	2016	OV	A	A	B	A	Y	Y	N	N	Y	Y
Brandt[2]	2015	OV	A	A	C	B	Y	Y	N	N	Y	Y
Chong[3]	2015	OV	B	A	A	A	Y	Y	N	N	Y	Y
Cools[4]	2003	OV	A	A	C	B	Y	N	Y	N	Y	Y
Haagensen[5]	2020	OV	C	A	A	B	Y	Y	N	N	Y	Y
Kobayashi[6]	2019	OV	A	A	C	B	Y	Y	N	N	Y	Y
Le Bouc[7]	2016	OV	C	B	A	B	Y	Y	N	N	Y	Y
Le Heron[8]	2018	OV	A	A	A	A	Y	Y	N	N	Y	Y
Mcguigan[9]	2018	OV	A	A	A	A	Y	Y	N	N	Y	Y
Torta[10]	2009	OV	A	B	C	B	Y	Y	N	N	Y	Y
Sharp[11]	2013	OV	A	A	C	B	Y	N	N	N	Y	Y
Voon[12]	2011	OV	A	A	n/a	n/a	Y	Y	N	N	Y	Y
Balconi[13]	2018	RL	A	A	n/a	n/a	Y	N	N	N	Y	Y
Balusubramani[14]	2015	RL	C	A	C	A	N	N	N	N	Y	Y
Bentivoglio[15]	2012	RL	A	A	n/a	n/a	Y	Y	Y	N	Y	Y
Biars[16]	2019	RL	C	B	n/a	n/a	Y	Y	Y	N	N	Y
Bodi[17]	2009	RL	C	B	C	A	Y	N	Y	Y	Y	Y
Buelow[18]	2014	RL	A	A	A	A	Y	Y	Y	N	Y	Y
Castrioto[19]	2015	RL	C	B	C	B	Y	Y	N	N	Y	Y
Cavanagh[20]	2017	RL	C	A	C	B	Y	Y	Y	N	Y	Y
Czernecki[21]	2002	RL	A	B	B	A	Y	Y	N	N	Y	Y
Delazer[22]	2009	RL	A	A	C	A	Y	Y	N	N	Y	Y
Euteneuer[23]	2009	RL	C	A	C	B	Y	Y	N	N	Y	Y
Evens[24]	2015	RL	A	A	A	A	Y	Y	N	N	Y	Y
Garofalo[25]	2017	RL	A	A	C	B	Y	Y	Y	N	Y	Y
Gescheidt[26]	2012	RL	A	A	C	A	Y	Y	N	N	Y	Y
Graef[27]	2010	RL	A	B	B	A	Y	Y	N	N	Y	Y
Herzallah[28]	2017	RL & RV	B	A	A	A	Y	N	N	N	Y	N
Housden[29]	2010	RL	C	A	A	A	Y	Y	Y	N	Y	Y
Ibarretxe-Bilbao[30]	2009	RL	A	A	A	B	Y	Y	N	N	Y	Y
Kobayakawa[31]	2008	RL	C	A	A	A	Y	Y	N	N	Y	Y
Kobayakawa[32]	2010	RL	C	A	A	A	Y	Y	N	N	Y	Y
Mapelli[33]	2014	RL	A	A	A	A	Y	Y	N	N	Y	Y
Martinez-Horta[34]	2013	RL	A	A	n/a	n/a	Y	N	N	N	Y	Y
Mimura[35]	2006	RL	C	A	B	A	Y	Y	N	N	Y	Y
Pagonabarraga[36]	2007	RL	A	A	A	A	Y	Y	N	N	Y	Y
Paz-Alonso[37]	2019	RL	A	A	A	B	Y	Y	Y	N	Y	Y
Perretta[38]	2005	RL	A	A	A	A	Y	Y	N	N	Y	Y
Pignatti[39]	2012	RL	A	B	C	B	N	N	N	N	N	N
Pineau[40]	2016	RL	A	A	n/a	n/a	Y	Y	N	N	Y	Y
Piray[41]	2014	RL	C	B	C	A	Y	N	Y	N	Y	N
Poletti[42]	2010	RL	A	A	C	B	Y	Y	N	N	Y	Y
Poletti[43]	2011	RL	A	B	n/a	n/a	Y	Y	N	N	N	Y
Rossi[44]	2010	RL	A	A	n/a	n/a	Y	Y	N	N	Y	Y
Sáez-Francàs[45]	2014	RL	C	A	n/a	n/a	Y	Y	N	N	Y	N
Thiel[46]	2003	RL	C	A	C	A	Y	N	N	N	Y	Y
Timmer[47]	2017	RL	A	A	A	A	Y	Y	Y	N	Y	Y
Xi[48]	2015	RL	A	B	C	B	Y	Y	N	N	Y	Y

Yildirim[49]	2020	RL	A	A	B	A	Y	Y	N	N	Y	Y
Drew[50]	2020	RV	A	B	C	A	Y	Y	N	N	Y	Y
Evans[51]	2010	RV	A	A	B	B	Y	Y	N	N	Y	Y
Lawrence[52]	2011	RV	A	A	n/a	n/a	Y	N	N	N	Y	Y
Muhammed[53]	2016	RV	C	A	B	B	Y	Y	Y	N	Y	N
Renfroe[54]	2016	RV	B	B	A	A	Y	Y	N	N	Y	Y
Timmer[55]	2018	RV	A	A	A	B	Y	N	Y	N	Y	Y

