



Physical activity and cognition in young-onset Parkinson's disease

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Background: A relationship has been observed between physical activity and cognition in older-onset Parkinson's disease, as well as improvements in cognition after a physical activity intervention. To date, this has not been investigated in young-onset Parkinson's disease (YOPD).

Objectives: To examine the baseline relationship between physical activity and cognition in YOPD; and to examine whether a physical activity intervention can improve cognition in YOPD.

Methods: Two interrelated online studies were conducted. In the first study, 132 participants with YOPD completed self-reported measures of physical activity, and objective and subjective measures of cognition. A subset of 38 participants was then randomly allocated to either a six-week physical activity intervention or control condition. Following the intervention, participants repeated the objective and subjective cognitive measures.

Results: No relationship was found between self-reported physical activity and objective cognition; however, there was a relationship between physical activity and subjective cognition. Similarly, following the intervention subjective improvements were found for concentration, attention, and processing speed, but not for memory. Furthermore, medium effect sizes were evident for objective measures of processing speed and small-medium effect sizes for planning and cognitive flexibility, although statistical significance was not reached.

Conclusions: In this first study investigating physical activity and cognition in YOPD, the results suggest that increased physical activity relates to improved processing speed and attention. Replication is recommended with a larger sample size. A longer, more intense physical activity manipulation and utilizing the study's strengths of on-line recruitment and intervention delivery are also recommended.

KEYWORDS

cognition, early-onset Parkinson's disease, intervention, non-motor symptoms, physical activity

1 | INTRODUCTION

Cognitive impairments are frequently observed in people with Parkinson's disease (PD) and are a major determinant of quality of life.¹⁻³ Recent research has suggested a relationship between physical activity (PA) and cognition in PD, whereby people who report greater levels of physical activity are less likely to experience objective cognitive impairments, specifically in semantic fluency and verbal episodic memory.⁴ Moreover, a recent systematic review suggests that PA interventions can improve aspects of cognition (eg, verbal fluency, cognitive flexibility, planning) in PD, both in animal models and in humans⁵; however, to date PA intervention studies have predominantly used participants over the age of 60 (mean 58.6-74.4 years).⁶⁻¹⁵ It is widely established, however, that PA interventions can improve cognition (eg, global cognition, executive function, inhibition, memory, attention) in typically aging adults over the age of 60.^{3,16-19} Therefore in older adults, with or without PD, cognitive improvements would be expected after a PA intervention, due to age-related processes.

Approximately 10% of people with PD have young-onset PD (YOPD),²⁰ and it is unknown whether PA improves cognition for them. While there is considerable overlap in the characteristics of YOPD and older-onset PD, some important differences have been established.^{21,22} Notably, people with YOPD are more likely to have a slower disease progression than people with older-onset PD, and as a result, they live longer with the disease.²¹ Despite the slower progression of symptoms, people with YOPD are more likely to develop dyskinesias (abnormality or impairment of voluntary movement) and dystonias (eg, twisting, repetitive movements, or abnormal posture), and experience motor fluctuations (eg, medication *on-off* effects) earlier than people with older-onset PD.^{21,22} Furthermore, as people with YOPD are diagnosed during the most productive years of their life, psychosocial issues arise that are not relevant to people with older-onset PD. For example, compared to people with older-onset PD, with similar disease duration and severity, people with YOPD are more likely to be unemployed or have retired early, experience greater marital and family difficulties, perceive more stigma, to be depressed, and rate their quality of life as worse.²³ Thus, it is important to study people with YOPD independently of older-onset PD as a result of the unique challenges and stressors they encounter.

Additionally, it is unclear whether the observed improvement in cognition in PD interventional studies is due to the expected effect when anyone over the age of 60 undertakes additional exercise, or whether improvements are associated with mechanisms related to PD. Investigating a young-onset population may help further the knowledge in this area, as the effect of age-related improvements is eliminated.

The aims of the present study were twofold: firstly, to examine the baseline relationship between PA and cognition in people with YOPD; and secondly, to investigate, via a pilot randomized controlled trial, to what extent a PA intervention can improve cognition in YOPD.

