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Original Research

# Sleep Symptoms Differentially Predict Cognition in Younger and Older-Onset Parkinson's Disease

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**Abstract**

***Background*:** Both disrupted sleep and cognitive impairment are frequent in Parkinson's disease (PD), but the evidence for a relationship between self-reported sleep disturbance and cognitive symptoms has been equivocal. If sleep symptoms differentially predict cognition in different subtypes, effects may be obscured in a general PD sample.

***Objective*:** First, to determine whether the associations between participant and disease variables, sleep symptoms and cognitive performance vary by subtype (younger and older-onset); then to establish whether these effects remain when the sample is reanalysed as a whole.

***Methods*:** Multi-group path analyses were used to model the relationships between participant and PD variables; factor scores derived from our bifactor analysis of the

Parkinson's Disease Sleep Scale-Revised; and, measures of memory and executive function. Path analyses were replicated as single group analyses.

***Results*:** Increased general sleep disturbance predicted *better* verbal recall in younger-onset PD and poorer visual episodic memory in older-onset PD. Increased insomnia scores predicted *better* verbal recognition memory in younger-onset PD, *better* verbal fluency in both groups and *poorer* spatial working memory (SWM) in older-onset PD. Higher OSA and RBD scores predicted poorer spatial recognition memory and spatial working memory in younger-onset PD, but did not predict cognition in older-onset PD. Many regression coefficients were weakened or reduced to non-significance in the single-sample models.

***Conclusions*:** The relationships between participant variables, sleep, and cognition were markedly different in younger and older-onset PD. The influence of sex and premorbid IQ as moderating variables warrant further investigation.

**Keywords**

Parkinson's disease; subtypes; sleep; path analysis; neuropsychology; memory; executive function

## 1. Introduction

Both cognitive impairment and sleep problems are common in Parkinson's disease (PD), affecting 19-38% and 60-98% of people with PD, respectively [1, 2]. A number of factors interact to disrupt sleep in PD: motor symptoms, medication and mood symptoms may delay sleep onset, and interfere with sleep maintenance. REM sleep behaviour disorder (RBD) is present in a significant proportion of patients, as are sleep-related breathing disorders (SRBD). In comparison to healthy controls, people with PD tend to sleep for shorter periods; this sleep is often fragmented, with a paucity of slow wave sleep and REM [3, 4]. The sleep medicine literature contains extensive evidence that cognitive function is dependent on restorative sleep [5-8]. For this reason, it would be reasonable to expect an association between sleep disturbance and cognitive symptoms in PD.

Studies examining the relationship between disturbed night-time sleep and poorer cognitive performance in PD have had mixed results. For example, previous research has reported a small-moderate effect of disturbed night-time sleep on working and verbal memory [9], and between sleep disturbance as measured by the Parkinson's Disease Sleep Scale (PDSS) and global cognitive performance [10, 11]. However, the inclusion of covariates in all of these studies decreased all main effects to non-significance. On the other hand, there are a series of studies which have reported no relationship between disturbed sleep and cognitive performance (e.g. [12-14]). Given this mixed pattern of results, the contribution of disturbed sleep to cognitive symptoms in PD remains ambiguous. There does appear to be *some* relationship between sleep disturbance and cognition, but the effects may be relatively small and heterogeneous; therefore, easily becoming non-significant in multivariate analysis.

There is a high degree of inter-individual variability in the symptoms of PD; such that PD itself is considered to be comprised of multiple subtypes [15-17]. Empirically determined subtype

classifications are typically either based on motor symptom profile or on age at disease onset [16]. Those with younger-onset PD tend to have a disease trajectory characterised by slower progression, fewer cognitive symptoms, more frequent affective symptoms, and an increased likelihood of motor complications, relative to those with older-onset PD [18-21]. While the relationship between sleep symptoms and subtype is less well-understood, there may also be marked differences between the relationships between sleep symptoms and cognition in younger and older onset-PD. If this is the case, pooling the two groups for analysis is, at best, likely to dilute effects, but may eliminate effects entirely.

Thus, the present study examines self-reported sleep data using the Parkinson's Disease Sleep Scale-Revised [22] to examine whether different aspects of self-reported sleep problems are differentially associated with memory and executive function (EF) in younger versus older-onset PD. Variants of the Parkinson's Disease Sleep Scales (PDSS [23]; PDSS-2 [24]) have been widely adopted by clinicians and integrated as outcome measures in clinical trials [25-27], therefore, understanding systematic differences in the antecedents and associations of sleep disturbances within PD subtype is critical.

Multi-group path analysis, for younger and older-onset PD subtypes, was used to model the impact of self-reported sleep problems on memory and EF performance, whilst taking account of the effect of participant characteristics (such as sex, age, mood, and medication) on sleep and cognition. To test the hypothesis that self-reported sleep and cognition would not be related if subtype were not considered, path analyses were repeated as single sample models. We predicted that some significant effects would be lost in single group models due to the high degree of heterogeneity in PD.

## 2. Materials and Methods

### *2.1 Participants*

One hundred and ninety-one participants with idiopathic PD (diagnosed by a neurologist or geriatrician using United Kingdom Parkinson's Disease Society Brain Bank Clinical Criteria) [28] participated in this study. Participants were recruited through Parkinson's Western Australia, support groups, advertisements, radio, newspaper, and via referral from health professionals. Participants were excluded if they had significant cognitive impairment (scored < 24 on the Mini-Mental Status Examination; *N* = 11), had neurological co-morbidities, such as a history of stroke, encephalitis or significant loss of consciousness (*N* = 9), or were later found to have been misdiagnosed (*N* = 5), leaving 166. The ParkC study, which has been well-characterised in previous publications (see [29-31]) is a longitudinal cohort study that examines cognitive and motor heterogeneity in PD. Genetic screening was completed as part of participant evaluation; all of the participants comprising the sample for the current study were confirmed, sporadic PD cases.

### *2.2 Measures*

Demographic data for each participant were collected and included a brief medical history, current medication schedule, sex, age, and date of diagnosis. Pre-morbid IQ was estimated using the Australian version of the National Adult Reading Test (AUSNART) [32]. Mood was measured using the total score of the short form of the depression, anxiety and stress scale (DASS-21) [33].

#### 2.2.1 The Parkinson's Disease Sleep Scale-Revised

The PDSS-R [22] is a 15-item, self-administered scale, in which patients rate aspects of sleep frequently affected in PD. Factor scores were derived from our earlier bifactor analysis of the PDSS-R [34]. In a bifactor model, an overall or 'general' score is a factor on which all items load (so it accounts for variance common to all scale items). The general factor is referred to as 'general sleep disruption' as it encompasses: insomnia symptoms; motor symptoms that impact sleep; medication wearing off; nocturia; OSA; RBD; nightmares; and, sleep refreshment. There were two significant sub-factors in our bifactor analysis: Insomnia (subjective sleep quality, sleep initiation, sleep maintenance); and OSA and RBD symptoms (snoring, apnoea, distressing dreams and violent behaviour).

#### 2.2.2 Memory

Episodic verbal memory was measured using the Hopkins Verbal Learning Test-Revised (HVLT) [35]. Scores derived from the HVLT are verbal learning (total correct, max. 36), delayed verbal recall (max. 12), and delayed verbal recognition adjusted for response bias (max. 12). Episodic visual recognition memory was assessed using the Pattern Recognition Memory (PRM) and Spatial Recognition Memory (SRM) sub-tests from the CANTAB™. The outcomes used for these measures were the percentage of correct responses (out of 24 and 20 trials, respectively).

#### 2.2.3 Executive Function (EF)

Verbal fluency was measured using the Controlled Oral Word Association test (COWA) [36], using letters F, A, S. The outcome measure used was the number of correct responses in all three trials less repetitions and rule breaks. Working memory was assessed using the total number or errors on the spatial working memory sub-test of the CANTAB™ (SWM). Planning was assessed using the Stockings of Cambridge (SOC) sub-test from the CANTAB™ (no. problems solved in minimum moves: max. 12).

### *2.3 General Procedure*

Participants were asked to complete questionnaires before their appointment. Neuropsychological and UPDRS examination were completed while participants were in a medication 'on' state (approximately 1 hour after last medication dose). Testing took approximately 2.5 hours with rest breaks offered as needed.

### *2.4 Statistical Analyses*

Data screening, collinearity diagnostics, and descriptive analyses were performed using SPSS version 22 for Windows. Path analyses were conducted in MPlus Version 7.3 for Windows [37], using maximum likelihood robust (MLR) estimation. As LED was measured on a markedly different scale to all other variables, z-scores for the sample were created and used in path analyses.

