

VISUAL-SPATIAL ABILITY IN PARKINSON'S DISEASE

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1. ABSTRACT

Parkinson's Disease (PD) has traditionally been viewed as primarily a disturbance of motor functioning, typically involving tremor, rigidity, hypokinesia, gait disturbance, and postural instability. More recently, decline in cognitive function has been recognized as a feature of PD. One prominent cognitive symptom of PD involves deficits on tasks of spatial ability. However, findings of visual-spatial deficits in individuals with PD have been inconsistent. There are several methodological issues in this area of research that potentially confound the interpretation of data and need to be taken into consideration, including subject characteristics (e.g., age, sex and education), duration of illness, the current level of disability, the presence of emotional depression, the current level of medications, and the presence of dementia. Further, the tests that have shown visual-spatial deficits in PD are often complex, showing sensitivity to other cognitive processes as well. Another problem in this area of research is the lack of a clear understanding of the brain mechanisms that underlie visual-spatial deficits in PD. One theory of cognitive dysfunction in PD suggests that these cognitive deficits are in some way related to disruption of frontal-basal ganglia neural circuits important in executive functions. However, frontal-basal ganglionic dysfunction does not appear to account entirely for the visual-spatial cognitive deficits seen in PD. Subtle differences in performance on executive function measures appear to dissociate individuals with frontal lobe damage from individuals with PD.

Findings from two recent studies indicate that PD is indeed associated with deficits in visual-spatial ability. These findings also indicate that the relationship between visual-spatial ability and frontal-executive function in PD is likely complex, and that the visual-spatial deficits in PD may be sensitive to the sex of the individual with PD.

2. INTRODUCTION

Parkinson's Disease (PD), with its prominent symptoms of tremor, rigidity, bradykinesia, shuffling gait,

posture disturbance, and imbalance, is typically thought of as strictly a movement disorder, with limited impact on other neurocognitive functions. This conceptualization of PD may be related, in part, to James Parkinson's emphasis on the motor symptoms in his original explication of this disease (see 1 for review). As such, cognitive functions were generally considered to be unaffected in PD until more advanced stages of the disease process.

More recently, however, research in PD has revealed deficits in specific domains of cognitive function. Further, these deficits do not appear to be limited to the final stages of the disease. PD has been associated with cognitive difficulties in visual-spatial skills (2, 3), language (4), memory (see 5, 6 for reviews), and executive functions (7, 8, 9). Because PD is associated with dopamine depletion in nigrostriatal pathways that affect connections between the cortex (predominantly frontal regions) and the basal ganglia, these findings suggest that this dopamine dysfunction in some way affects these cognitive abilities. In particular, given the connectivity between the frontal lobes and basal ganglia, it has been suggested that the cognitive difficulties in PD are due, either directly or secondarily, to frontal-executive dysfunction (10, 11). The remainder of this paper will focus on the findings of visual-spatial deficits in PD, data substantiating these findings, and possible neuropsychological factors that may influence these findings.

3. SUMMARY OF LITERATURE ON VISUAL-SPATIAL ABILITY IN PARKINSON'S DISEASE

Although visual-spatial deficits are commonly thought to occur in PD (see 2), data supporting this supposition have been less than consistent. The reader is directed to two review articles that present a relatively thorough summary of the literature on visual-spatial ability in PD (12, 13). To briefly summarize the findings of Lazaruk (12), visual-spatial deficits were found on tasks involving disembedding target stimuli from a distracting background and on facial recognition. Deficits were also

found in individuals with PD on tasks involving the judgment of vertical and horizontal, as well as tests such as the Block Design and Object Assembly subtests of the Wechsler Adult Intelligence Scale - Revised. However, Lazaruk's review indicated that these findings were not consistent, with discrepant results on tasks of facial recognition, and judging the angular orientation of lines.