2 | MATERIALS AND METHODS

2.1 | Study design and participants

Given the difficulties in recruiting a sufficient sample of YOPD locally, the study made use of novel online recruitment methods to ensure the enrollment of a large sample in the study. Two interrelated online studies were undertaken: Study 1 was a correlational study between self-reported PA and cognition, and Study 2 was a pilot randomized controlled trial of the effects of a PA intervention on cognition.

Study 1 consisted of 132 participants (68 males and 64 females) with YOPD. Ages ranged from 30 to 60 years ($M = 50.96$, $SD = 6.60$), and time since diagnosis ranged from 1 month to 20 years and 3 months ($M = 5.48$, $SD = 4.24$). A subset of participants (20 males and 18 females) from Study 1 participated in the second study. Ages ranged from 35 to 59 years ($M = 50.26$, $SD = 6.90$), and time since diagnosis ranged from 1 month to 18 years and 5 months ($M = 4.46$, $SD = 4.07$). Analyses comparing participants across the two studies did not find any significant differences in gender, age, or time since diagnosis, indicating the sample in Study 2 was representative of the complete sample. Furthermore, the intervention and control groups in Study 2 did not differ on any demographic variables. Further sample characteristics for both studies are summarized in Table 1.

Participants were recruited via social media (national and international Facebook community support groups), national and international PD organizations (websites and Facebook pages), the Michael J Fox Foundation, and the Australian Parkinson's Disease Registry. The inclusion criteria for both studies were as follows: (a) a diagnosis of YOPD, (b) ability to complete the questionnaires and cognitive tasks without assistance, and (c) adequate English skills to be able to read the questionnaire and cognitive task instructions. To ensure that participants were physically capable of undertaking the intervention, an additional inclusion criterion for Study 2 was medical approval from a health professional (eg, general practitioner, neurologist/ movement disorder specialist). Exclusion criteria for Studies 1 and 2 were as follows: (a) dementia diagnosis, (b) age > 60, and (c) any impairment (eg, visual) that would interfere with study participation. Separate informed consent was obtained prior to participation in Study 1 and Study 2. Ethics approval was obtained from the La Trobe University Human Ethics Committee.

2.2 | Flow of participants

Two hundred and sixteen participants consented to participate in Study 1. Of these, one did not meet the selection criteria and eighty-three did not complete at least one objective measure of cognition. Moreover, the number of cases used in the primary analysis varied as some participants were unable to complete all four cognitive tasks, due to technical difficulties, such as incompatibility of smart device (eg, an iPad) with the software used by

TABLE 1 Demographic characteristics of participants (Study 1, N = 132; Study 2, N = 38)

Characteristics	Study 1		Study 2	
	n	%	n	%
Educational achievement ^a				
Non-tertiary	39	29.5	10	26.3
Tertiary	93	70.5	28	87.5
Employment status ^{a,b}				
Full time	54	41.5	15	39.8
Part time	23	17.7	9	23.7
Unemployed	16	12.3	4	10.5
Retired	35	26.9	7	18.4
Home duties	4	3.1	3	7.9
Relationship status ^{a,c}				
Single	8	6.1	3	7.9
Non-cohabiting partner	8	6.1	2	5.3
Married/de facto	103	78.6	30	78.9
Divorced/separated	11	8.4	2	5.3
Widow/er	1	0.8	1	2.6
Country of residence ^a				
United States of America	78	59.1	18	47.4
Australia and New Zealand	22	16.7	7	18.4
Canada	12	9.1	5	13.2
United Kingdom	8	6.1	2	5.3
Europe	5	3.8	3	7.9
Central and South America	3	2.3	2	5.3
Asia	2	1.5	0	0.0
Russian Federation	1	0.7	1	2.6
South Africa	1	0.7	0	0.0
Cognitive measure ^a				
MFS (mean, SD) ^d	3.22	0.59	0.00	0.00
Detection.RT (median, IQR) ^e	2.56	0.13	2.53	0.08
OneBack.RT (median, IQR) ^e	2.88	0.10	2.87	0.10
ToL.Tot (median, IQR) ^e	32.00	5.00	33.00	6.46
WCST.Perserr (median, IQR) ^e	8.00	4.00	6.00	3.18

Note: Total of percentages do not equal 100 for every characteristic due to rounding.