To maximise power for multi-group analysis, we divided the sample into younger and older-onset PD by a median split, which yielded two equal subgroups each comprising 83 participants. Theoretically, this approach carries risk, as onset-age cut-offs may be skewed depending on the

parameters of a given sample. However, the median of our sample (61.17 years) was very close to the cut-off between intermediate-onset and old-onset PD of 60 years, recommended for subtyping using age-at-onset [16]. Classically defined young-onset PD (<40 years) [16] accounts for very few cases (<1%) [15] or 1.8% of our sample. Moreover, the terms 'early-onset' PD, 'young-onset' PD and 'intermediate-onset' PD are inconsistently applied at various cut-off ages [38]. Therefore, we divided our groups at the median age-at onset, creating an 'older-onset' group and a younger-onset group which contained all individuals who developed PD before 61.17 years).

By dividing the sample into subtypes, statistical power was lost. Therefore, multi-group path models were estimated separately for memory and EF measures, whilst single-sample models analysed EF and memory together. For comparative purposes, path diagrams and regression tables for multi-group analyses include both memory and EF measures. Age, disease duration, sex (1 = male, 2 = female), mood (DASS-21 total), and standardized LED were entered as covariates both of sleep scores and of cognitive outcomes. Predicted premorbid IQ was entered as a covariate of cognition alone. Model fit was evaluated using recommended indices [39]. An alpha level of .05 was used throughout.

## 3. Results

Between-group comparisons revealed that the younger-onset group was significantly younger, had longer disease duration, higher LED, and higher MMSE than the older-onset group. Additionally, while males were over-represented across the entire sample, the gender imbalance was particularly marked in the older-onset group, where 79.5% were men cf. 53.0% in the younger-onset group ($\chi^2$ = 13.04, $p$ < .001). As expected, the younger-onset group performed significantly better than the older-onset group on all cognitive measures, excepting visual episodic memory (PRM and SRM), where there were no differences. For descriptive statistics and between-groups comparisons see Table 1. As very few variables were normally distributed, Mann-Whitney U was used for all between-groups comparisons (excepting gender).

Although the results of our bifactor analysis of the PDSS-R [34] have left us cautious about the utility of summing the items to provide a total score for the PDSS scales, we are aware that this is common practice, so we have provided total scores for the purposes of comparison with other data. The overall median total PDSS-R score was 26.85 (*SD* = 21.80, *Range* = 2.30-112.00). There was a significant difference in median total PDSS-R scores between Younger and Older-Onset groups ($U$ = 2425, $p$ = .016), with the younger-onset group having significantly higher median scores indicating more severe sleep problems. Younger- and older-onset groups did not differ in general factor ($U$ = 2953, $p$ = .112) or OSA and RBD sub-factor scores ($U$ = 3177, $p$ = .388), though older-onset participants reported better sleep on the insomnia sub-factor ($U$ = 2807, $p$ = .040).

**Table 1** Descriptive Statistics and between-group comparisons for younger-onset and older-onset groups.

| | **Entire Sample *N* = 166** | | | | **Younger-Onset *N* = 83** | | | | **Older-Onset *N* = 83** | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | ***M*** | ***SD*** | **Min** | **Max** | ***M*** | ***SD*** | **Min** | **Max** | ***M*** | ***SD*** | **Min** | **Max** | ***p*** |
| Sex (% male) | 66.3 | | | | 53.0 | | | | 79.5 | | | | <.001 |
| Age | 66.13 | 9.29 | 41 | 85 | 59.13 | 6.51 | 41.00 | 75 | 73.13 | 5.65 | 63 | 85 | <.001 |
| Age-at-Onset | 60.70 | 10.46 | 39 | 84 | 52.18 | 6.32 | 39 | 61 | 69.21 | 5.80 | 62 | 84 | <.001 |
| Disease Duration (yrs) | 5.44 | 4.96 | 0.03 | 27.08 | 6.95 | 5.95 | .17 | 27.08 | 3.92 | 3.07 | 0.03 | 11.58 | <.001 |
| PDSS-R total score (Median) | 36.85 | 21.80 | 2.30 | 112.00 | 42.00 | 19.01 | 2.30 | 101.00 | 31.40 | 24.18 | 2.50 | 112.00 | .016[a] |
| LED | 589.64 | 443.68 | 0 | 2312.50 | 714.48 | 501.44 | 0 | 2312.50 | 464.81 | 336.36 | 0 | 1650.00 | <.001 |
| H&Y | 1.83 | 0.64 | 1 | 4 | 1.78 | 0.68 | 1 | 4 | 1.87 | 0.60 | 1 | 3 | .352 |
| MMSE | 28.16 | 1.39 | 24 | 30 | 28.55 | 1.34 | 24 | 30 | 27.76 | 1.33 | 24 | 30 | .001[a] |
| DASS-21 | 22.06 | 17.82 | 0 | 106 | 23.71 | 18.55 | 0 | 106 | 20.41 | 17.02 | 0 | 78 | .234 |
| Premorbid IQ | 106.11 | 8.80 | 80.20 | 120.91 | 106.42 | 8.16 | 83.20 | 118.99 | 105.81 | 9.43 | 80.20 | 120.91 | .657 |
| HVLT Verbal Learning | 23.25 | 6.10 | 10 | 36 | 24.90 | 6.09 | 10 | 36 | 21.6 | 5.67 | 10 | 33 | <.001 |
| HVLT Delayed Recall | 8.35 | 2.67 | 0 | 12 | 9.08 | 2.54 | 3 | 12 | 7.61 | 2.59 | 0 | 12 | <.001[a] |
| HVLT Delayed Recognition | 10.42 | 1.69 | 3 | 12 | 10.73 | 1.68 | 3 | 12 | 10.11 | 1.66 | 5 | 12 | .003[a] |
| Pattern Recognition Memory | 84.32 | 11.98 | 37.5 | 100 | 85.54 | 12.67 | 37.5 | 100 | 83.08 | 11.18 | 41.67 | 100 | .188 |
| Spatial Recognition Memory | 78.00 | 10.27 | 50 | 100 | 79.22 | 10.01 | 55 | 100 | 76.77 | 10.43 | 50 | 100 | .126 |
| Controlled Oral Word Association | 36.30 | 11.67 | 4 | 76 | 39.42 | 11.28 | 11 | 76 | 33.18 | 11.26 | 4 | 63 | <.001 |
| Spatial Working Memory (total errors) | 42.28 | 21.01 | 0 | 95 | 38.25 | 22.00 | 0 | 95 | 46.37 | 19.26 | 0 | 79 | .013 |
| Stockings of Cambridge | 7.24 | 2.26 | 0 | 12 | 7.86 | 2.05 | 2 | 12 | 6.61 | 2.29 | 0 | 11 | <.001 |

*Note*: [a] Mann-Whitney *U*; PDSS-R = Parkinson's Disease Sleep Scale- Revised; LED = levodopa equivalent dose; H&Y = Hoehn and Yahr score; MMSE = Mini-Mental State Examination; DASS-21 = Depression Anxiety and Stress Scale, short form score; HVLT = Hopkins Verbal Learning Test.

### *3.1 Path Analyses*

All path models fit well (see Table S1). For ease of reading, only significant paths are shown in figures and standardised regression coefficients, standard errors and *p* values are provided in adjacent tables. Tables of all regression coefficients (including non-significant paths), standard errors, significance levels and model fit are provided in supplementary tables (Tables S2-S5).

#### 3.1.1 Path Models for General Sleep Disturbance

Regardless of age-of-onset, poorer mood predicted more severe overall (general) sleep disturbance. In older-onset PD, only *shorter* disease duration and higher LED also predicted more severe overall sleep disturbance. Greater overall (general) sleep disturbance had different effects on memory in younger- and older-onset PD. In younger-onset PD, more severe general sleep disturbance was associated with *better* delayed verbal recall, whereas in older-onset PD, greater general sleep disturbance predicted *poorer* pattern recognition and spatial recognition memory. For both subtypes, there was no association between general sleep disruption and EF (Figure 1, Table 2).

When collapsing subtypes into a single sample, the effects of poor mood and higher LED on increased overall sleep disturbance remained. However, there was no longer an effect of disease duration. As predicted, the association between increased sleep disturbance and cognition was no longer significant for some effects. The effect of general sleep disturbance on verbal recognition remained, but the effects on spatial and pattern recognition (driven by the older-onset group) fell to trend levels (Figure 2, Table 3, Part i).

#### 3.1.2 Path Analysis for Insomnia Sub-Factor

None of the participant characteristics predicted insomnia in younger-onset PD, whilst in older onset-PD more severe insomnia was predicted by both female sex and higher LED. Again, there were differential effects of insomnia on cognition in younger- and older-onset PD. In younger-onset PD more severe insomnia predicted better performance on both verbal recognition and verbal fluency, whilst in older-onset PD severe insomnia predicted poorer spatial working memory (See Figure 3 and Table 4).