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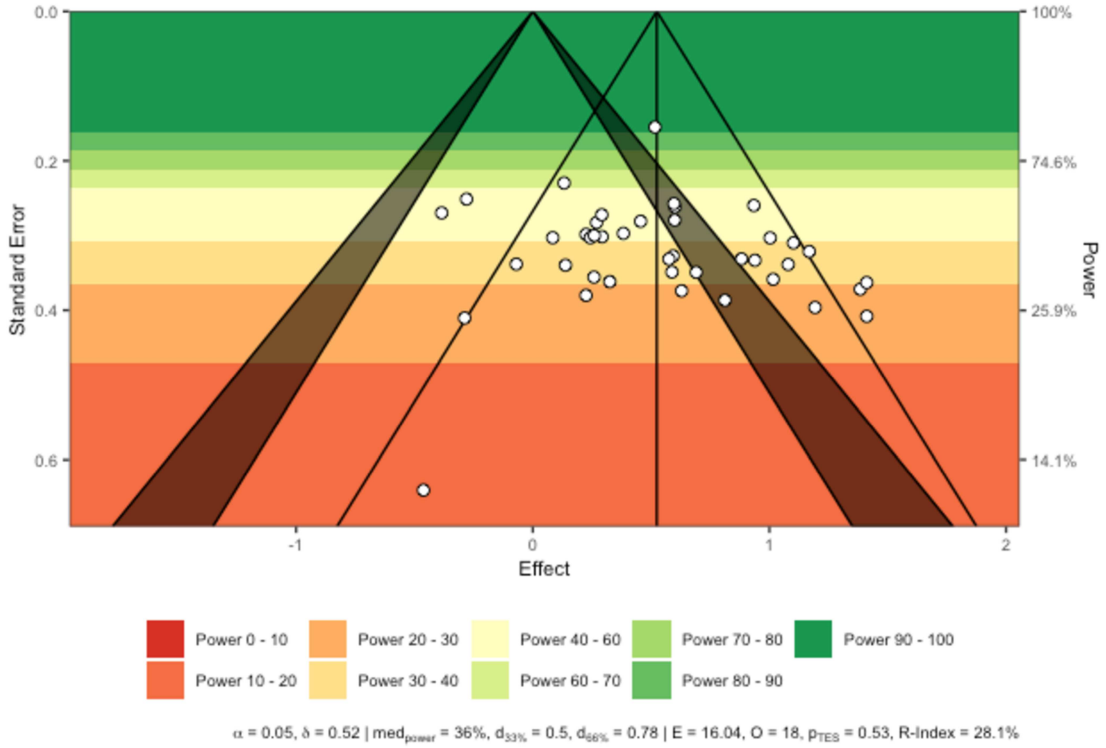
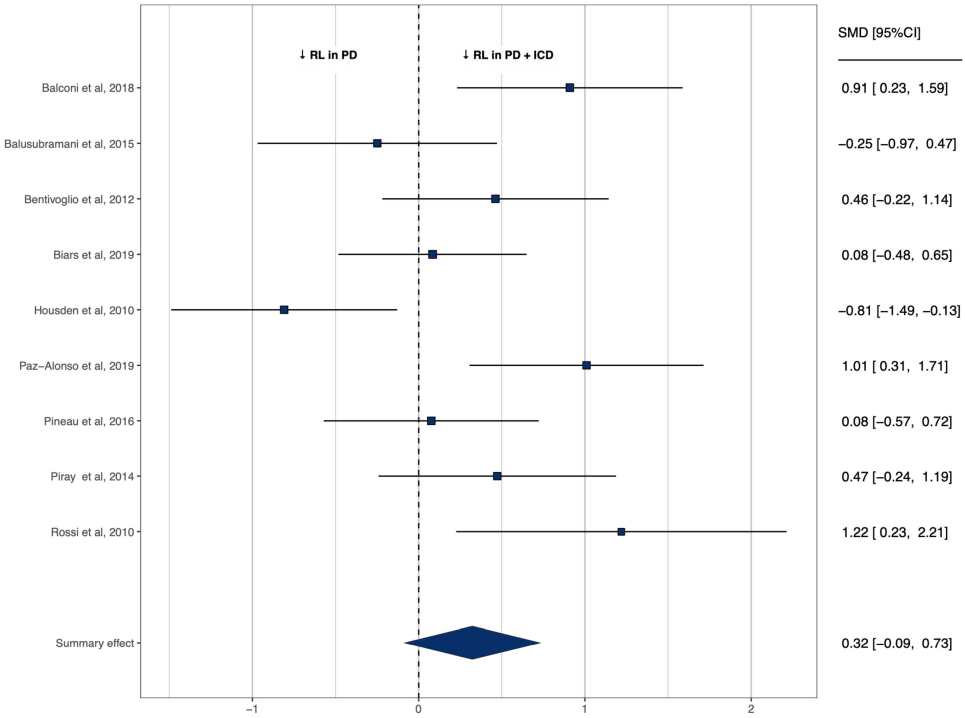
Supplement figure 1. Contour-Enhanced Funnel Plot of all studies Parkinson's versus healthy controls



Supplement figure 2. Forest plot of reinforcement learning (RL) in Parkinson's patients with and without Impulse Control Disorder (ICD)



Formulae used to convert study measures into Cohen's ds and associated variances.

The following formulae were used to convert study measures into Cohen's ds and associated variances **between subjects:**

$$d = \frac{M_1 - M_2}{SD_{pooled}}$$

Equation 1. Cohen's d from Means and Standard Deviations of 2 samples. d is Cohen's d, M1 is the mean of one sample M2 is the mean of the other sample, SDpooled is the pooled standard deviation of the two samples (please see below.)

$$SD_{pooled} = \sqrt{(N_1 - 1)SD_1^2 + (N_2 - 1)SD_2^2}$$

Equation 2. Pooled standard deviation of 2 samples. SDpooled is the pooled standard deviation of the two samples, N1 is the size of one sample N2 is the size of the other sample, SD1 is the standard deviation of one sample, SD2 is the standard deviation of the other sample.

$$d = \frac{t}{\sqrt{\frac{1}{\frac{1}{N_1} + \frac{1}{N_2}}}}$$

Equation 3. Cohen's d from t-statistic. d is Cohen's d, N1 is the size of one sample N2 is the size of the other sample, t is the t-statistic

$$d = \frac{F}{\sqrt{\frac{1}{\frac{1}{N_1} + \frac{1}{N_2}}}}$$

Equation 4. Cohen's d from F-statistic. d is Cohen's d, N1 is the size of one sample N2 is the size of the other sample, F is the F-statistic.

$$Var_d = \frac{N_1 + N_2}{N_1 \times N_2} + \frac{d^2}{2(N_1 + N_2)}$$

Equation 5. Variance on Cohen's d for between subjects. Vard is the Variance on Cohen's d, N1 is the size of one sample N2 is the size of the other sample, d is Cohen's d.

The following formulae were used to convert study measures into Cohen's ds and associated variances **within subjects:**

$$d = \frac{M_d}{SD_d}$$

Equation 6. Cohen's d from Means and Standard Deviations from within subjects sample. Where M_d is the mean change and SD_d is the SD of the change scores
(equal to $SD_d = \sqrt{SD_1^2 + SD_2^2 - 2 \times r \times SD_1 SD_2}$).

$$d = \frac{t}{\sqrt{N}}$$

Equation 7. Cohen's d from t-statistic for within subjects results. d is Cohen's d, N is the sample size, t is the t-statistic

$$d = \sqrt{\frac{F}{N}}$$

Equation 8. Cohen's d from F-statistic. d is Cohen's d, N is the sample size, F is the F-statistic.

$$Var[d] = \frac{1}{n} + \frac{d^2}{2n}$$

Equation 9. Variance on Cohen's d for within subjects, n is the size of the sample.

Supplement table 1. Option Valuation study characteristics and participant demographics.