Abbreviations: Detection.RT, Cogstate Detection reaction time; MFS, Mental Flexibility Scale; OneBack.RT, Cogstate One Back reaction time; ToL.Tot, Tower of London total score; WCST.Perserr, Wisconsin Card Sorting Test perseverative errors.

^aNo significant differences between Study 1 and Study 2.

^bStudy 1, n = 130.

^cStudy 1, n = 131.

^dNot measured for Study 2.

^eMedian and interquartile range are reported for raw scores and analyses conducted with transformed scores.

the participants for undertaking the survey, difficulty downloading the plug-in, or the computer freezing while undertaking the tasks.

Figure 1 shows the flow of participants and the number of participants that were analyzed for each objective measure of cognition for Study 2. A small number of participants also had technical difficulties in the second study.

2.3 | Assessments

Questionnaires and cognitive tasks were accessed via Qualtrics²⁴ (online survey software), including general health and demographic data. The cognitive tasks used Cogstate²⁵ and Inquisit²⁶ software via embedded hyperlinks.

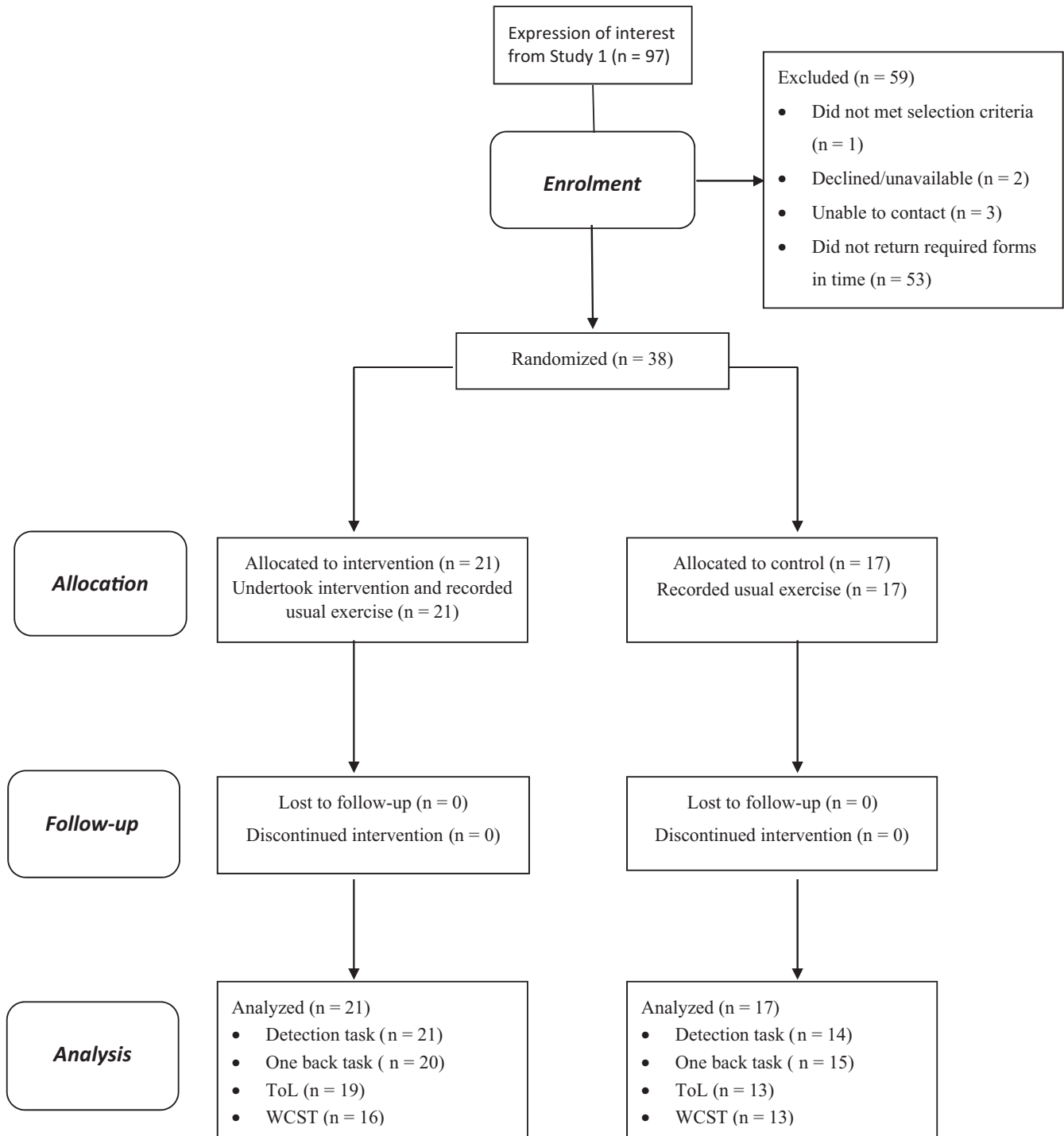


FIGURE 1 Participant flow through Study 2. Note: ToL, Tower of London, WCST, Wisconsin Card Sorting Test

2.4 | Physical activity assessment

The International Physical Activity Questionnaire²⁷ was used to measure participants' current self-reported levels of PA. The participants' weekly PA was determined by calculating the duration x frequency x metabolic equivalent (MET) intensity (weighted energy expenditure) of PA and reported as MET-min.

2.5 | Cognitive assessments

Cognitive measures chosen for this study had to be suitable for on-line delivery and be physically appropriate for someone with YOPD (eg, not requiring fine motor skills).

Objective cognitive outcomes for Studies 1 and 2 were as follows: processing speed, which was measured by reaction time on the

Cogstate Detection Task²⁵; attention, which was assessed by reaction time on the Cogstate One Back Task²⁵; planning abilities, which were measured by number of moves on the Tower of London Task²⁸; and cognitive flexibility, which was assessed by number of perseverative errors on the Wisconsin Card Sorting Test.²⁹

Subjective cognitive measures for Study 1 included asking participants to indicate (yes/no) whether they had difficulties with multitasking, learning new skills, concentrating, making decisions, judging distances, and memory. They also completed the 12-item Mental Flexibility Scale.³⁰