In the single-sample model, only higher LED predicted more severe insomnia scores; the effect of sex on insomnia became non-significant. As for cognition, only the path between more severe insomnia and better verbal fluency performance remained significant; the relationships between insomnia and verbal fluency and spatial working memory both became non-significant (See Figure 4 and Table 3, Part ii).

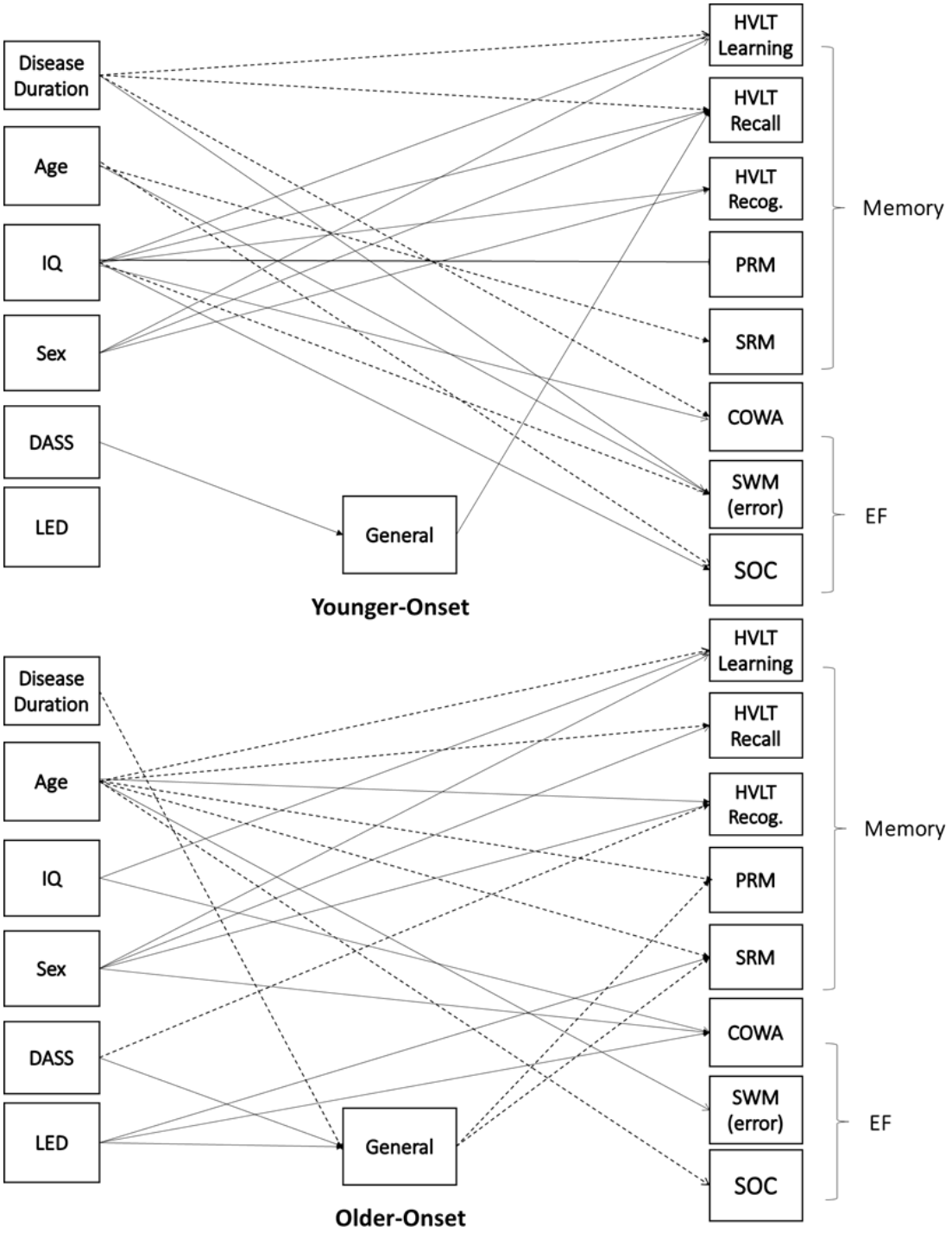


**Figure 1** Path models for younger and older-onset sub-samples showing significant paths between insomnia factor scores, cognition and participant characteristics. Dotted lines represent negative regression coefficients and solid lines represent positive regression coefficients. Regression paths all significant at .05; for standardised beta weights, standard errors and p-values, please see Table 2. (*Note:* EF= executive function; DASS= Depression, Anxiety and Stress Scale-short form; LED= Levodopa Equivalent Dose; HVLT= Hopkins Verbal Learning Test; PRM= Pattern Recognition Memory; SRM= Spatial Recognition Memory; COWA= Controlled Oral Word Association; SWM= Spatial Working Memory; SOC= Stockings of Cambridge.)

**Table 2** Significant standardised regression coefficients, standard errors and significance values for the multi-group path models of general factor scores.

| | **Younger-Onset** | | | **Older-Onset** | | |
|---|---|---|---|---|---|---|
| **Dependent variable**<br>**Predictor variable** | *β* | *SE* | *P* | *β* | *SE* | *P* |
| ***General*** | | | | | | |
| **DASS** | 0.29 | 0.09 | .001 | 0.46 | 0.11 | <.001 |
| **LED** | | | | 0.32 | 0.11 | .003 |
| | | | **Memory** | | | |
| **HVLT Total** | | | | | | |
| **Disease Duration** | -0.22 | 0.10 | .020 | | | |
| **Age** | | | | -0.34 | 0.10 | .001 |
| **Premorbid IQ** | 0.42 | 0.08 | <.001 | 0.26 | 0.09 | .002 |
| **Sex** | 0.33 | 0.08 | <.001 | 0.38 | 0.10 | <.001 |
| **HVLT Recall** | | | | | | |
| ***General*** | 0.19 | 0.09 | .044 | | | |
| **Disease Duration** | -0.23 | 0.12 | .046 | | | |
| **Age** | | | | -0.40 | 0.10 | <.001 |
| **Premorbid IQ** | 0.42 | 0.08 | <.001 | | | |
| **Sex** | 0.36 | 0.08 | <.001 | 0.35 | 0.09 | <.001 |
| **HVLT recognition** | | | | | | |
| **Premorbid IQ** | 0.31 | 0.09 | <.001 | | | |
| **Sex** | 0.31 | 0.08 | <.001 | 0.30 | 0.09 | <.001 |
| **DASS** | | | | -0.36 | 0.10 | <.001 |
| **PRM** | | | | | | |
| ***General*** | | | | -0.30 | 0.15 | .045 |
| **Age** | | | | -0.38 | 0.10 | <.001 |
| **Premorbid IQ** | 0.32 | 0.10 | .001 | | | |
| **SRM** | | | | | | |
| ***General*** | | | | -0.36 | 0.10 | <.001 |
| **Age** | -0.23 | 0.11 | .030 | -0.22 | 0.10 | .027 |
| **LED** | | | | 0.24 | 0.11 | .033 |
| | | | **EF** | | | |
| **COWA** | | | | | | |
| **Disease Duration** | -0.23 | 0.11 | .035 | | | |
| **Premorbid IQ** | 0.37 | 0.08 | <.001 | 0.54 | 0.08 | <.001 |
| **Sex** | | | | 0.36 | 0.09 | <.001 |
| **LED** | | | | 0.29 | 0.11 | .010 |

| | Younger-Onset | | | Older-Onset | | |
|---|---|---|---|---|---|---|
| **Dependent variable**<br>**Predictor variable** | *β* | *SE* | *P* | *β* | *SE* | *P* |
| **SWM** | | | | | | |
| **Disease Duration** | 0.35 | 0.11 | .002 | | | |
| **Age** | 0.28 | 0.09 | .002 | 0.37 | 0.11 | .001 |
| **Premorbid IQ** | -0.21 | 0.09 | .020 | | | |
| **SOC** | | | | | | |
| **Age** | -0.30 | 0.12 | .011 | -0.32 | 0.13 | .010 |
| **Premorbid IQ** | 0.32 | 0.09 | <.001 | | | |

*Note:* HVLT = Hopkins Verbal Learning Test; DASS = Depression, Anxiety and Stress Scale; LED = Levodopa equivalent dose; SRM = Spatial Recognition Memory; EF = Executive Function; COWA = Controlled Oral Word Association; SWM = Spatial Working Memory; SOC = Stockings of Cambridge. Shaded rows represent non-significant paths.

