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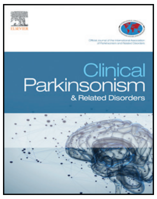

Intact wayfinding abilities in patients with Parkinson's disease

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ABSTRACT

Introduction: Previous studies have found that patients with Parkinson's Disease (PD) showed impairments in certain aspects of spatial orientation. The current study aimed to systematically investigate whether these impairments extend to wayfinding abilities in patients with PD. Wayfinding refers to the ability to navigate to an unseen location in the environment and is essential to one's everyday functioning.

Methods: A total of 24 patients with PD, 20 ability matched controls, 21 college students participated in a series of experimental behavioral tasks and a self-report of environmental abilities. In the route learning task, participants learned and then recalled routes. In the survey learning task, participants were asked to form configurational or survey knowledge. In the map tracing tack, participants were asked to trace the turning directions of a route on a map.

Results: Patients with PD showed no impairments in the behavioral measures of wayfinding relative to ability matched controls. Both groups performed worse than college students, who had higher cognitive levels. Patients with PD, however, reported a higher competency in environmental abilities than college students.

Conclusion: Although wayfinding abilities may decrease as cognitive abilities decline, they do not appear as a unique impairment for patients with PD relative to their cognitive level.

As an epitome of spatial cognition, wayfinding is a complex spatial skill and refers to the ability to identify one's current location and successfully navigate to an unseen location in the environment [1]. It is integral to everyday life, as people often need to travel to and spend time in familiar and unfamiliar environments. Human spatial navigation may not be associated with modular or localized brain functions, but rather depend on brain networks where the retrosplenial region serves as a hub interacting with other critical nodes such as hippocampus, posterior parietal cortex, posterior paraphippocampal cortex, and dorsolateral prefrontal cortex [2]. Wayfinding varies greatly as a function of environmental features, complexity, and scale, and as a function of individual characteristics such as age, intelligence, and experience. It consists of route learning and survey learning abilities [1]. Route learning, such as following a fixed route, is based on an egocentric frame of reference and place-action associations in the sequence of the route. Survey learning, such as forming a mental map of the environment, is based on an allocentric frame of reference and independent of viewing direction and position. Route and survey learning involve different brain networks. For instance, while the parahippocampal and retrosplenial cortex are more involved in route learning, the inferior frontal gyrus is more involved in cartographic map learning [3]. Previous studies have found that people with PD show impairments following route directions [4,5], and are rather inconsistent regarding whether PD patients show deficits in survey-based wayfinding [6,7].

The purpose of this study is to examine a variety of wayfinding abilities for PD patients relative to ability matched controls and college students. Different from previous studies [4–7], the current study employed both experimental procedures and self-reports. Moreover, we employed three measures of wayfinding abilities: route learning, survey learning, and map route tracing. Hence, the current study may provide a more comprehensive picture of wayfinding abilities in people with PD. Also different from previous studies that matched participants on chronological age, we matched participants with PD and controls on cognitive levels (as measured by an intelligence test). Hence, it excludes the possibility that any possible wayfinding deficit is simply a reflection of lower cognitive levels of patients with PD.

1. Method

1.1. Participants

We recruited and tested 24 patients with PD (age: 60.13 ± 9.68 years old) from local hospitals in Guangzhou, China, 20 ability matched controls (i.e., AM, age: 53.85 ± 11.97 years old) from local communities, and 21 college student controls (i.e., CS, age: 19.91 ± 1.48 years old) from the

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local university. As a group, the patients with PD were cognitively within normal limits. Participants in the two control groups were free from any neurological disorders or cognitive deficits via self-report. See Table S1 for more complete information about participant characteristics.

1.2. Tests

All the below measures and tests have been used in a variety of children and adult samples and are suitable for the participants in the current study.

1.2.1. Intelligence tests

The Combined Raven's Test [8] is a standardized intelligence test and measures non-verbal reasoning ability. Different from screening tools such as MMSE and MoCA, Raven's test uses visual patterns that gradually increase in difficulty and can assess a wider range of cognitive ability. Raw scores were used, and there were no differences between PD patients and AM controls, $p = 1.0$; and both were lower than CS controls, $ps < 0.001$.

1.2.2. Route learning task [9]

A virtual reality (VR) environment (Fig. S1) consisted of a set of hallways with 26 turns (11 were choice points) and 20 landmarks (e.g., a green cabinet, a box). In the learning phase, participants watched a video depicting a navigating agent traveling a route through the environment. Participants were instructed to pay attention and try to remember the correct path leading to the destination. The test phase consisted of 3 trials. In the first two trials (the forward trials), the experimenter played the video again, stopped at each choice point, and asked participants which direction to continue. In the third trial (i.e., the backward trial), participants traveled the route in reverse and were asked at each choice point which way to return to the starting location. Accuracy and time (in minutes) for each trial were recorded. After completing all three trials, participants were asked to recall the objects in the environment.