Subjective cognitive measures for Study 2 were as follows: a post-intervention questionnaire that asked participants to rate changes in multitasking, learning new skills, concentrating, making decisions, judging distances, and memory, over the six-week intervention period, on a 5-point Likert scale (ranging from 1 = *a lot worse* to 5 = *a lot better*). Participants were also asked whether their abilities on seven everyday cognitive activities (eg, recall of appointment details, names of people, or plots of movies or books) had changed over the past six weeks, which were also rated on a 5-point Likert scale (ranging from 1 = *a lot worse* to 5 = *a lot better*).³⁰

2.6 | Study procedures

2.6.1 | Study 1

Advertisements for the study contained a hyperlink that directed participants to the online survey documents, where participants completed all the demographic and health questionnaires and accessed the Cogstate and Inquisit software via embedded hyperlinks to complete the cognitive tasks. Overall, the questionnaires and cognitive tasks took between 30 and 40 minutes to complete.

2.6.2 | Study 2

Upon completion of Study 1, participants were invited to participate in a randomized controlled trial, which involved a six-week walking activity taking approximately two hours per week. This was comparable to PA studies in older people with PD.^{7-9,12,13} Interested participants were emailed a consent form and were asked to obtain their health professional's approval to participate in the intervention. Upon return of the consent form and medical approval, participants were randomly allocated using a computer algorithm to either the control group or the intervention group, stratified according to gender. The control group participants were asked to continue with their usual exercise for six weeks. The intervention group participants were asked to add walking at a comfortable pace for 30 minutes, four times a week, for six weeks to their usual routine. Both groups were sent weekly emails to record their usual PA for the previous week.

At the end of the six-week period, participants were sent an email with a hyperlink to the post-intervention survey, which took approximately 25 minutes to complete and consisted of the

post-intervention questionnaire (including general cognitive abilities questions) and the four cognitive tasks.