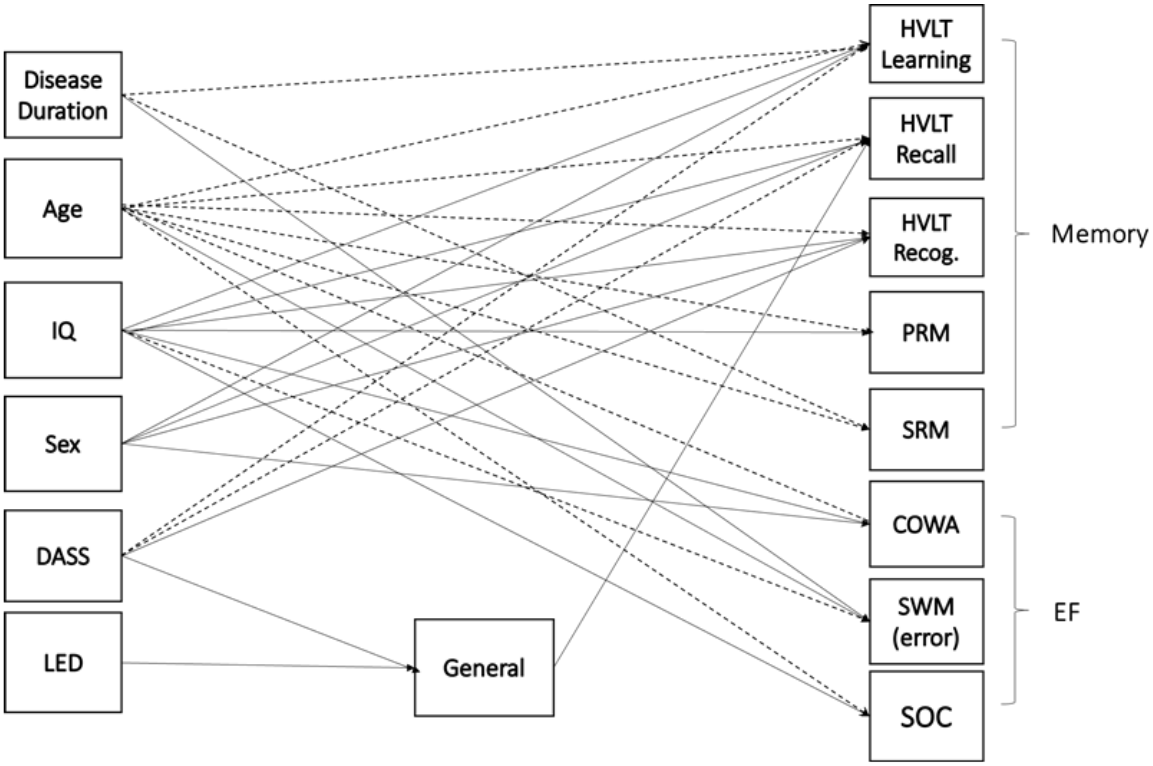


**Figure 2** Path model for the general sleep factor using combined sample showing significant paths between general sleep factor scores, cognition and participant characteristics. Dotted lines represent negative regression coefficients and solid lines represent positive regression coefficients. Regression paths all significant at .05; for standardised beta weights, standard errors and p-values, please see Table 3, Part i. (*Note*: EF = executive function; DASS = Depression, Anxiety and Stress Scale; LED = Levodopa Equivalent Dose; HVLT = Hopkins Verbal Learning Test; PRM = Pattern Recognition Memory; SRM = Spatial Recognition Memory; COWA = Controlled Oral Word Association; SWM = Spatial Working Memory; SOC= Stockings of Cambridge.)

**Table 3** Standardised regression coefficients, standard errors and significance values for single-sample path models for general, insomnia, and OSA and RBD PDSS-R factors.

| | Part i. *General* | | | | Part ii. *Insomnia* | | | | Part iii. *OSA and RBD* | | |
|---|---|---|---|---|---|---|---|---|---|---|---|
| **Dependent variable**<br>**Predictor variable** | *β* | *SE* | *P* | | *β* | *SE* | *P* | | *β* | *SE* | *p* |
| ***General*** | | | | ***Insomnia*** | | | | ***OSA/ RBD*** | | | |
| **DASS** | 0.39 | 0.07 | <.001 | **DASS** | | | | **DASS** | | | |
| **LED** | 0.28 | 0.08 | .001 | **LED** | 0.21 | 0.08 | .006 | **LED** | | | |
| | | | | **Memory** | | | | | | | |
| **HVLT Total** | | | | **HVLT Total** | | | | **HVLT Total** | | | |
| **Disease Duration** | -0.17 | 0.06 | .007 | **Disease Duration** | -0.17 | 0.06 | .005 | **Disease Duration** | -0.18 | 0.06 | .003 |
| **Age** | -0.33 | 0.06 | <.001 | **Age** | -0.31 | 0.06 | <.001 | **Age** | -0.32 | 0.06 | <.001 |
| **Premorbid IQ** | 0.33 | 0.06 | <.001 | **Premorbid IQ** | 0.33 | 0.06 | <.001 | **Premorbid IQ** | 0.32 | 0.06 | <.001 |
| **Sex** | 0.33 | 0.06 | <.001 | **Sex** | 0.33 | 0.06 | <.001 | **Sex** | 0.34 | 0.06 | <.001 |
| **DASS** | -0.15 | 0.08 | .047 | **DASS** | | | | **DASS** | | | |
| **HVLT Recall** | | | | **HVLT Recall** | | | | **HVLT Recall** | | | |
| ***General*** | 0.20 | 0.07 | .006 | ***Insomnia*** | | | | ***OSA/RBD*** | | | |
| **Disease Duration** | | | | **Disease Duration** | -0.14 | 0.07 | .043 | **Disease Duration** | -0.15 | 0.07 | .034 |
| **Age** | -0.33 | 0.07 | <.001 | **Age** | -0.31 | 0.07 | <.001 | **Age** | -0.32 | 0.07 | <.001 |
| **Premorbid IQ** | 0.25 | 0.06 | <.001 | **Premorbid IQ** | 0.24 | 0.06 | <.001 | **Premorbid IQ** | 0.24 | 0.06 | <.001 |
| **Sex** | 0.33 | 0.06 | <.001 | **Sex** | 0.34 | 0.06 | <.001 | **Sex** | 0.34 | 0.06 | <.001 |
| **DASS** | -0.18 | 0.07 | .015 | **DASS** | | | | **DASS** | | | |
| **HVLT recognition** | | | | **HVLT recognition** | | | | **HVLT recognition** | | | |
| **Disease Duration** | | | | **Disease Duration** | | | | **Disease Duration** | -0.15 | 0.06 | .034 |
| **Age** | -0.23 | 0.08 | .004 | **Age** | -0.21 | 0.08 | .010 | **Age** | -0.32 | 0.07 | <.001 |
| **Sex** | 0.15 | 0.08 | .046 | **Sex** | 0.16 | 0.08 | .034 | **Sex** | 0.24 | 0.06 | <.001 |
| **DASS** | 0.29 | 0.06 | <.001 | **DASS** | 0.29 | 0.06 | <.001 | **DASS** | 0.34 | 0.06 | <.001 |
| **LED** | -0.26 | 0.09 | .003 | **LED** | -0.24 | 0.08 | .002 | **LED** | | | |
| **PRM** | | | | **PRM** | | | | **PRM** | | | |
| ***General*** | | | | ***Insomnia*** | | | | ***OSA/ RBD*** | -0.16 | 0.08 | .032 |
| **Age** | -0.22 | 0.07 | .002 | **Age** | -0.23 | 0.07 | .001 | **Age** | -0.22 | 0.07 | .003 |
| **Premorbid IQ** | 0.17 | 0.07 | .011 | **Premorbid IQ** | 0.18 | 0.07 | .005 | **Premorbid IQ** | 0.20 | 0.07 | .002 |

| | | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|
| **SRM** | | | | **SRM** | | | | **SRM** | | |
| ***General*** | | | | ***Insomnia*** | | | | ***OSA/RBD*** | | |
| **Disease Duration** | -0.20 | 0.08 | .014 | **Disease Duration** | -0.19 | 0.09 | .038 | **Disease Duration** | -0.20 | 0.09 | .024 |
| **Age** | -0.25 | 0.07 | <.001 | **Age** | -0.26 | 0.07 | <.001 | **Age** | -0.25 | 0.07 | .001 |
| | | | | | **EF** | | | | | |
| **COWA** | | | | **COWA** | | | | **COWA** | | |
| ***General*** | | | | ***Insomnia*** | 0.27 | 0.06 | <.001 | ***OSA/ RBD*** | | |
| **Age** | -0.21 | 0.07 | .002 | **Age** | -0.17 | 0.07 | .011 | **Age** | -0.20 | 0.07 | .005 |
| **Premorbid IQ** | 0.42 | 0.06 | <.001 | **Premorbid IQ** | 0.44 | 0.06 | <.001 | **Premorbid IQ** | 0.41 | 0.06 | <.001 |
| **Sex** | 0.26 | 0.07 | <.001 | **Sex** | 0.25 | 0.06 | <.001 | **Sex** | 0.26 | 0.07 | <.001 |
| **SWM** | | | | **SWM** | | | | **SWM** | | |
| ***General*** | | | | ***Insomnia*** | | | | ***OSA/ RBD*** | 0.12 | 0.06 | .047 |
| **Disease Duration** | 0.24 | 0.08 | .003 | **Disease Duration** | 0.25 | 0.08 | .002 | **Disease Duration** | 0.25 | 0.08 | .001 |
| **Age** | 0.40 | 0.07 | <.001 | **Age** | 0.40 | 0.07 | <.001 | **Age** | 0.39 | 0.07 | <.001 |
| **Premorbid IQ** | -0.16 | 0.08 | .014 | **Premorbid IQ** | -0.15 | 0.07 | .026 | **Premorbid IQ** | -0.17 | 0.07 | .011 |
| **SOC** | | | | **SOC** | | | | **SOC** | | |
| **Age** | -0.41 | 0.07 | <.001 | **Age** | -0.41 | 0.067 | <.001 | **Age** | -0.40 | 0.07 | <.001 |
| **Premorbid IQ** | 0.23 | 0.07 | .002 | **Premorbid IQ** | 0.22 | 0.074 | .003 | **Premorbid IQ** | 0.24 | 0.08 | .002 |