1.2.3. Survey learning task [10]

A different VR environment (Fig. S2) contained a long hallway with 5 turns and 4 landmarks. Participants watched a video where a navigating agent walked the path two times. They were told to pay attention and try to remember the relative locations of each object (i.e., landmark) in the environment. Participants were also told that the distance from the start to the first object was 100 m. In the testing phase, the experimenter stopped the participants at each landmark. They were asked to point to the direction of and estimate the distance to each of the other three landmarks. There were 12 choices in total. The angle and distance of disparity were calculated between participants' estimate and the correct answer for each trial.

1.2.4. Map route tracing [11]

A winding path of 20 turns (Fig. S3) was presented to the participants on a piece of paper. Participants needed to imagine themselves walking down the path and indicate directions (i.e., right or left) at each turn. Participants were not allowed to rotate the paper. Total accuracy was obtained.

1.2.5. Santa Barbara sense of direction questionnaire [12]

The Questionnaire is a standardized self-report scale of environmental spatial ability and contained 15 items (internal reliability: 0.88). Participants rated each statement (e.g., I am very good at judging distances) on a 5 point Likert scale. A Chinese translated version was used. After reverse coding of negative items, higher total scores indicated better self-reports of environmental abilities.

2. Results

All the ANOVA results comparing different groups are presented in Table 1 whereas statistics from MANOVA are presented in the text below. All the analyses were re-run with gender as a between-subject factor. However, none of the effects associated with gender was significant and are not reported.

2.1. Route learning performance

The MANOVA on accuracies of 1st trial, 2nd trial, and 3rd trial found a significant main effect of group, Wilks' $\lambda = .716$, $F(6, 120) = 3.64$, $p = .002$, $\eta^2_p = .154$. The same MANOVA on navigation time also found a significant main effect of group, Wilks' $\lambda = .793$, $F(6,120) = 2.45$, $p = .028$, $\eta^2_p = .109$. Overall, PD patients performed worse than CS controls on all measures and did not differ from AM controls on any measures.

2.2. Survey learning

MANOVA on the average angle of disparities of the 1st object, 2nd object, 3rd object, and 4th object found a significant main effect of group, Wilks' $\lambda = .734$, $F(8,116) = 2.43$, $p = .018$, $\eta^2_p = .143$. The MANOVA on the average distance of disparities of the four objects found no significant main effect of group, Wilks' $\lambda = .855$, $F(8,114) = 1.17$, $p = .326$. Overall, when estimating angles, CS controls did better than both PD patients and AM controls, who did not differ from each other. The three groups did not differ from each other when estimating distances.

2.3. Map route tracing and self-report

PD patients did not differ from either AM or CS controls on map route tracing. However, PD patients were more confident than college students and reported a higher competency in the self-report.

3. Discussion

Using experimental behavioral tasks, the current study showed that PD patients did not differ from AM controls on several measures of wayfinding that tapped into route learning, survey learning, and map route tracing. Meanwhile, PD patients did perform worse than CS controls in route learning and certain aspects of survey learning. PD patients were also more confident when rating their environmental abilities than CS controls. Therefore, although PD patients may show impairments in wayfinding due to cognitive decline, this impairment is no larger than expected based on their cognitive level.

Although they performed worse than CS controls, participants with PD performed at their current cognitive level on route learning. They were able to encode and retrieve spatial sequential memory, and integrate turn and landmark information for route knowledge. Performance similarity in the reverse trials further showed that their route knowledge was flexible and they could recognize the landmarks, turns, and scenes from different perspectives. This is also consistent with results from the map route tracing task where patients with PD performed similarly to AM controls. In the map route tracing task, one needed to mentally imagine the route from a different spatial perspective [11]. Different from previous studies, our study provides more comprehensive outcome measures of route learning in large-scale environments [4]. Additionally, our study tested route learning *after* participants had direct experience with the environment [5].

Regarding survey learning, results from our studies are aligned with one study [6], but not the other study [7]. Rather than using a virtual water maze, as in both previous studies [6,7], we presented an indoor environment of hallways which afforded turn and direction information. The structural information about the environment may be more conducive to eliciting spatial configurational knowledge. Hence we found that PD patients did not differ from AM controls in estimating angles. Therefore, participants with PD demonstrated the ability to represent the relative relations between objects and encode them into a cognitive map. All three groups did not differ from each other in estimating distances. However, this may have reflected the difficulty of estimating distances for all participants. Therefore, although cognitive maps may include the relative spatial relations between objects, they may not contain precise metric information.

To our knowledge, our study was the first to investigate route learning, survey learning, and map route tracing using experimental behavioral tasks

Table 1
ANOVA results comparing groups on various measures.