Option valuation in Parkinson's vs Healthy Controls				Age (years)			Disease duration (years)		UPDRS		Cognition			Depression		
Study	Task	Group	n	Mean	SD	% female	Mean	SD	Mean	SD	Cognitive measure	Mean	SD	Depression measure	Mean	SD
Bayard, 2016	Game of dice task	PD	78	67.49	8.16	35	7	.	24	(5-80)	MMSE	28.1	1.93	BDI	12.5	7.38
		HC	96	67.95	6.75	32	-	-	-	-		28.46	1.38		10.04	11.76
Brandt, 2015	Game of dice task	PD	15	64.78	8.09	46.66	.	.	14.43	10.14	MoCA	26.87	1.69	GDS-15	3.33	3.54
		HC	15	62.39	10.04	40	-	-	-	-		27.6	1.43		1.33	1.18
Chong, 2015	Effort based decision making task	PD	26	66.6	6.8	34.6	.	.	21.6	11.7	MoCA	28.2	1.3	DASS	2	2.23
		HC	26	66.2	6.4	42.3	-	-	-	-		28.2	1.7		1.5	1.84
Cools, 2003	Decision making gambling task	PD	12	64.6	1.5	58.33	6.5	1.4	30.9	6.8	MMSE	29.5	0.15	BDI	7.7	1.1
		HC	12	.	.	.	-	-	-	-		.	.		.	.
Kobayashi, 2019	Economic choice task	PD	15	63	6.58	40	6.93	6.2	39	14.6	MMSE	28.3	1.76	.	.	.
		HC	21	60	6.69	57.1	-	-	-	-		28.7	1.99		.	.
Le Bouc, 2016	Incentivised grip force choice task	PD	24	60.2	1.6	29.17	11.4	1.3	11.7	1.7	MMSE	27.3	1.3	MADRS	5.9	1
		HC	25	57	2.1	52	-	-	-	-		.	.		2.9	0.7
Le Heron, 2018	Effort based decision making task	PD	39	67.8	7.6	19.04	.	.	29.5	9.9	ACE	91.1	7.9	BDI	14.3	7.7
		HC	32	68.9	6.9	40.6	-	-	-	-		95.6	3.8		3.8	3.7
Mcguigan, 2018	Cognitive effort task	PD	20	67.1	9.1	40	5.4	4.9	27.3	18.1	MoCA	27.7	1.92	BDI	9.5	4.98
		HC	20	61.1	13.6	40	-	-	-	-		28.1	1.37		3.55	4.13
Torta, 2009	Cambridge gamble task	PD	15	58.4	6.9	13.33	13.2	3.2	16.52	7.5	MMSE	28.2	1.5	BDI	10	6.6
		HC	13	58.2	5.7	15.38	-	-	-	-		.	.		.	.
Sharp, 2013	Vancouver gambling task (modified)	PD	18	65.47	9.17	27.78	5.59	4.04	20.65	6.91	MOCA	27.94	1.14	BDI	6.06	3.78
		HC	18	66.76	5.83	50	-	-	-			28.85	1.32		5.18	3.57
Option valuation in Parkinson's with psychiatric syndrome vs without				**Age (years)**			**Disease duration (years)**		**UPDRS**		**Cognition**			**Depression**		
Study	**Task**	**Group**	**n**	**Mean**	**SD**	**% female**	**Mean**	**SD**	**Mean**	**SD**	**Cognitive measure**	**Mean**	**SD**	**Depression measure**	**Mean**	**SD**
Haagensen, 2020	Game of dice task	PD	13	61.4	9.7	46.15	4.5	2	22.8	6.9	MoCA	28.7	1.3	BDI	7	5
		ICD	13	59.4	10.9	38.46	6.5	3.6	22.6	6		28.7	0.9		7.4	6.5
Kobayashi, 2019	Economic choice task	PD	15	63	6.58	40	6.93	6.2	39	14.6	MMSE	28.3	1.76	.	.	.
		ICD	10	63.1	9.68	40	8.4	2.99	49.9	26.3		28.3	1.77	.	.	.
Le Heron, 2018	Effort based decision	PD	18	68.2	6.5	44.44	.	.	27.1	13.2	ACE	93.5	5	BDI	11	7
		Apathy	21	67.5	8.5	19.05	.	.	29.5	9.9		89.4	9.4		17.1	7.4

Voon, 2011	Gambling task	PD	14	54.5	12.5	71.4	.	.	.	.	.	.	.	.	.	.	.
		ICD	14	51.5	8.3	71.4	.	.	.	.	.	.	.	.	.	.	.

PD = Parkinson's disease, HC = healthy controls, ICD = Impulse control disorder, SD = standard deviation, IQR = interquartile range, '.' = not reported, '-' = not applicable, UPDRS = Unified Parkinson's Disease Rating Scale, MMSE = Mini-mental state examination, MoCA = Montreal cognitive assessment, ACE = Addenbrooke's cognitive examination, BDI = Beck depression inventory, DASS = Depression, Anxiety and Stress Scale, GDS = Geriatric depression scale, MADRS = Montgomery-Asberg Depression Rating Scale

Supplement table 2. Reinforcement Learning study characteristics and participant demographics.

Reinforcement learning in Parkinson's vs Healthy Controls				Age (years)			Disease duration (years)		UPDRS		Cognition			Depression		
Study	**Task**	**Group**	**n**	**Mean**	**SD or (IQR)**	**% female**	**Mean**	**SD or (IQR)**	**Mean**	**SD or (IQR)**	**Measure**	**Mean**	**SD or (IQR)**	**Measure**	**Mean**	**SD or (IQR)**
Castrioto, 2015	IGT	PD	20	53.2	6.6	45	10.3	3.8	12.3	6.1	MDRS	137.6	4.2	.	.	.
		HC	24	54.9	7.6	62.5	-	-	-	-		140.7	2.4		.	.
Balusubramani, 2015	Probabilistic rewarded categorisation learning task	PD	30	.	.	18.75	9.5	.	.	.	MMSE	.	.	BDI	.	.
		HC	20	.	.	13.04	-	-	-	-					.	.
Bodi, 2009	Probabilistic classification task	PD	22	44.8	5.2	30.77	0.266	0.166	27.5	6.1	.	.	.	HAM-D	4.2	1.4
		HC	20	45.3	8.5	25	-	-	-	-		.	.		.	.
Buelow, 2014	IGT	PD	24	68.04	7.86	45.8	.	.	29.89	13.14	MMSE	28.33	1.63	GDS	2.5	1.91
		HC	14	69.62	6.36	53.85	-	-	-	-		29.31	1.11		1.15	1.57
Cavanagh, 2017	Cost of conflict task	PD	28	69.75	8.59	39.28	5.54	4.18			MMSE	28.64	1.06	BDI	7.64	5.23
		HC	28	69.21	9.23	39.28	-	-	-	-		28.82	1.02		4.93	4.69
Czernecki, 2002	IGT	PD	23	57.6	2.1	60.87	14.9	1.2	12.4	2	MDRS	139.1	0.8	MADRS	8.3	1.4
		HC	28	58.1	1.7	35.71	-	-	-	-		141.1	0.3		6.2	0.8
Delazer, 2009	IGT	PD	20	68.5	5.9	25	5.25	6.38	17.6	8.7	MMSE	27.8	1.9	HADS	6.6	3.2
		HC	20	71.3	3.5	85	-	-	-	-		29.8	0.4		.	.
Euteneuer, 2009	IGT	PD	21	67.6	7.31	67	7.14	6.06	17.7	9.2	MMSE	29	1.1	BDI	3.9	2.12
		HC	23	64.4	8.56	48						29.65	0.65		0.83	1.3
Evens, 2015	IGT	PD	32	65.12	8.25	25	7.38	4.33	16.58	7.36	MMSE	29.25	0.98	MADRS	4.33	3.68
		HC	32	65.53	5.94	31	-	-	-	-		29.34	0.83		1.59	2.19
Garofalo, 2017	Instrumental conditioning task	PD	17	63.29	9.94	50	16.42	28.77	.	.	MMSE	28.41	1.37	BDI	12.66	7.83
		HC	24	61.91	5.83	44	-	-	-	-		28.94	1.54		8.88	4.94
Gescheidt, 2012	IGT	PD	19 (early onset)	50.32	8.74	25	11.32	6.42	14.6	8.7	MMSE	29.37	0.96	MADRS	.	.
		HC	20	49.95	9.03	26.3	-	-	-	-		29.7	0.47		.	.
Graef, 2010		PD	15	65.27	8.14	40	4.3	4	19.64	7.7	MMSE	29	1	BDI	6.93	5.55