*Note*: HVLT = Hopkins Verbal Learning Test; DASS = Depression, Anxiety and Stress Scale; LED = Levodopa equivalent dose; SRM = Spatial Recognition Memory; COWA = Controlled Oral Word Association; SWM = Spatial Working Memory; SOC = Stockings of Cambridge.

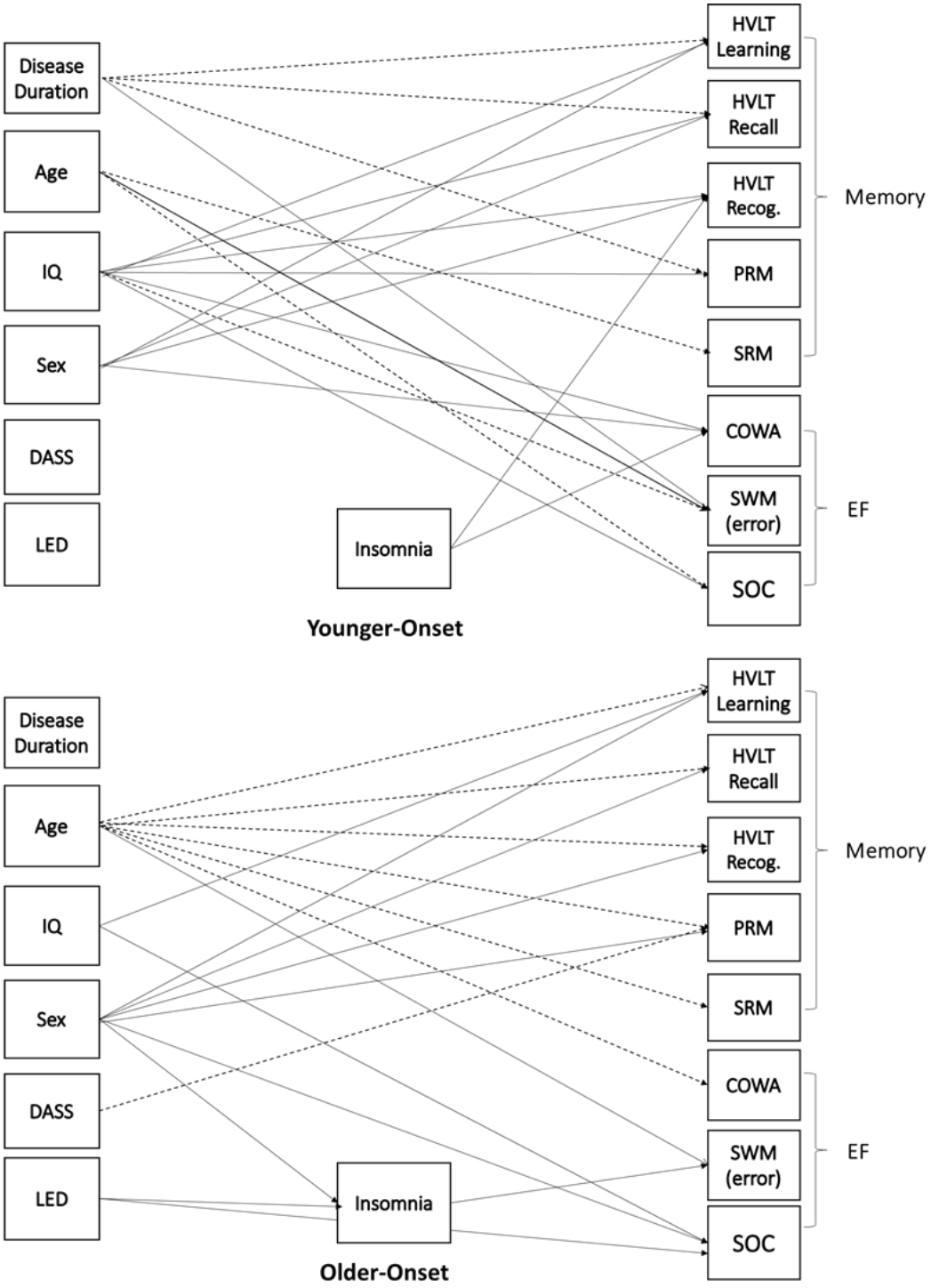


**Figure 3** Path models for younger and older-onset sub-samples showing significant paths between insomnia factor scores, cognition and participant characteristics. Dotted lines represent negative regression coefficients and solid lines represent positive regression coefficients. Regression paths all significant at .05; for standardised beta weights, standard errors and p-values, please see Table 4. (*Nore*: EF = executive function; DASS = Depression, Anxiety and Stress Scale; LED = Levodopa Equivalent Dose; HVLT = Hopkins Verbal Learning Test; PRM = Pattern Recognition Memory; SRM = Spatial Recognition Memory; COWA = Controlled Oral Word Association; SWM = Spatial Working Memory; SOC = Stockings of Cambridge.)

**Table 4** Standardised regression coefficients, standard errors and significance values for the multi-group path models of insomnia factor scores.

| | Younger Onset | | | Older Onset | | |
|---|---|---|---|---|---|---|
| **Dependent variable**<br>**Predictor variable** | *β* | *SE* | *P* | *β* | *SE* | *P* |
| ***Insomnia*** | | | | | | |
| **Sex** | | | | 0.26 | 0.09 | .002 |
| **LED** | | | | 0.38 | 0.12 | .001 |
| | | **Memory** | | | | |
| **HVLT Total** | | | | | | |
| **Disease Duration** | -0.21 | 0.09 | .019 | | | |
| **Age** | | | | -0.34 | 0.10 | <.001 |
| **Premorbid IQ** | 0.42 | 0.09 | <.001 | 0.26 | 0.09 | .003 |
| **Sex** | 0.34 | 0.08 | <.001 | 0.40 | 0.10 | <.001 |
| **HVLT Recall** | | | | | | |
| **Disease Duration** | -0.23 | 0.10 | .025 | | | |
| **Age** | | | | -0.41 | 0.11 | <.001 |
| **Premorbid IQ** | 0.42 | 0.08 | <.001 | | | |
| **Sex** | 0.36 | 0.09 | <.001 | 0.40 | 0.10 | <.001 |
| **HVLT recognition** | | | | | | |
| ***Insomnia*** | 0.18 | 0.08 | .027 | | | |
| **Age** | | | | -0.41 | 0.11 | <.001 |
| **Premorbid IQ** | 0.32 | 0.08 | <.001 | | | |
| **Sex** | 0.32 | 0.08 | <.001 | 0.40 | 0.10 | <.001 |
| **PRM** | | | | | | |
| **Disease Duration** | -0.28 | 0.14 | .049 | | | |
| **Age** | | | | -0.26 | 0.13 | .048 |
| **Premorbid IQ** | 0.31 | 0.10 | .001 | | | |
| **Sex** | | | | 0.34 | 0.09 | <.001 |
| **DASS** | | | | -0.29 | 0.10 | .003 |
| **SRM** | | | | | | |
| **Age** | -0.23 | 0.11 | .030 | -0.37 | 0.10 | <.001 |
| | | **EF** | | | | |
| **COWA** | | | | | | |
| ***Insomnia*** | 0.32 | 0.08 | <.001 | | | |
| **Age** | | | | -0.20 | 0.10 | .049 |
| **Premorbid IQ** | 0.40 | 0.07 | <.001 | | | |
| **Sex** | 0.19 | 0.09 | .037 | | | |
| **SWM** | | | | | | |
| ***Insomnia*** | | | | 0.21 | 0.09 | .022 |
| **Disease Duration** | 0.35 | 0.12 | .002 | | | |
| **Age** | 0.27 | 0.09 | .003 | 0.40 | 0.11 | <.001 |
| **Premorbid IQ** | -0.20 | 0.09 | .023 | | | |
| **SOC** | | | | | | |
| **Age** | -0.29 | 0.116 | .010 | | | |

| | | | | | | |
|---|---|---|---|---|---|---|
| **Premorbid IQ** | 0.31 | 0.088 | <.001 | 0.54 | 0.08 | <.001 |
| **Sex** | | | | 0.34 | 0.08 | <.001 |
| **LED** | | | | 0.27 | 0.12 | .026 |

*Note:* HVLT = Hopkins Verbal Learning Test; DASS= Depression, Anxiety and Stress Scale; LED = Levodopa equivalent dose; PRM = Pattern Recognition Memory; SRM = Spatial Recognition Memory; COWA = Controlled Oral Word Association; SWM= Spatial Working Memory; SOC = Stockings of Cambridge. Shaded rows represent non-significant paths.