	DV	PD: M(SD)	AM: M(SD)	CS: M(SD)	F	p	η^2_p	Post hoc tests (Tukey)
Route learning	1st trial: accuracy (%)	0.49(0.16)	0.56(0.18)	0.66(0.12)	6.783	**0.002**	0.180	PD < CS, p = .001, neither differed from AM
	2nd trial: accuracy (%)	0.63(0.20)	0.64(0.20)	0.77(0.12)	4.491	**0.015**	0.127	(PD = AM) < CS, p = .021, p = .048 respectively
	3rd trial: accuracy (%)	0.68(0.16)	0.69(0.16)	0.84(0.11)	7.473	**0.001**	0.194	(PD = AM) < CS, p = .002; p = .007 respectively
	1st trial: time (minutes)	5.63(2.73)	5.15(0.81)	4.05(0.67)	4.625	**0.013**	0.130	PD < CS, p = .011, neither differed from AM
	2nd trial: time (minutes)	4.79(2.08)	4.30(0.80)	3.62(0.67)	3.953	**0.024**	0.113	PD < CS, p = .018, neither differed from AM
	3rd trial: time (minutes)	4.96(1.12)	4.80(0.89)	4.10(0.70)	5.268	**0.008**	0.145	(PD = AM) < CS, p = .008; p = .048 respectively
	Object recall	7.04(2.42)	8.05(3.12)	9.86(2.61)	6.117	**0.004**	0.165	PD < CS, p = .003, neither differed from AM
Survey learning	1st object: angle	44.48(29.53)	43.35(25.91)	32.57(21.45)	1.365	0.263	0.043	NA
	2nd object: angle	49.22(31.45)	57.00(31.87)	25.67(23.31)	6.500	**0.003**	0.176	(PD = AM) < CS, p = .026; p = .003 respectively
	3rd object: angle	58.17(30.06)	69.75(34.39)	49.57(43.02)	1.612	0.208	0.050	NA
	4th object: angle	95.96(32.62)	88.60(27.51)	62.52(39.15)	5.922	**0.004**	0.163	(PD = AM) < CS, p = .004; p = .040 respectively
	1st object: distance	74.32(51.94)	69.15(26.10)	50.90(18.89)	2.513	0.090	0.077	NA
	2nd object: distance	60.73(41.85)	54.80(27.65)	47.25(15.68)	1.044	0.358	0.034	NA
	3rd object: distance	62.56(41.72)	50.32(22.87)	46.32(21.59)	1.660	0.199	0.052	NA
	4th object: distance	66.12(84.73)	54.70(38.92)	55.22(39.24)	0.254	0.776	0.008	NA
	Average angle	61.96(18.97)	64.68(22.70)	42.58(23.89)	6.376	**0.003**	0.173	(PD = AM) < CS, p = .013; p = .005 respectively
	Average distance	65.93(52.72)	57.24(19.06)	49.92(15.75)	1.181	0.314	0.038	NA
Map route tracing	Accuracy (%)	0.82(0.19)	0.70(0.19)	0.93(0.10)	9.608	**0.000**	0.240	PD = AM; PD = CS; AM < CS, p < .001
Self-report	Total score	52.23(8.93)	48.70(9.97)	42.86(11.00)	0.804	**0.012**	0.138	PD > CS, p = .009; neither differed from AM.

Note: Significant results are in bold. PD: patients with Parkinson's disease. AM: age matched controls. CS: college student controls.

in addition to self-reports in the same setting for patients with PD. It showed that if anything, participants with PD are more confident in their wayfinding ability. They are not impaired in following a route, recalling landmarks, generating a mental map of the environment, or taking different spatial perspectives cartographically relative to their cognitive-ability matched counterparts. In our study, all PD patients were in stable treatment at the time of testing. Previous studies have found dopamine treatment may improve both striatal-based and hippocampal-based spatial learning [6]. One limitation, however, is that our results cannot rule out possible neurological differences between patients with PD and AM controls when undertaking various wayfinding tasks. Another limitation is that we used relatively early-stage and cognitively normal PD patients. It is possible different results would be obtained for more advanced, cognitively impaired PD patients. Future studies may shed light on these issues. Overall, on a behavioral level, spatial abilities in terms of wayfinding may not present a unique challenge for patients with PD above and beyond what is expected of their cognitive level.

Ethical statement

The study received ethical approval from Sun-Yat Sen University. Participant consent was obtained before the start of the study. All the recruitment and testing procedures followed the ethical guidelines of the university.

Credit author statement

Yingying Yang: conceptualization, methodology, data analysis, writing, supervision.

Yingwei (Catherine) Wu: participant recruitment, data collection, data analysis, writing.

Lulu Jiang: participant recruitment, supervision.

Ling Chen: participant recruitment, supervision.

Zhong Pei: participant recruitment, supervision.

Declaration of competing interest

None.

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Appendix A. Supplementary data

Supplementary data to this article can be found online at https://doi.org/10.1016/j.prdoa.2020.100067.

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