	Probabilistic reversal learning task	HC	16	67.75	4.55	37.5	-	-	-	-		28.64	1.15		5.31	2.98
Herzallah, 2017	Rewarded categorisation task	PD	17	59.4	12.6	11.76	5.24	4	28.6	14.6	MMSE	28.5	1.1	BDI	8.3	5.2
		HC	15	54.3	12.3	33.33	-	-	-	-		29.3	0.7		6.7	5.3
Housden, 2010	Rewarded salience attribution test	PD	18	67.7	5.5	38.89	12.9	8.3	20	6.6	MMSE	28.6	2.1	BDI	12.9	9.9
		HC	20	65.5	6	33.33	-	-	-	-		29.4	0.8		11.3	6.9
Ibarretxe-Bilbao, 2009	IGT	PD	24	56.13	8.5	33	3.06	1.6	14.67	3.5	MMSE	29.63	0.5	BDI	.	.
		HC	24	57.58	8.9	33	-	-	-	-		29.83	0.4			
Kobayakawa, 2008	IGT	PD	34	69.9	8.9	64.7	6.4	3.4	.	.	MMSE	28	2.2	SDS	36.1	8.9
		HC	22	67.6	6.9	40.9	-	-	-	-		28.8	1.6		29.1	6
Kobayakawa, 2010	IGT	PD	14	68.9	8	50	5.6	2.7	.	.	MMSE	28.2	1.9	SDS	32.9	7.8
		HC	22	67.6	6.9	69.2	-	-	-	-		28.8	1.6		29.1	6
Mapelli, 2014	IGT	PD	15	61.4	9.6	25	4.8	3.4	8.9	4	MMSE	28.3	1.2	BDI	Excluded if >14	
		HC	15	60.7	9.8	26.7	-	-	-	-		27.86	1.5		.	.
Mimura, 2006	IGT	PD	18	68.9	7	72.2	.	.	.	.	MMSE	27.8	1.9	ZSRD	39.4	6.9
		HC	20	.	.	70	-	-	-	-		29.1	1.5		30.5	6
Pagonabarraga, 2007	IGT	PD	35	67.2	8	37.2	8.4	5	21.2	8	MDRS	133	6	.	.	.
		HC	31	70.2	10	47.7	-	-	-	-		136	5		.	.
Paz-Alonso, 2019	IGT	PD	17	61	8.7	11.8	7	(4-10)	25.9	8.2	.	.	.	HADS-D	2.2	2.6
		HC	18	63	9.7	16.7	-	-	-	-		.	.		1.9	1.3
Perretta, 2005	IGT	PD (late stage)	16	77.7	6	50	.	.	27.2	1.3	MMSE	Excluded if <27	.	BDI	12.7	1.5
		PD (early stage)	16	72.4	2.3	43.75	.	.	11.3	1.1					6.9	0.7
		HC	19	72.6	8.28	42.1	-	-	-	-					5.2	0.8
Pignatti, 2012	IGT	PD	15	64.27	10.5	.	.	.	.	.	MMSE	28.31	1.11	.	.	.
		HC	16	41.56	13.9	.	-	-	-	-					.	.
Piray, 2014	Rewarded categorisation task	PD	40	63.33	3.98	23.07	9.72	2.64	19.6	6.42	MMSE	27	0.93	BDI	8	1.69
		HC	20	66.45	4.7	35	-	-	-	-		27.65	1.18		7.75	1.97
Poletti, 2010	IGT	PD (off)	24	64.9	5.8	27	0 (de novo)		14.3	8.1	MMSE	28.8	2	GDS	4.7	3.3
		HC	25	65.4	2.2	44						28.5	1.8		2.8	1.4
Thiel, 2003	IGT	PD	5	62.6	12.5	40	8	2.55	20.6	6.47	MMSE	.28.4	2.07	.	.	.
		HC	5	44.2	21.3	20	-	-	-	-						
Xi, 2015	IGT	PD	15	60.73	11.7	53	4.33	5.05	15.87	8.96	MMSE	27.6	4.63	HAMD	4.67	1.29

		HC	15	56.33	14.5	60	-	-	-	-		29.4	1.12		3.8	1.37
Yildirim, 2020	IGT	PD	39	65.9	7.3	21	7.8	4.3	11.6	6.1	MMSE	.	.	.	.	.
		HC	37	64.4	8	24	-	-	-	-		.	.		.	.
Reinforcement learning in Parkinson's with psychiatric syndrome vs without				**Age**			**Disease duration (years)**		**UPDRS**		**Cognition**				**Depression**	
Study	**Task**	**Group**	**n**	**Mean**	**SD or (IQR)**	**% female**	**Mean**	**SD or (IQR)**	**Mean**	**SD or (IQR)**	**Measure**	**Mean**	**SD or (IQR)**	**Depression measure**	**Mean**	**SD or (IQR)**
Balconi, 2018	IGT	PD	20	63.9	7.1	15	.	.	13	9.3	.	.	.	BDI	11.3	6
		PG	17	60.7	6.1	17.65	.	.	17	7.8		.	.		15.9	9.1
Balusubramani, 2015	Rewarded categorisation task	PD	14	.	.	21.4	8.35	.	.	.	MMSE	.	.	BDI	.	.
		ICD	16	.	.	12.5	9.56	.								
Bentivoglio, 2012	IGT	PD	17	63.94	9.2	35.29	7.3	4.4	22.5	6.9	MMSE	28.6	1.4	HAM-D	5.6	4.1
		ICD	17	62	10.1	17.65	6.9	3.8	23.8	11		28.4	1.6		7.5	6.3
Biars, 2019	IGT	PD	24	60.5	7.8	12.5	11.9	7.1	37.2	14.8	DRS	136.5	5.9	BDI	8.5	5.3
		ICD	24	61.2	8.3	12.5	13.2	7.1	21.6	9.9		138	3.5		11.2	6.8
Buelow, 2014	IGT	PD	14	69	6.19	57.14	.	.	29.62	6.85	MMSE	28.71	1.38	GDS	2.14	1.41
		Apathy	10	66.7	9.96	30	.	.	29.89	13.14		27.8	1.87		3	2.45
Garofalo, 2017	Instrumental conditioning task	PD	17	63.29	9.94	44	10.94	10.38	.	.	MMSE	28.94	1.54	BDI	8.88	4.94
		Psychosis	12	60.83	6.6	50	16.42	28.77	.	.		28.41	1.37		12.66	7.83
Herzallah, 2017	Rewarded categorisation task	PD	17	59.4	12.6	11.76	5.24	4	.	.	MMSE	28.5	1.1	BDI	8.3	5.2
		MDD	13	55.2	11.9	69.2	4.84	3.7	28.6	14.6		27.5	1.8		26.9	7.7
Housden, 2010	Rewarded salience attribution test	PD	18	67.7	5.5	33.33	12.9	8.3	21.3	0.4	MMSE	29.4	0.8	BDI	11.3	6.9
		ICD	18	62.3	7.6	38.89	13.9	9	20	6.6		28.6	2.1		12.9	9.9
Martinez-Horta, 2013	IGT	PD	17	65.06	4.85	.	5.38	4.25	18	4.61	MMSE	28.94	1.24	HADS	3.88	3.6
		Apathy	17	68.25	6.06	.	6.75	4.93	18.65	5.8		28.55	1.23		5.65	2.92
Paz-Alonso, 2019	IGT	PD	17	61	8.7	11.8	7	(4-10)	25.9	8.2	.	.	.	HADS	2.2	2.6
		ICD	18	62.3	7.6	11.1	8	(5.1-10)	22.31	6.6		.	.		3.1	2.4
Pineau, 2016	IGT (adapted)	PD	20	55	(40-62)	35	5.5	(4-12)	8.5	(0-34)	MDRS	139	(131-143)	.	.	
		ICD	17	55	(37-65)	17.64	7	(2-10)	7	(0-23)		140	(133-144)		.	.
Piray, 2014	Rewarded categorisation task	PD	40	63.33	3.98	25.9	8.87	3.14	19.6	6.42	MMSE	27	0.93	BDI	8	1.69
		ICD	16	64.38	3.32	11.1	9.63	2.45	19	5.32		27.19	1.11		6.75	1.69
Poletti, 2011	IGT	PD	12	63.92	7.17	16.66	.	.	.	.	MMSE	28.72	2.41	GDS-15	3.33	2.34
		Alexithymia	12	66.17	5.2	41.66	.	.	.	.		28.49	1.94		6.33	3.89
Rossi, 2010	IGT	PD	13	65.1	3.8	23	.	.	14.7	6.7	MMSE	.	.	MADRS	14.1	7.9