2.7 | Statistical analysis

Normality of distribution of the data was checked. Outliers were assigned the nearest non-outlier value plus 0.01, and denoted with the superscript "O." Variables that were not normally distributed were transformed using natural logarithm or reflect natural logarithm to rectify for skewness or kurtosis, and are thus denoted with the superscripts "LN" and "RLN," respectively. Reflected variables were re-reflected after transformation for ease of interpretation.

2.7.1 | Study 1

A series of hierarchical multiple regressions were used to determine whether self-reported PA levels predict cognition (objective processing speed, attention, and planning, and subjective and objective cognitive flexibility) in YOPD, after controlling for individual characteristics (age, education, and years since diagnosis). In addition, bivariate correlational analyses were performed to explore the relationship between self-reported PA and subjective cognitive deficits in multitasking, learning new skills, concentrating, making decisions, judging distances, and memory in YOPD.

2.7.2 | Study 2

A series of one-way analyses of covariance (ANCOVAs) were used to compare mean differences between the intervention and control group on cognitive (processing speed, attention, planning, and cognitive flexibility) measures after the PA intervention. Preintervention cognitive scores were used as covariates. *t* tests were used to compare mean differences between the intervention and control group on subjective measures of changes in non-motor symptoms, and general cognitive abilities. As Study 2 was conducted as a pilot study, statistical significance was not anticipated.

Effect sizes were interpreted in accordance with Cohen's conventions.³¹ All statistical tests were two-tailed, with an α of 0.05.

3 | RESULTS

3.1 | Intervention fidelity

Of the 21 participants in the intervention group, 19 completed the stipulated intervention (total additional walking hours, two hours per week, for 6 weeks), with seven (33%) completing more than the stipulated intervention (average three hours and five minutes per week). Two participants (9.5%) completed less than the stipulated intervention (average one hour and 15 minutes per week). This is

TABLE 2 Hierarchical multiple regression analyses predicting cognition

Cognitive measure	Predictors	β	ΔR^2	P
MFS	Step 1			
	Age ^{RLN}	0.12	.02	.288
	Education	0.10		
	Step 2			
	Dx.years ^{LN}	0.03	<.01	.889
	Step 3			
	Self-reported PA.TA ^{LN}	2.87	.08	.001*
Detection.RT ^{LN}	Step 1			
	Age ^{RLN}	-0.12	.04	.107
	Education	-0.14		
	Step 2			
	Dx.years ^{LN}	0.04	<.01	.690
	Step 3			
	Self-reported PA.TA ^{LN}	-0.05	<.01	.599
OneBack.RT ^{OLN}	Step 1			
	Age ^{RLN}	-0.07	.01	.551
	Education	-0.09		
	Step 2			
	Dx.years ^{LN}	-0.04	<.01	.635
	Step 3			
	Self-reported PA.TA ^{LN}	0.12	.01	.199
Tol.Tot ^{ORLN}	Step 1			
	Age ^{RLN}	0.13	.01	.626
	Education	-0.05		
	Step 2			
	Dx.years ^{LN}	0.14	.02	.228
	Step 3			
	Self-reported PA.TA ^{LN}	-0.01	<.01	.928
WCST.Perserr ^{OLN}	Step 1			
	Age ^{RLN}	-0.02	.01	.591
	Education	-0.13		
	Step 2			
	Dx.years ^{LN}	-0.06	<.01	.588
	Step 3			
	Self-reported PA.TA ^{LN}	0.09	.01	.473

Abbreviations: Detection.RT^{LN}, Cogstate Detection reaction time; Dx.years, number of years diagnosed with PD; MFS, Mental Flexibility Scale; OneBack.RT^{OLN}, Cogstate One Back reaction time; Self-reported PA.TA^{LN}, leisure-time activity MET-min; Tol.Tot^{ORLN}, Tower of London total score; WCST.Perserr^{OLN}, Wisconsin Card Sorting Test perseverative errors.

* $P < .001$.

comparable to participation rates in other PA interventions in community samples.¹⁸ No adverse events or side effects were reported.