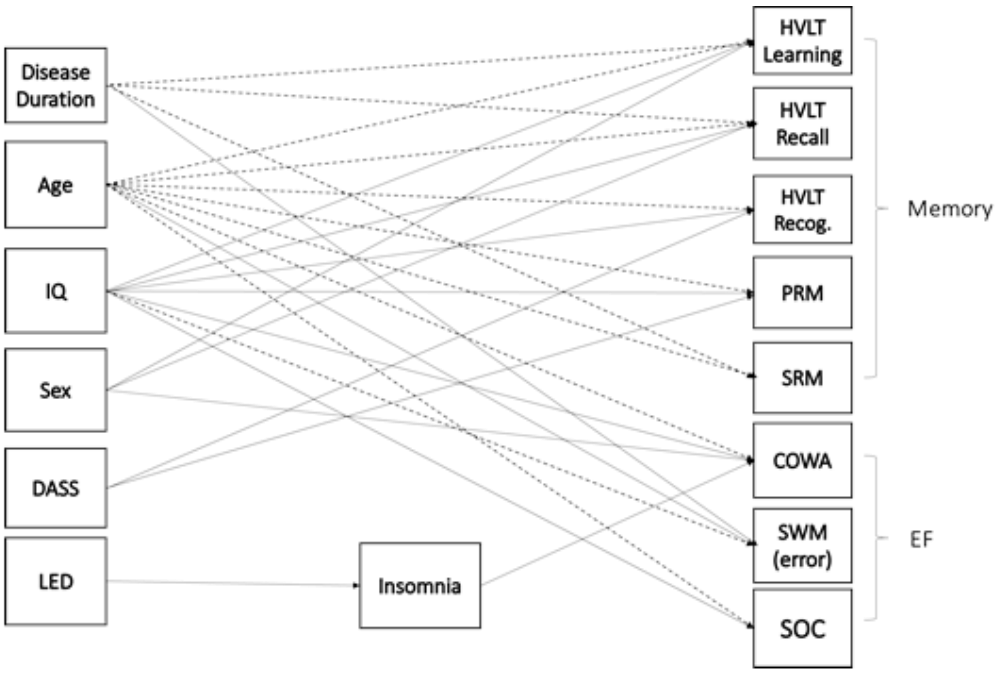


**Figure 4** Path model for the insomnia factor using the combined sample showing significant paths between general sleep factor scores, cognition and participant characteristics. Dotted lines represent negative regression coefficients and solid lines represent positive regression coefficients. Regression paths all significant at .05; for standardised beta weights, standard errors and p-values, please see Table 3, part ii. (*Note:* EF = executive function; DASS = Depression, Anxiety and Stress Scale; LED = Levodopa Equivalent Dose; HVLT = Hopkins Verbal Learning Test; PRM = Pattern Recognition Memory; SRM = Spatial Recognition Memory; COWA = Controlled Oral Word Association; SWM = Spatial Working Memory; SOC = Stockings of Cambridge.)

### 3.1.3 Path Analysis for OSA and RBD Sub-Factor

OSA and RBD severity was not predicted by any variable in younger-onset PD, however, in older-onset PD, higher OSA and RBD factor scores were predicted by *shorter* disease duration. In this path model, the severity of OSA and RBD predicted cognition in younger-onset PD only; higher scores predicted poorer visual episodic memory (SRM) and poorer spatial working memory (SWM) (see Figure 5 and Table 5).

In the single-sample model, no variable predicted OSA and RBD factor score; disease duration was no longer significant. The effect of OSA and RBD symptoms on spatial working memory remained significant, albeit the effect had become weaker. There was still an effect of more

severe OSA and RBD symptoms on visual episodic memory. However, poor visual recognition memory (PRM) was now predicted by OSA and RBD symptoms, while the significant effect on spatial recognition memory (SRM) revealed in the younger-onset group fell to trend-level. (See Figure 6 and Table 3, Part iii).

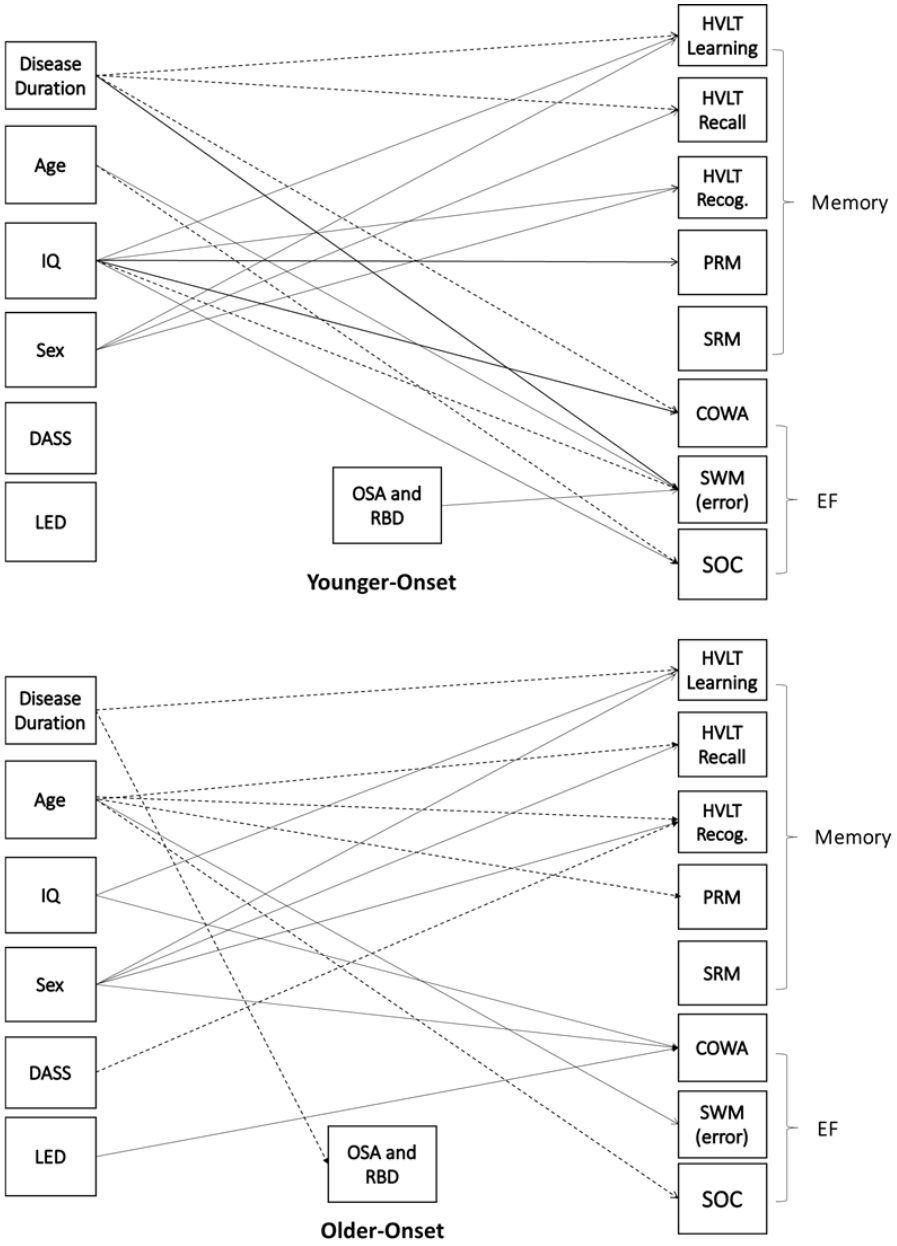


**Figure 5** Path model for the OSA and RBD factor using the combined sample showing significant paths between general sleep factor scores, cognition and participant characteristics. Dotted lines represent negative regression coefficients and solid lines represent positive regression coefficients. Regression paths all significant at .05; for standardised beta weights, standard errors and p-values, please see Table 3, Part ii. (*Note*: EF = executive function; DASS = Depression, Anxiety and Stress Scale; LED = Levodopa Equivalent Dose; HVLT = Hopkins Verbal Learming Test; PRM = Pattern Rccognition Memory; SRM = Spatial Recognition Memory; COWA = Controlled Oral Word Association; SWM = Spatial Working Memory; SOC = Stockings of Cambridge.)