		PG	7	61.4	6.9	14	.	.	17	9.1		Excluded if <24	.		17.1	6.5
Sáez-Francàs, 2014	IGT	PD	56	62.64	9.06	32.14	4.31	3.65	18.41	5.82	MMSE	.	.	HAM-D	3.64	3.37
		Fatigue	33	61.73	9.85	39.4	4.94	3.44	20.85	6.31		Excluded if <26	.		8.64	7.06
Timmer, 2017	Rewarded task-switching paradigm	PD	22	61.1	7.6	36.4	.	.	21.9	6.8	MMSE	28.6	1.2	BDI	4.3	2.3
		MDD	19	58.4	5.3	36.8	.	.	.	.		28.5	1.3		8.7	5

PD = Parkinson's disease, HC = healthy controls, IGT = Iowa Gambling Task, ICD = Impulse control disorder, MDD = Major depressive disorder, SD = standard deviation, IQR = interquartile range, '.' = not reported, '**-**' = not applicable, UPDRS = Unified Parkinson's Disease Rating Scale, MMSE = Mini-mental state examination, MoCA = Montreal cognitive assessment, MDRS = Mattis dementia rating scale, BDI = Beck depression inventory, HAM-D = Hamilton depression rating scale, HADS = Hospital anxiety and depression scale ZSRD = Zung Self-Rating Depression scale, DASS = Depression, Anxiety and Stress Scale, GDS = Geriatric depression scale, MADRS = Montgomery-Asberg Depression Rating Scale, SDS = Self-rated depression scale

Supplement table 3. Response Vigor and Reward Bias study characteristics and participant demographics.

Response vigor in Parkinson's vs Healthy Controls				**Age**			**Disease duration**		**UPDRS**		**Cognition**			**Depression**		
Study	**Task**	**Group**	**n**	**Mean**	**SD**	**% female**	**Mean**	**SD**	**Mean**	**SD**	**Cognitive measure**	**Mean**	**SD**	**Depression measure**	**Mean**	**SD**
Muhammed, 2016	Speed of gaze shifting task	PD	16	67.3	6.4	.	3.2	2.2	19.4	9.8	MoCA	27.8	2.3	BDI	11.7	5.5
		HC	31	65.9	5.6	.	-	-	-	-		28.2	1.6		15.2	7.8
Renfroe, 2016	Rewarded speed of response to specific visual stimuli	PD	18	66	7.99	22.2	8.39	4.57	26	9.55	.	.	.	BDI	7.82	4.85
		HC	15	70	6.94	40	-	-	-	-		.	.		1.8	2.44
Timmer, 2018	Stroop-like incentive task switching	PD	23	61	7.4	39.13	4.5	2.2	21.8	6.7	MMSE	28.5	1.3	BDI	4.1	2.3
		HC	23	60.9	5.9	39.13	-	-	-	-		28.8	1.2		3.1	2.1
Response vigor in Parkinson's with psychiatric syndrome vs without				**Age**			**Disease duration**		**UPDRS**		**Cognition**			**Depression**		
Study	**Task**	**Group**	**n**	**Mean**	**SD**	**% female**	**Mean**	**SD**	**Mean**	**SD**	**Cognitive measure**	**Mean**	**SD**	**Depression measure**	**Mean**	**SD**
Drew, 2020	Speed of gaze shifting task	PD	26	67.19	5.92	26.9	4.87	4.09	18.62	9.38	MoCA	27.77	1.95	BDI	13	7.1
		ICD	23	63.7	7.56	47.82	8.71	4.25	24.22	16.94		27.39	2.55		12.26	5.84
Evans, 2010	Card arranging reward responsivity test	PD	20	59.5	7.9	.	13.6	8	19.2	2.5	MMSE	29.1	(27-30)	GDS	9	4.9
		DDS	20	55.4	7.6	.	14	5.7	22.7	2.5		29	(24-30)		17.6	6.4
Lawrence, 2011	Spatial search task	PD	10	59.6	6.4	.	.	.	25.6	11	MMPD	25.6	11	GDS	4.7	2
		Apathy	10	61.7	6.1	.	.	.	28.2	11.4		29.3	2.8		8.2	3.5
Muhammed, 2016	Speed of gaze shifting task	PD	16	65.9	5.6	.	6.8	4.6	18.4	2.6	MoCA	28.2	1.6	BDI	11.7	5.5
		Apathy	14	67.3	6.4	.	3.2	2.2	20.4	2.4		27.8	2.3		15.2	7.8
Timmer, 2018	Stroop-like incentive task switching	PD	23	61	7.4	39.13	4.5	2.2	21.8	6.7	MMSE	28.5	1.3	BDI	4.1	2.3
		Depression	22	58.4	5.7	36.36	5	3.5	23.1	9.6		28.4	1.4		9.6	6.1

PD = Parkinson's disease, HC = healthy controls, ICD = Impulse control disorder, SD = standard deviation, IQR = interquartile range, '.' = not reported, '**-**' = not applicable, UPDRS = Unified Parkinson's Disease Rating Scale, MMSE = Mini-mental state examination, MoCA = Montreal cognitive assessment, MMPD = Mini-mental Parkinson's examination BDI = Beck depression inventory, GDS = Geriatric depression scale

Supplement table 4. Study summary statistics, tasks and measures included in the Meta-Analysis of Parkinson's versus healthy controls.

Reward processing summary statistics for Parkinson's disease patients versus healthy controls													**Tasks and Measures Included in the Meta-Analysis.**	
Author, Year	Category	OFF/ON	N (HC)	N (PD)	t	F	M (HC)	SD (HC)	M (PD)	SD (PD)	d	Vard	Task	Measure
Bayard et al, 2016 (ON)	OV	ON	96	78			6.90	7.65	2.77	8.41	0.52	0.02	Game of dice task	Net score
Chong et al, 2015 (ON)	OV	ON	26	26							-0.35	0.08	Effort based decision making task (apple gathering)	Effort indifference point (mean effect size across stake levels, fig 4)
Chong et al, 2015 (OFF)	OV	OFF	26	26		2.70					0.46	0.08	Effort based decision making task (apple gathering)	Effort indifference point
Brandt et al, 2015 (ON)	OV	ON	15	15			14.93	15.72	-8.67	17.67	1.41	0.17	Game of dice task	Net score (fig 1)
Kobayashi et al, 2019 (ON)	OV	ON	21	15			0.21	0.78	0.30	0.66	0.12	0.11	Economic choice task	Relative risk aversion coefficient (fig 2C, first session)
Kobayashi et al, 2019 (OFF)	OV	OFF	21	15			0.21	0.78	0.97	0.70	1.02	0.13	Economic choice task	Relative risk aversion coefficient (fig 2C, first session)
Le Heron et al, 2018 (ON)	OV	ON	32	18	1.30						0.38	0.09	Effort based decision making task (apple gathering)	Mean difference in proportion of offers accepted
Mcguigan et al, 2018 (ON)	OV	ON	20	20	-0.32						-0.10	0.10	Cognitive effort task	Mean difference in k-value
Mcguigan et al, 2018 (OFF)	OV	OFF	20	20	2.79						0.88	0.11	Cognitive effort task	Mean difference in k-value
Sharp et al, 2013 (ON)	OV	ON	18	18	0.43						0.14	0.07	Vancouver gambling task	Gain phase adjust y intercept
Sharp et al, 2013 (OFF)	OV	OFF	18	18	1.79						0.60	0.07	Vancouver gambling task	Gain phase adjust y intercept
Torta et al, 2009 (ON)	OV	ON	13	15							0.24	0.14	Cambridge gamble task	Average bet (across risk levels)
Torta et al, 2009 (OFF)	OV	OFF	13	15							0.23	0.14	Cambridge gamble task	Average bet (across risk levels)
Cools et al, 2003 (ON)	OV	ON	12	12			54.91	12.09	59.65	16.11	-0.33	0.17	Incentivised decision making task	Mean % bets across ascending & descending conditions
Cools et al, 2003 (OFF)	OV	OFF	12	12			54.91	12.09	58.95	15.73	-0.29	0.17	Incentivised decision making task	Mean % bets across ascending & descending conditions
Le Bouc et al, 2016 (ON)	OV	ON	25	24			80.89	7.75	78.56	12.49	0.23	0.08	Effort based decision making task: Binary choice task	Choice of effort level at the highest stake level. (fig 4D)
Le Bouc et al, 2016 (OFF)	OV	OFF	25	24	3.51						1.00	0.09	Effort based decision making task: Binary choice task	Choice of effort level at the highest stake level. (fig 4D)
Castrioto et al, 2015 (ON)	RL	ON	24	20			4.38	40.22	-1.79	44.72	0.15	0.09	Iowa Gambling Task	Baseline final round mean score. (fig 1A)
Castrioto et al, 2015 (OFF)	RL	OFF	24	20			4.38	40.22	0.98	40.34	0.08	0.09	Iowa Gambling Task	Baseline final round mean score. (fig 1A)
Balusubramani et al, 2015 (ON)	RL	ON	20	14			64.10	84.84	61.54	78.69	0.03	0.12	Probabilistic rewarded categorisation learning task	% Optimality during expected reward (fig 3A)
Balusubramani et al, 2015 (OFF)	RL	OFF	20	26			64.10	84.84	43.07	99.38	0.23	0.09	Probabilistic rewarded categorisation learning task	% Optimality during expected reward (fig 3A)
Bodi et al, 2009 (ON)	RL	Medicated	20	22			81.18	18.43	89.18	17.12	-0.45	0.10	Feedback-based probabilistic classification task	Final block % optimal decisions (fig 2)
Bodi et al, 2009 (Never medicated)	RL	Never medicated	20	26			81.18	18.43	59.53	18.61	1.17	0.10	Feedback-based probabilistic classification task	Final block % optimal decisions (fig 2)
Buelow et al, 2014 (ON)	RL	ON	14	24							1.38	0.14	Iowa Gambling Task	Final block score (authors provided)