3.2 | Study 1: Relationship between self-reported PA and cognition in YOPD

Five hierarchical multiple regressions (Table 2) showed that self-reported PA did not predict processing speed (Detection.RT^{LN}), attention (OneBack.RT^{OLN}), planning (Tol.Tot^{ORLN}), or objective cognitive

flexibility (WCST.Perserr^{OLN}); however, self-reported PA did predict subjective cognitive flexibility (MFS). Demographic variables (Step 1) and years of diagnosis (Step 2) did not explain any variance in the model, whereas self-reported PA (Step 3) explained 8% of the variance in subjective cognitive flexibility, F change (1, 124) = 11.25, $P < .001$.

Next, to explore the relationship between self-reported PA and self-reported cognitive deficits, point-biserial correlational analyses were performed. Small-to-medium positive correlations were found between self-reported PA and subjective cognition ($n = 132$):

TABLE 3 Pre- and post-intervention means and standard deviations, and analysis of covariance results for cognitive measures

Measure	Intervention group				Control group control group				df	F	P	Cohen's d
	Preintervention		Post-intervention		Preintervention		Post-intervention					
	M	SD	M	SD	M	SD	M	SD				
Detection.RT ^{LN}	-0.57	0.20	-0.62	0.13	-0.62	0.21	-0.55	0.14	(1, 32)	3.37	.076	0.65
OneBack.RT ^{OLN}	-0.12	0.12	-0.13	0.10	-0.16	0.10	-0.12	0.12	(1, 31)	0.22	.640	0.17
ToL.Tot ^{ORLN}	2.13	1.15	2.49	0.90	2.39	0.84	2.86	0.72	(1, 28)	1.19	.285	0.41
WCST.Perserr ^{OLN}	2.48	0.41	2.35	0.23	2.48	0.37	2.43	0.23	(1, 22)	0.61	.443	0.33

Abbreviations: Detection.RT^{LN}, Cogstate Detection reaction time; OneBack.RT^{OLN}, Cogstate One Back reaction time; Preintervention M, Mdn; SD = IQR; ToL.Tot^{ORLN}, Tower of London total score; WCST.Perserr^{OLN}, Wisconsin Card Sorting Test perseverative errors.

TABLE 4 Post-intervention differences in subjective cognitive changes

	Intervention group		Control group		df	t	P	Cohen's d
	M	SD	M	SD				
Cognitive symptom								
Multitasking	3.19	0.60	3.06	0.56	36.00	0.69	.492	0.22
Learning new skills	3.14	0.36	3.06	0.24	36.00	0.83	.415	0.26
Concentrating	3.47	0.51	2.88	0.33	34.54	4.31	<.001***	1.34
Making decisions	3.35	0.67	3.00	0.50	34.47	1.82	.078	0.58
Judging distances	3.14	0.57	3.11	0.33	36.00	0.16	.873	0.06
Memory	3.24	0.70	3.06	0.24	25.66	1.10	.284	0.33
Everyday cognitive abilities								
Paying attention	3.48	0.60	2.94	0.24	27.45	3.72	.001***	1.13
Switching attention tasks	3.33	0.58	3.06	0.24	28.01	1.97	.058	0.59
Memory	3.19	0.68	3.00	0.35	31.24	1.11	.275	0.34
Problem-solving	3.52	0.51	3.23	0.44	35.87	1.87	.069	0.60
Thinking speed	3.57	0.68	3.12	0.33	30.33	2.70	.011*	0.81
Perceiving visual information	3.38	0.67	3.06	0.24	26.16	2.05	.051	0.61
Managing daily activities	3.43	0.60	3.00	0.50	35.95	2.41	.021*	0.77

*P < .05.

***P < .001.

multitasking, $r_{pb} = .21, P < .05$, concentrating, $r_{pb} = .24, P < .01$, making decisions, $r_{pb} = .27, P < .01$, and judging distances, $r_{pb} = .21, P < .05$. No significant correlation was found between self-reported PA and subjective learning of new skills, $r_{pb} = .02, P = .857$, or memory, $r_{pb} = .12, P = .166$.