**Table 5** Standardised regression coefficients, standard errors and significance values for the multi-group path models of OSA and RBD symptoms factor scores.

| | Younger Onset | | | Older Onset | | |
|---|---|---|---|---|---|---|
| **Dependent Variable**<br>**Predictor Variable** | *β* | *SE* | *P* | *β* | *SE* | *P* |
| ***OSA and RBD*** | | | | | | |
| **Disease Duration** | | | | -0.25 | 0.12 | .030 |
| **Memory** | | | | | | |
| **HVLT Total** | | | | | | |
| **Disease Duration** | -0.23 | 0.09 | .010 | | | |
| **Age** | | | | -0.34 | 0.10 | .001 |
| **Premorbid IQ** | 0.42 | 0.09 | <.001 | 0.26 | 0.09 | .003 |
| **Sex** | 0.32 | 0.08 | <.001 | 0.39 | 0.09 | <.001 |
| **HVLT Recall** | | | | | | |
| **Disease Duration** | -0.24 | 0.10 | .020 | | | |
| **Age** | | | | -0.40 | 0.11 | <.001 |
| **Premorbid IQ** | 0.42 | 0.09 | <.001 | | | |
| **Sex** | 0.35 | 0.09 | <.001 | 0.38 | 0.10 | <.001 |
| **HVLT recognition** | | | | | | |
| **Age** | | | | -0.26 | 0.13 | .049 |
| **Premorbid IQ** | 0.35 | 0.08 | <.001 | | | |
| **Sex** | 0.28 | 0.08 | .001 | 0.34 | 0.09 | <.001 |
| **DASS** | | | | -0.28 | 0.10 | .005 |
| **PRM** | | | | | | |
| **Age** | | | | -0.36 | 0.10 | <.001 |
| **Premorbid IQ** | 0.34 | 0.10 | .001 | | | |
| **SRM** | | | | | | |
| ***OSA and RBD*** | -0.21 | 0.09 | .013 | | | |
| **Age** | -0.22 | 0.10 | .028 | | | |
| **EF** | | | | | | |
| **COWA** | | | | | | |
| **Disease Duration** | -0.23 | 0.11 | .040 | | | |
| **Premorbid IQ** | 0.38 | 0.08 | <.001 | 0.52 | 0.08 | <.001 |
| **Sex** | | | | 0.39 | 0.08 | <.001 |
| **SWM** | | | | | | |
| ***OSA and RBD*** | 0.20 | 0.08 | .015 | | | |
| **Disease Duration** | 0.34 | 0.11 | .002 | | | |
| **Age** | 0.25 | 0.09 | .007 | 0.36 | 0.11 | .001 |
| **Premorbid IQ** | -0.24 | 0.09 | .004 | | | |
| **SOC** | | | | | | |
| **Age** | -0.28 | 0.11 | .013 | -0.31 | 0.13 | .014 |
| **Premorbid IQ** | 0.33 | 0.09 | <.001 | | | |

*Note*: HVLT = Hopkins Verbal Learning Test; DASS = Depression, Anxiety and Stress Scale; LED = Levodopa equivalent dose; PRM = Pattern Recognition Memory; SRM = Spatial Recognition Memory; COWA = Controlled Oral Word Association; SWM = Spatial Working Memory; SOC = Stockings of Cambridge.

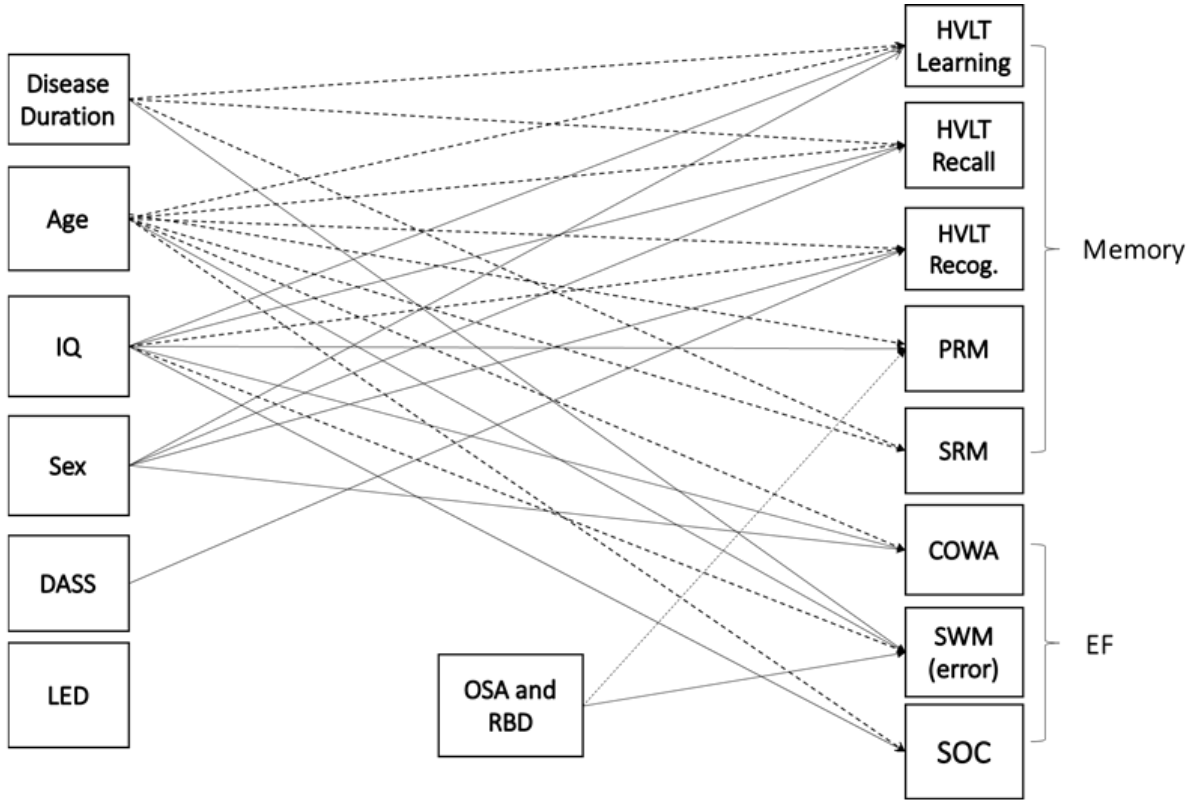


**Figure 6** Path model for the OSA and RBD factor using the combined sample showing significant paths between general sleep factor scores, cognition and participant characteristics. Dotted lines represent negative regression coefficients and solid lines represent positive regression coefficients. Regression paths all significant at .05; for standardised beta weights, standard errors and p-values, please see Table 3, Part ii. (*Note*: EF = executive function; DASS = Depression, Anxiety and Stress Scale; LED = Levodopa Equivalent Dose; HVLT = Hopkins Verbal Learning Test; PRM = Pattern Recognition Memory; SRM = Spatial Recognition Memory; COWA = Controlled Oral Word Association; SWM = Spatial Working Memory; SOC = Stockings of Cambridge.)

## 4. Discussion

The present study tested two hypotheses: First, that specific clusters of self-reported sleep symptoms would i) be predicted by different variables in younger- and older-onset PD, and ii) differentially predict cognition in younger and older-onset PD. The second, that these relationships would be weaker or obscured when the sample was analysed as a whole, rather than by age of onset group. Both hypotheses were supported by path analysis.

The older-onset group was older, with shorter disease duration, lower LED and was disproportionately male. In older-onset PD, significantly poorer performance across the majority of neuropsychological tests was evident, consistent with previous research exploring cognitive subtypes in PD [21]. Sleep symptoms were similar for both groups with respect to both general sleep disturbance and OSA and RBD symptoms. Those with younger-onset PD, however, reported more severe insomnia symptoms.

### *4.1 General Sleep Disturbance and Insomnia*

#### 4.1.1 Predictors of Sleep

Poorer mood predicted increased general sleep disturbance in both younger and older-onset PD. Additionally, both shorter disease duration and higher LED predicted general sleep disruption in the older-onset group. None of the variables in our model predicted insomnia in younger-onset PD. However, in older-onset PD, higher LED (as in general sleep disturbance) and being female were both associated with increased insomnia severity.