Piray et al, 2014 (ON)	RL	ON	20	15			0.12	0.16	0.14	0.20	-0.10	0.12	Probabilistic learning task	Actor's learning rate (fig 6C)
Piray et al, 2014 (OFF)	RL	OFF	20	25			0.12	0.16	0.08	0.13	0.29	0.09	Probabilistic learning task	Actor's learning rate (fig 6C)
Yildirim et al, 2020 (ON)	RL	ON	37	39			0.65	5.72	-0.11	5.77	0.13	0.05	Iowa Gambling Task	Final block mean score (author provided)
Gescheidt et al, 2012 (ON)	RL	ON	20	19			10.30	29.42	-6.00	25.26	0.59	0.11	Iowa Gambling Task	Mean total score
Herzallah et al, 2017 (ON)	RL	ON	15	17			76.49	17.36	72.10	16.62	0.26	0.13	Feedback-based probabilistic classification task	Mean % optimal responses for positive feedback (fig 5A)
Housden et al, 2010 (ON)	RL	ON	20	18			56.50	22.40	27.00	19.10	1.41	0.13	Salience Attribution Test	Visual analogue scale rating for high probability stimuli
Mapelli et al, 2014 (ON)	RL	ON	15	15			9.81	10.19	4.74	5.11	0.63	0.14	Iowa Gambling Task	Final block mean score (fig 1)
Mimura et al, 2006 (ON)	RL	ON	20	18			3.70	7.35	-0.33	6.59	0.58	0.11	Iowa Gambling Task	Final 50 cards mean score
Pagonabarraga et al, 2007 (ON)	RL	ON	31	35			6.10	17.00	-10.80	19.00	0.93	0.07	Iowa Gambling Task	Mean total score
Paz-Alonso et al, 2019 (ON)	RL	ON	18	17			40.60	18.82	41.80	15.38	-0.07	0.11	Iowa Gambling Task	Mean difference % optimal choice, final block. (supplement fig 1)
Garofalo et al, 2017 (ON)	RL	ON	24	17			21.50	5.26	15.15	6.68	1.08	0.11	Instrumental conditioning task	Reward learning index (fig 2B)
Czernecki et al, 2002 (ON)	RL	ON	28	23			8.32	11.06	2.86	16.59	0.40	0.08	Iowa Gambling Task	Final block mean score (fig 1, second session)
Czernecki et al, 2002 (OFF)	RL	OFF	28	23			8.32	11.06	5.36	10.89	0.27	0.08	Iowa Gambling Task	Final block mean score (fig 1, second session)
Graef et al, 2010 (ON)	RL	ON	15	14	1.80		68.49	14.07	60.07	11.08	0.67	0.15	Instrumental learning task	% correct choices with constant reward contingencies
Graef et al, 2010 (OFF)	RL	OFF	15	14	2.19		68.49	14.07	59.05	8.86	0.81	0.15	Instrumental learning task	% correct choices with constant reward contingencies
Thiel et al, 2003 (OFF)	RL	OFF	5	5			53.6	15.8	61.2	17.1	-0.46	0.41	Iowa Gambling Task	Mean number of advantageous cards selected.
Perretta et al, 2005 (late PD)	RL	ON late PD	19	16			7.80	1.31	6.80	1.60	0.69	0.12	Iowa Gambling Task	Mean total score
Perretta et al, 2005 (early PD)	RL	ON early PD	19	16			7.80	1.31	7.60	1.60	0.14	0.12	Iowa Gambling Task	Mean total score
Kobayakawa et al, 2008 (ON)	RL	ON	22	34		4.80	4.90	12.20	-16.00	21.57	0.60	0.08	Iowa Gambling Task	Group difference in choice patterns (advantageous - disadvantageous)
Kobayakawa et al, 2010 (ON)	RL	ON	22	14		2.96					0.59	0.12	Iowa Gambling Task	Group difference in choice patterns (advantageous - disadvantageous)
Poletti et al, 2010 (OFF)	RL	OFF (de novo)	25	30			6.00	6.82	3.07	12.07	0.29	0.07	Iowa Gambling Task	Mean total score
Delazer et al, 2009 (ON)	RL	ON	20	20		8.81					0.94	0.11	Iowa Gambling Task	Group difference in choice patterns (advantageous - disadvantageous)
Euteneuer et al, 2009 (ON)	RL	ON	23	21		0.65					0.24	0.09	Iowa Gambling Task	Group difference in choice patterns (advantageous - disadvantageous)
Ibarretxe-Bilbao et al, 2009 (ON)	RL	ON	24	24		14.56					1.10	0.10	Iowa Gambling Task	Group difference in choice patterns (advantageous - disadvantageous)
Pignatti et al, 2012 (ON)	RL	ON	16	15			12.50	14.87	7.47	16.06	0.33	0.13	Iowa Gambling Task	Total score over the last 50 choices
Evens et al, 2015 (ON)	RL	ON	32	32			-7.31	20.78	-2.09	16.27	-0.28	0.06	Iowa Gambling Task	Mean total score