3.3 | Study 2: Cognitive performance post-PA intervention

As summarized in Table 3, after controlling for preintervention cognitive scores, there were no significant differences between the

intervention and control group on any of the cognitive measures; however, a medium effect size ($d = 0.65$) was detected for processing speed (Detection.RT^{LN}) and small-to-medium effect sizes ($d = 0.41$ and $d = 0.33$, respectively) for planning (Tol.Tot) and cognitive flexibility (WCST.Perserr^{O.LN}). There was a crossover interaction between the two groups, with the control group performing better than the intervention group on the cognitive measures preintervention and post-intervention. The results indicated that the intervention group's cognitive scores improved, while the control group's cognitive scores declined.

Next, a series of independent-samples *t* tests were conducted to determine whether there were mean differences between the intervention and control group on subjective cognitive changes post-intervention. As shown in Table 4, with the exception of concentrating, there were no significant changes in subjective cognitive symptoms. The difference in means was significant for concentrating (mean difference = 0.59, 95% CI [0.31, 0.87], $d = 1.34$), with the intervention group reporting greater subjective improvements.

Finally, a series of independent-samples *t* tests were conducted to determine mean differences between the intervention and control groups on subjective changes in everyday cognitive abilities post-intervention. As shown in Table 4, the difference in means was significant for three tasks/abilities, with an extra-large effect size ($d = 1.13$) for paying attention, and large effect sizes for thinking speed ($d = 0.81$) and for managing daily activities ($d = 0.77$), with the intervention group showing greater subjective improvements.

4 | DISCUSSION

The current study was the first to investigate the relationship between PA and cognition in YOPD. Furthermore, the present pilot study is the first to conduct a remote randomized controlled trial PA intervention investigating cognition in YOPD (or older-onset PD). Moreover, this is the first study in PD (YOPD or older-onset PD), to use both subjective and objective measures of cognition to assess a PA intervention. As such, the study sheds novel insights into the relationship between PA and cognition in PD.

4.1 | Study 1: Self-reported PA and objective cognition

In this study, self-reported PA did not predict any of the objective measures of cognition (processing speed, attention, planning, or cognitive flexibility). This differs from perhaps the only other study that has investigated the baseline relationship between PA and cognition in PD, whereby a dose-dependent relationship was found.⁴ A possible reason for the discrepancy in findings is the participants in Oguh et al's⁴ study had older-onset PD, whereas participants in this study had YOPD. This could suggest that the relationship between PA and cognition in PD is mediated by age-related factors.

Another possible explanation for the discrepancy in findings is different cognitive domains and processes were under investigation. It is possible that the mechanisms by which PA influences cognitive processes have a stronger effect for the cognitive domains examined by Oguh et al⁴ than the current study.

4.2 | Study 2: PA intervention and cognition

As Study 2 was a pilot study, with a small sample size, statistical significance was not anticipated, which needs to be considered when interpreting the results. None of the objective cognitive measures demonstrated a significant difference between the intervention and control groups after the intervention period, although a medium effect size was evident for processing speed and small-to-medium effect sizes for planning and cognitive flexibility.

Previous studies examining a PA intervention and cognition in PD are conflicting. Some studies have found improvements in processing speed,¹¹ attention,⁸ planning,¹¹ or cognitive flexibility,^{14,15} and other studies have not found an improvement in processing speed^{9,14} or attention.^{6,13,15} An explanation for the discrepancy in the findings in PA interventional studies, including this one, may be due to variation in the duration, frequency, and intensity of PA.^{6,8,13,15} In particular, the intensity of the intervention appears to play an important role. Previous studies have found improvements in cognition after a PA intervention that worked toward a targeted heart rate,¹¹ which were moderate in intensity or maximal speed interventions. In support of this, animal models also suggest vigorous activity improves cognition in PD.^{5,32} Further investigation may assist in understanding the optimal frequency, duration, and intensity of PA required to improve cognition in YOPD (and older-onset PD).

A factor that may contribute to the intensity of the intervention is that all of the previous intervention studies in PD were done with a health professional (eg, a physiotherapist) with most, but not all, encouraging participants to exercise at their maximum capacity, thus potentially strengthening the intervention by utilizing a more intense PA manipulation. In this study, to increase the likelihood of participants' safety, participants were instructed to walk at a pace that was comfortable for them, and therefore, they may not have reached the intensity required for a substantial difference in cognitive performance.