Considering the evidence that sleep is increasingly disturbed with the progression of PD [40], our finding that *shorter* disease duration predicted *more* disturbed sleep appears counterintuitive. However, compared to the younger-onset group, the older-onset group had shorter disease duration and higher LED, both of which predicted increased general sleep disturbance, and, in the case of LED, more severe insomnia. These findings are consistent with the observation that, in the early stages of PD, dopaminergic treatment tends to disrupt sleep via overstimulation of D2 receptors [41, 42]. As PD progresses, pharmacotherapy no longer has marked effects on sleep architecture due to loss of D2 receptors [43, 44].

#### 4.1.2 The Relationship between Sleep and Cognition

In younger-onset PD, increased general sleep disturbance predicted *better* verbal recall memory, whilst increased overall sleep disturbance predicted *poorer* performance on both tests of visual recognition memory in older-onset PD. Similarly, in younger-onset PD, higher insomnia scores predicted *better* verbal recognition memory and *better* verbal fluency. These results are consistent with previous work which found more night-time sleep problems were predicted by younger age, female sex, higher L-Dopa dosages and better cognition [45]. Simultaneously, more severe insomnia predicted *poorer* spatial working memory (SWM) performance in older-onset PD.

Executive function deficits are relatively common in PD and are not necessarily indicative of severe cognitive decline [46, 47]. Spatial working memory (SWM) is a measure of EF that is exceptionally sensitive to deficit. In PD, SWM is affected early in the disease course, followed by visual working memory then verbal recognition memory [48]. Moreover, a cumulative 'loss' of protective factors in this group may make those with older-onset PD particularly sensitive to sleep loss. Sex did not predict SWM performance in either group, however, in the younger-onset group, higher premorbid IQ (i.e. greater cognitive reserve) [49] and younger age predicted fewer SWM errors. Neither factor had an effect in older-onset PD. It may be that the compound effects of ageing and PD deplete cognitive reserve, such that it no longer forms a cognitive 'buffer', and additional insults, such as inadequate sleep, are more apparent.

#### 4.1.3 Why does Poorer Sleep Predict Better Cognition?

There were paths in both the general sleep disruption and insomnia models where results were counter-intuitive: poorer sleep predicted *better* cognition. It is tempting to draw on a neurobiological account to explain these results, where low scores on the general sleep disruption and insomnia factors serve as proxies for sleepiness. In sleep medicine, the principle of homeostatic sleep pressure contends that if an individual has poor sleep during the night, they will

be sleepier the next day [50]. However, in PD there seems to be an uncoupling of night-time sleep quality and daytime arousal in many individuals such that difficulty sleeping at night is instead associated with higher levels of daytime arousal [50]; it is not an unreasonable hypothesis to expect a cognitive advantage associated with higher levels of physiological arousal. Indeed, in PD daytime sleepiness, associated with erosion of the ascending arousal systems, is frequently associated with impaired cognition and may precede dementia [51, 52].

However, examination of the regression coefficients across path models suggests that this simple neurobiological account is unlikely to explain entirely the different pattern of results between the two groups. Each of these 'counter-intuitive paths' share a common feature; they predict verbal tasks, where sex is a strong predictor of performance. None of the non-verbal memory tasks (SRM, PRM) or EF tasks (SWM, SOC) was predicted by poor sleep. If lower scores on the general and insomnia factors, indicated less sleep disturbance due to increased sleepiness arising from damage to arousal mechanisms, we would expect that increased general sleep disturbance or insomnia would predict better performance across a cognitive domain, or sub-domain, irrespective of whether the task is verbal or visual.

There is a tendency for women to outperform men on verbal (but not visual) neuropsychological tests by a small margin [53]. This gender difference may be amplified in PD due to differences in the way PD manifests in and is experienced by men and women. While men tend to have more severe motor and non-motor symptoms, women report more distress associated with these symptoms [54]. The motor symptom profile shows some variation by gender: women more frequently present with tremor as their first symptom whilst men demonstrate an increased propensity toward rigidity [55]. There are also systematic differences in sleep symptoms: many studies have described an increased prevalence of RBD in men [56], and EDS is also more common in men. In contrast, insomnia is more frequent in women [57]. Finally, men are at greater risk for cognitive impairment than women [58, 59].

Taken together, there are differences in how men and women tend to experience and self-report symptoms, in the manifestation of PD symptoms impacting sleep, and, in the variables we are most interested in measuring: sleep disturbance and cognition. Therefore, a path model should include sex, *not* as a covariate, but as a *moderator*. However, sample size (particularly in the older-onset group, which was ~80% male), precluded this analysis.

It is unlikely, however, that sex is the only factor driving the relationships between poorer sleep and better cognition. A second, potential, moderating variable which should be considered in future path models is cognitive reserve. A recent meta-analysis [60], revealed an association between greater cognitive reserve and higher scores on tests of global cognitive function, attention, visuospatial function, memory, and EF in PD. Premorbid verbal IQ predicted performance for all tests in the younger-onset group (excepting SRM) but was frequently not a predictor of performance in the older-onset group. Moreover, whether or not premorbid IQ predicted performance on a given test in older-onset PD varied between models (i.e. depending on sleep factor). This suggests an interaction between cognitive reserve and specific clusters of sleep symptoms in older-onset PD. Again, sample size precluded investigation of such an interaction hypothesis.

### *4.2 OSA and RBD*

Our path models did not predict OSA and RBD severity in younger-onset PD and the only variable associated with more severe symptoms in older-onset PD was *shorter* disease duration. This result is unexpected, as prior studies of predictors of OSA and RBD in PD have noted that the risk of both disorders increases with age, disease duration, and male sex [40, 44].

Higher OSA and RBD symptom scores predicted poorer performance on EF (spatial working memory) and memory (spatial recognition memory) in younger-onset PD but did not predict cognition in the older onset group. The lack of association between most cognitive tasks and OSA and RBD was also unexpected, given that both OSA and RBD have been shown to be related to deficits in memory and EF, even independently of PD. Verbal episodic memory, visual memory, attention, EF, non-verbal learning, and planning are frequently affected both in idiopathic RBD (iRBD) and PD-RBD [61-63]. In people with OSA, the domains of attention, delayed verbal and visual memory, visuospatial/ constructional ability and EF are particularly impaired [64].

One possibility for a lack of association between OSA and RBD symptoms and cognition is that the index of sleep was a self-report measure. While self-report measures, in general, may be relatively insensitive to OSA and RBD, we used only a sub-factor derived from 4 items on an omnibus scale of sleep disorder in PD. The items measuring SRBD and RBD are worded in such a way that they are likely to have high specificity but may be insensitive to subtle manifestations of both disorders. For example, items '5. Do you have violent behaviours such as hitting your spouse or falling out of bed when acting out dreams at night?' and '7. Are you told by others that you snore loudly and have breathing pauses (Both) during the night?' [22] may be insensitive to less marked, but nonetheless significant symptoms (p320). Further, sleep-related breathing disorders may be less apparent in older adults, who often do not fit the classic 'profile' of younger apnoeic patients (snoring, observed arousals, elevated BMI) [65]. Clearly, patients will not report symptoms of which they are not aware.

Similarly, iRBD typically presents with violent, dream-enacting behaviour prompting further investigation [66]. In PD, this behaviour is often less dramatic and is, therefore, less likely to be recognised. The sensitivity to detect RBD in PD via self-report is highly variable and frequently depends either on the patient's own awareness of the condition, or family reports of behaviour consistent with RBD [67, 68]. The OSA and RBD symptoms factor of the PDSS-R likely identifies only patients with florid manifestations of OSA or RBD. Objective sleep assessment is needed to explore the unique contributions of OSA and RBD to impaired memory and EF performance.

## 5. Conclusions

This study demonstrates that the relationships between self-reported sleep and cognition are markedly different in younger and older-onset PD. Further research is needed to delineate the effects of sleep quality from physiological arousal and to explore whether the relationship between sleep and cognition is modified by sex or cognitive reserve. Path analysis is a powerful tool for visualising the relationships between variables. It will be important to test the utility of split-group path analysis in a larger, gender-balanced sample, with more sensitive, objective sleep measures.

## Additional Materials

The following additional materials are uploaded at the page of this paper.

1. Table S1: Model fit indices for path models.
2. Table S2: Standardised regression coefficients, standard errors and significance values for the multi-group path models of general factor scores.
3. Table S3: Standardised regression coefficients, standard errors and significance values for the multi-group path models of insomnia factor scores.
4. Table S4: Standardised regression coefficients, standard errors and significance values for the multi-group path models of OSA and RBD symptoms factor scores.
5. Table S5: Standardised regression coefficients, standard errors and significance values for single-sample path models for general, insomnia and, OSA and RBD PDSS-R factors.

## Author Contributions

Project conceptualisation, Data Analysis, Writing first draft- MEP, RSB; Major Editing- MEP; Project Management, Participant recruitment, Manuscript refinement, Data Management – MGT, NG, AML, RSB.

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## Competing Interests

The authors have declared that no competing interests exist.

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