Xi et al, 2015 (ON)	RL	ON	15	15		10.67					1.19	0.16	Iowa Gambling Task	Group difference in choice patterns (advantageous - disadvantageous)
Cavanagh et al, 2017 (ON)	RL	ON	28	28	-1.64						-0.44	0.07	Cost of conflict task	% selection of most (A) vs least (D) rewarding stimuli
Cavanagh et al, 2017 (OFF)	RL	OFF	28	28	-1.44						-0.38	0.07	Cost of conflict task	% selection of most (A) vs least (D) rewarding stimuli
Muhammed et al, 2016 (ON)	RV	ON	31	30	5.50						0.60	0.07	Rewarded speed of gaze shifting task	Reward sensitivity in peak velocity
Timmer et al, 2018 (ON)	RV	ON	23	23			5.00	4.50	14.40	4.40	-2.11	0.14	Rewarded task switching paradigm	Reward related speeding 'repeat' condition
Timmer et al, 2018 (OFF)	RV	OFF	23	23			5.00	4.50	3.80	4.70	0.26	0.09	Rewarded task switching paradigm	Reward related speeding 'repeat' condition

Supplement table 5. Study summary statistics, tasks and measures included in the Meta-Analysis of Parkinson's with & without psychiatric syndrome

Reward processing summary statistics for Parkinson's disease versus Parkinson's disease plus psychiatric syndrome													**Tasks and Measures Included in the Meta-Analysis.**	
Author, Year	Category	Psychiatric syndrome	N (PD)	N (PD+PSYCH)	t	F	M (PD)	SD (PD)	M (PD +Psych)	SD (PD+Psych)	d	Vard	Task	Measure
Balusubramani et al, 2015 (ON)	RL	ICD	14	16			61.54	78.69	78.97	61.56	-0.25	0.13	Probabilistic reward and punishment learning task	% Optimality during expected reward (fig 3A)
Piray et al, 2014 (ON)	RL	ICD	15	16			0.135	0.198	0.067	0.06	0.47	0.13	Probabilistic learning task	Actor's learning rate (fig 6C)
Housden et al, 2010 (ON)	RL	ICD	18	18			27	19.1	42.7	19.7	-0.81	0.12	Salience Attribution Test	Visual analogue scale rating for high probability stimuli
Biars et al, 2019 (ON)	RL	ICD	24	24			3.5	9.7	2.75	8.2	0.08	0.08	Iowa Gambling Task	Final block score (authors provided)
Balconi et al, 2018 (ON)	RL	PG	20	17		7.60					0.91	0.12	Iowa Gambling Task	Group difference in choice patterns (advantageous - disadvantageous)
Paz-Alonso et al, 2019 (ON)	RL	ICD	17	18			41.80	15.38	27.00	13.94	1.01	0.13	Iowa Gambling Task	Mean difference % optimal choice, final block. (supplement fig 1)
Pineau et al, 2016 (ON)	RL	ICD	20	17			15.00	15.56	14.00	9.63	0.08	0.11	Iowa Gambling Task	Mean number of cards selected from winning deck
Bentivoglio et al, 2012 (ON)	RL	ICD	17	17			8.40	22.10	-4.60	33.10	0.46	0.12	Iowa Gambling Task	Mean total score
Rossi et al, 2010 (ON)	RL	PG	13	7	2.60						1.22	0.26	Iowa Gambling Task	Final block mean net score
Garofalo et al, 2017 (ON)	RL	Psychosis	17	12			15.15	6.68	8.67	8.34	0.88	0.16	Instrumental conditioning task	Reward learning index (fig 2B)
Sáez-Francàs et al, 2014 (ON)	RL	Fatigue	56	33			1.79	14.80	-4.18	11.13	0.44	0.05	Iowa Gambling Task	Final three blocks mean net score
Martinez-Horta et al, 2013 (ON)	RL	Apathy	17	20			-1.82	5.80	4.10	4.80	-1.12	0.13	Iowa Gambling Task	Final block score
Buelow et al, 2014 (ON)	RL	Apathy	14	10			22.12	16.80	-24.00	14.87	2.88	0.34	Iowa Gambling Task	Final block score (authors provided)
Herzallah et al, 2017 (ON)	RL	MDD	17	13			72.10	16.62	49.30	22.14	1.19	0.16	Feedback-based probabilistic classification task	Mean % optimal responses for positive feedback (fig 5A)
Timmer et al, 2017 (ON)	RL	MDD	22	19			0.10	0.06	0.07	0.06	-0.50	0.10	Deterministic reversal learning paradigm	Error rate for expected reward

Poletti et al, 2011 (OFF)	RL	Alexithymia	12	12			4.17	8.37	3.00	6.35	0.16	0.17	Iowa Gambling Task	Final block score
Kobayashi et al, 2019 (ON)	OV	ICD	15	10			0.30	0.66	-0.19	0.17	-0.93	0.18	Economic choice task	Relative risk aversion coefficient (fig 2C, first session)
Le Heron et al, 2018 (ON)	OV	Apathy	18	21	2.33						0.75	0.11	Effort based decision making task (apple gathering)	Mean difference in proportion of offers accepted
Voon et al, 2011 (ON)	OV	ICD	14	14							-0.68	0.14	Gambling task	Proportion of risky choices in gain phase (across risk levels, fig 2A)
Timmer et al, 2018 (ON)	RV	MDD	23	22			14.40	4.40	17.70	3.90	-0.79	0.10	Rewarded task-switching paradigm	Reaction time reward benefit (repeat)
Evans et al, 2010 (ON)	RV	DDS	20	20		12.7					-1.13	0.12	Card arranging reward responsivity objective test	Reward responsivity
Drew et al, 2020 (ON)	RV	ICD	26	23		2.78					-0.48	0.08	Rewarded speed of gaze shifting task	Residual velocity reward sensitivity
Lawrence et al, 2011 (ON)	RV	Apathy	10	10		0.38					0.20	0.28	Rewarded spatial search task	Reward related speeding

Supplement table 6. Study summary statistics, tasks and measures included in the Meta-Analysis of Parkinson's on and off dopaminergic medication

Reward processing summary statistics for Parkinson's disease patients ON vs OFF dopaminergic medication							**Tasks and Measures Included in the Meta-Analysis.**	
Author, Year	Category	N	t	F	d	Vard	Task	Measure
Czernecki et al, 2002	RL	22		0.05	0.048	0.046	Iowa Gambling Task	Number of advantageous minus disadvantageous choices
Graef et al, 2010	RL	14	-0.374		-0.100	0.072	Instrumental learning task	% correct choices with constant reward contingencies
Cavanagh et al, 2017	RL	28		2.87	0.320	0.0375	Value of volition task	% selection of A (90% reward) vs C (70% reward) – B (10% reward) vs D (30% reward) stimuli
Bodi et al, 2009	RL	26		13.47	0.720	0.0385	Feedback-based probabilistic classification task	Pattern of optimal decision selection over time
Chong et al, 2015	OV	26		25.9	0.998	0.058	Effort based decision making task (apple gathering)	Effort indifference point
Kobayashi et al, 2019	OV	24		7.48	0.558	0.048	Economic choice task	Relative risk aversion coefficient
Le Heron et al, 2018	OV	39	2.45		0.392	0.028	Effort based decision making task (apple gathering)	Mean difference in proportion of offers accepted
Mcguigan et al, 2018	OV	20	3.05		0.682	0.062	Cogntiive effort task	Mean difference in k-value
Cools et al, 2003	OV	12		5.9	0.701	0.104	Incentivised decision making task	Difference score of bets places in ascending and descending conditions.
Le Bouc et al, 2016	OV	20	2.76		0.617	0.060	Effort based decision making task: Binary choice task	Choice of effort level at the highest stake level.
Sharp et al, 2013	OV	18	1.17		0.276	0.058	Vancouver gambling task	Adjusted y intercept
Timmer et al, 2018	RV	23		3.031	0.363	0.046	Rewarded task switching paradigm	Reward related speeding 'repeat' condition
Muhammed et al, 2016	RV	30		10.8	0.600	0.039	Rewarded speed of gaze shifting task	Reward sensitivity in peak velocity
Evans et al, 2010	RV	38		0.4	0.103	0.026	Card arranging reward responsivity objective test	Reward responsivity
Drew, 2020	RV	26		5.178	0.446	0.042	Rewarded speed of gaze shifting task	Residual velocity reward sensitivity

Modified version of the Newcastle-Ottawa Scale for Assessing the Quality of Nonrandomized Studies in Meta-Analyses, used to assess potential sources of bias.