Nevertheless, many PA studies in typically aging populations have similarly used community samples, with participants exercising independently of the researcher/s, and still observe a significant improvement in cognition (for examples, see the following meta-analyses).¹⁷⁻¹⁹ This suggests that exercising with a health professional is not necessarily needed to reach the intensity required for an improvement in cognition. Further research is warranted comparing PA interventions undertaken with and without a health professional, as well as considering the intensity, duration, and frequency of the PA and its effect on cognition. In addition, future studies could use an objective measure of PA, to determine the intensity, duration, and frequency of the PA such as a pedometer or accelerometer;

however, the device would need to be suitable for participants who have a tremor, dyskinesia, or dystonia.

Another possible explanation is that the previously observed improvement in cognition after a PA intervention was not due to mechanisms related to PD; rather, it is due to the expected improvements due to age-related processes. Further studies, which include a young-onset and an older-onset PD group plus an aged-matched control group, may help in the resolution of this line of enquiry.

Despite all this, there was still some evidence of an improvement in cognition after the intervention, and therefore with a larger sample size, significance may have been reached.

4.3 | Studies 1 and 2: PA and subjective cognition

In contrast to the non-significant findings on the objective cognitive measures, a small-to-medium relationship between PA and subjective deficits was found for cognitive flexibility, multitasking, concentrating, making decisions, and judging distances in Study 1. Moreover, in Study 2 participants in the intervention group self-reported significant improvements in thinking speed, concentration, paying attention, and managing daily activities, with medium-to-large effect sizes.

These findings suggest there could be a relationship between PA and cognition in YOPD. This may be explained by subjective cognitive decline being a predictor of future objective cognitive decline. For example, Hong et al's³³ longitudinal study of cognition in PD found that those with subjective cognitive impairments had a greater decline in objective cognition (attention, verbal fluency, memory, visuospatial, and executive functions), after 2.5 years, than those without subjective cognitive impairments. Therefore, it is possible that in a few years' time the participants in this study that self-reported baseline cognitive impairments could show a greater decline in cognition than those who did not. A longitudinal study examining the relationship between subjective and objective cognitive decline in YOPD would further the knowledge in this area.

4.4 | Intervention format

The online recruitment and delivery of the intervention was a strength of this study as it enabled people with YOPD from all over the world to participate. As only 10% of people with PD have YOPD, with many still working, participants with YOPD are usually difficult to access. The online delivery appeared to be an effective method as all participants enrolled in the study completed the intervention with a high compliance (100%) of return of the activity sheets. Furthermore, the intervention is a cost-effective method of delivery, as a skilled professional is not required to conduct the intervention, therefore feasible for large-scale implementation; however, the method of intervention delivery may have been a limitation as undertaking the PA intervention in community setting could have had

an impact on the intensity of the PA (see earlier comments regarding intensity of intervention).

Another limitation of the online recruitment and intervention delivery is not obtaining scores to determine the severity of YOPD. Future studies could collect this information from participant's movement disorder specialist/neurologist when obtaining medical permission to undertake a PA intervention.

5 | CONCLUSIONS

Physical activity and cognition in YOPD is a new area of research, and PA and cognition in PD is an emerging area of research. As this is the first study to examine PA and cognition in YOPD, more research is needed, utilizing the strengths and addressing the limitations of the current study, to support or refute these findings.

These findings suggest that there may be an improvement in cognition in YOPD after a PA intervention. Further replications with a larger sample size and a more intense manipulation may assist in determining whether PA improves cognition in YOPD.

Furthermore, as the intervention group's processing speed, planning, and cognitive flexibility scores improved after the PA intervention it may well be that improvements in these cognitive domains may be related to PD mechanisms and the other cognitive domains are associated with age-related mechanisms. Further research with young- and older-onset PD participants, investigating different cognitive domains (eg, cortical-based and frontostriatal-based functions), will assist in determining this line of inquiry.

Knowledge of interventions to improve cognition in YOPD can potentially improve the quality of life in those with the condition; therefore, it is paramount that more research is conducted.

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Nothing to report.

CONFLICT OF INTEREST

The authors have no conflict of interest to report.

DATA AVAILABILITY

The data that support the findings of this study are available from the corresponding author upon reasonable request.

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