Potential sources of bias were assessed using a modified version of the Newcastle-Ottawa Scale for Assessing the Quality of Nonrandomized Studies in Meta-Analyses. The studies are scored on:

1. PD Definition: Is the case definition adequate?

A) Cases were defined as PD according to a validated assessment tool/criteria or by an experienced clinician
B) Cases were defined as PD according to a validated assessment tool/criteria but the method for assessing PD status was not stated.
C) Cases were described as 'clinically' but no further description was given.

2. PD Generality: Was a General sample of cases tested?

A) A General sample of PD was tested.
B) Recruitment of PD cases was restricted to a specific sub-sample (specific age range, hospitalised only etc.)

3. HC Selection: Selection of Controls

A) Controls were selected from the same population as cases
B) Controls were not selected from the same population as cases
C) No description

4. HC Definition: Definition of Controls

A) HC were defined clearly defined as having no current or past psychopathology
B) Controls were not clearly defined as having no current or past psychopathology.

Comparability (Comparability of cases and controls on the basis of the design or analysis)

1. Does the study control for Age: Yes/No/Unclear
2. Does the study control for Gender: Yes/No/Unclear
3. Does the study control for IQ: Yes/No/Unclear
4. Does the study control for Socioeconomic status: Yes/No/Unclear
5. Does the study control for PD severity: Yes/No/Unclear
6. Does the study control for medication status: Yes/No/Unclear

Key: A, B, C
Y = yes, N= no, N/A= Not applicable (such as if no healthy control group in study)

Supplement table 7. Quality rating of included studies

Study quality ratings			Modified version of the Newcastle-Ottawa Scale									
Study	**Year**	**Category**	**PD Definition**	**PD Generality**	**HC Selection**	**HC Definition**	**Age**	**Gender**	**IQ**	**Socioeconomic status**	**PD severity**	**PD medication**
Bayard[1]	2016	OV	A	A	B	A	Y	Y	N	N	Y	Y
Brandt[2]	2015	OV	A	A	C	B	Y	Y	N	N	Y	Y
Chong[3]	2015	OV	B	A	A	A	Y	Y	N	N	Y	Y
Cools[4]	2003	OV	A	A	C	B	Y	N	Y	N	Y	Y
Haagensen[5]	2020	OV	C	A	A	B	Y	Y	N	N	Y	Y
Kobayashi[6]	2019	OV	A	A	C	B	Y	Y	N	N	Y	Y
Le Bouc[7]	2016	OV	C	B	A	B	Y	Y	N	N	Y	Y
Le Heron[8]	2018	OV	A	A	A	A	Y	Y	N	N	Y	Y
Mcguigan[9]	2018	OV	A	A	A	A	Y	Y	N	N	Y	Y
Torta[10]	2009	OV	A	B	C	B	Y	Y	N	N	Y	Y
Sharp[11]	2013	OV	A	A	C	B	Y	N	N	N	Y	Y
Voon[12]	2011	OV	A	A	n/a	n/a	Y	Y	N	N	Y	Y
Balconi[13]	2018	RL	A	A	n/a	n/a	Y	N	N	N	Y	Y
Balusubramani[14]	2015	RL	C	A	C	A	N	N	N	N	Y	Y
Bentivoglio[15]	2012	RL	A	A	n/a	n/a	Y	Y	Y	N	Y	Y
Biars[16]	2019	RL	C	B	n/a	n/a	Y	Y	Y	N	N	Y
Bodi[17]	2009	RL	C	B	C	A	Y	N	Y	Y	Y	Y
Buelow[18]	2014	RL	A	A	A	A	Y	Y	Y	N	Y	Y
Castrioto[19]	2015	RL	C	B	C	B	Y	Y	N	N	Y	Y
Cavanagh[20]	2017	RL	C	A	C	B	Y	Y	Y	N	Y	Y
Czernecki[21]	2002	RL	A	B	B	A	Y	Y	N	N	Y	Y
Delazer[22]	2009	RL	A	A	C	A	Y	Y	N	N	Y	Y
Euteneuer[23]	2009	RL	C	A	C	B	Y	Y	N	N	Y	Y
Evens[24]	2015	RL	A	A	A	A	Y	Y	N	N	Y	Y
Garofalo[25]	2017	RL	A	A	C	B	Y	Y	Y	N	Y	Y
Gescheidt[26]	2012	RL	A	A	C	A	Y	Y	N	N	Y	Y
Graef[27]	2010	RL	A	B	B	A	Y	Y	N	N	Y	Y
Herzallah[28]	2017	RL & RV	B	A	A	A	Y	N	N	N	Y	N
Housden[29]	2010	RL	C	A	A	A	Y	Y	Y	N	Y	Y
Ibarretxe-Bilbao[30]	2009	RL	A	A	A	B	Y	Y	N	N	Y	Y
Kobayakawa[31]	2008	RL	C	A	A	A	Y	Y	N	N	Y	Y
Kobayakawa[32]	2010	RL	C	A	A	A	Y	Y	N	N	Y	Y
Mapelli[33]	2014	RL	A	A	A	A	Y	Y	N	N	Y	Y
Martinez-Horta[34]	2013	RL	A	A	n/a	n/a	Y	N	N	N	Y	Y
Mimura[35]	2006	RL	C	A	B	A	Y	Y	N	N	Y	Y
Pagonabarraga[36]	2007	RL	A	A	A	A	Y	Y	N	N	Y	Y
Paz-Alonso[37]	2019	RL	A	A	A	B	Y	Y	Y	N	Y	Y
Perretta[38]	2005	RL	A	A	A	A	Y	Y	N	N	Y	Y
Pignatti[39]	2012	RL	A	B	C	B	N	N	N	N	N	N
Pineau[40]	2016	RL	A	A	n/a	n/a	Y	Y	N	N	Y	Y
Piray[41]	2014	RL	C	B	C	A	Y	N	Y	N	Y	N
Poletti[42]	2010	RL	A	A	C	B	Y	Y	N	N	Y	Y
Poletti[43]	2011	RL	A	B	n/a	n/a	Y	Y	N	N	N	Y
Rossi[44]	2010	RL	A	A	n/a	n/a	Y	Y	N	N	Y	Y
Sáez-Francàs[45]	2014	RL	C	A	n/a	n/a	Y	Y	N	N	Y	N
Thiel[46]	2003	RL	C	A	C	A	Y	N	N	N	Y	Y
Timmer[47]	2017	RL	A	A	A	A	Y	Y	Y	N	Y	Y
Xi[48]	2015	RL	A	B	C	B	Y	Y	N	N	Y	Y

Yildirim[49]	2020	RL	A	A	B	A	Y	Y	N	N	Y	Y
Drew[50]	2020	RV	A	B	C	A	Y	Y	N	N	Y	Y
Evans[51]	2010	RV	A	A	B	B	Y	Y	N	N	Y	Y
Lawrence[52]	2011	RV	A	A	n/a	n/a	Y	N	N	N	Y	Y
Muhammed[53]	2016	RV	C	A	B	B	Y	Y	Y	N	Y	N
Renfroe[54]	2016	RV	B	B	A	A	Y	Y	N	N	Y	Y
Timmer[55]	2018	RV	A	A	A	B	Y	N	Y	N	Y	Y

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