To briefly summarize the findings of Waterfall and Crowe (13), a meta-analysis was conducted on the scientific literature published between 1965 and 1993, from which reported data was derived from 70 studies. In this meta-analysis, these investigators found that deficits have reliably been found on standardized tests of visual-spatial ability such as the Block Design and Object Assembly subtests of the Wechsler Adult Intelligence Scale - Revised, as well as Raven's Progressive Matrices. However, other tests that have traditionally been considered measures of visual-spatial ability, such as the Judgment of Line Orientation and the Embedded Figures Test, have not revealed consistent deficits in individuals with PD (but see also 14). Further, these investigators found that tests of facial recognition, visual-spatial memory (Logical Memory from the Wechsler Memory Scale - Revised), and "visual integration" (e.g., Hooper Visual Organization Test) also did not reveal consistent deficits in individuals with PD. Taken together, the discrepant data presented in these reviews suggests that further supporting results are needed before we can assume that PD is associated with primary visual-spatial deficits. The remainder of this paper will highlight methodological issues that likely contribute to the inconsistent findings in the literature, address emerging theoretical issues in the conceptualization of these cognitive findings in PD, and review recent findings in the study of visual-spatial ability in PD.

4. DISCUSSION OF METHODOLOGICAL LIMITATIONS IN THE LITERATURE

Several methodological issues likely contribute to the inconsistent findings of visual-spatial deficits in PD. With respect to subject selection, Waterfall and Crowe (13) point out in their review that many studies of visual-spatial ability in PD failed to characterize their subjects with respect to sex, duration of illness, current level of disability, current level of medications, presence of depression, or presence of dementia. For example, although reports vary widely, it is conservatively estimated that approximately 20% to 25% of individuals with PD also experience other dementing neurodegenerative disease processes as well (e.g., Senile Dementia of the Alzheimer's Type) (15, 16, 17, 18, 19, 20). Given this prevalence of dementia, failure to adequately screen and characterize PD subjects has obvious implications on the representativeness of these subjects, as well as the generalizability of these findings to the study of cognitive function in PD. Adequate selection and characterization of the PD symptomatology is necessary because, not only does dementia screening minimize the possibility of including subjects with other co-morbid neurodegenerative disease processes, information regarding predominant symptom presentation may provide some insight into the underlying mechanisms

that produce cognitive dysfunction in PD. Both symptom laterality (e.g., right versus left) and symptom presentation (e.g., tremor versus rigid-akinesia) have been shown to have some relationship with cognitive function in PD (21, 22, 23, 24). These symptom characteristics may reveal neuropsychological factors that mediate performance on visual-spatial tasks in PD. In addition, approximately 50% of individuals with PD experience symptoms of depression (19), and emotional dysfunction may also affect cognitive function (25). Although the effects of emotional dysfunction on cognition in PD remains unclear (19, 24, 26, see also 27, 28), it would be methodologically beneficial to take this factor into consideration.

Another methodological issue involves the demographics of the research participants. Tests of visual-spatial ability are often sensitive to subject characteristics such as age (29, 30), sex (31), and handedness (32). Level of education also likely has an influence on visual-spatial ability (see 33 for a review). Suffice it to say, failure to take these subject characteristics into consideration may distort the visual-spatial test presentation of the individuals with PD. Moreover, having a control group that is appropriately matched on these subject characteristics is necessary for the experimental control for the influence of these factors on visual-spatial ability.

When dealing with visual-spatial functions in PD, it is important to take into consideration issues of basic visual perceptual acuity. Because dopamine, which is produced by amacrine cells, is also involved in retinal function, dopaminergic dysfunction may also affect basic visual acuity. Supporting this notion, visual disturbances have been reported in PD (34, 35, 36, 37). However, these visual disturbances have been shown to be responsive to dopaminergic treatment, and are minimized when the individual with PD is appropriately medicated. Nevertheless, it may be methodologically beneficial to include a control task of basic visual perception to assess and account for possible limitations in visual acuity that may otherwise confound test results.

When dealing with cognitive function in PD, in general, another issue to take into consideration involves fatigue. PD is frequently associated with significant sleep disturbances and excessive daytime fatigue (38, 39, 40, 41, 42). Although the nature of these sleep disturbances in PD remain somewhat unclear (see 38, 40 for review and discussion), chronic sleep deprivation and daytime fatigue have an obvious detrimental impact on cognitive function (43). Consequently, it may be beneficial to assess research volunteers for sleep disturbances and excessive daytime fatigue as a possible confound in their cognitive function.

Another issue involves the specific task used in the assessment of visual-spatial ability in PD. As noted above, deficits have reliably been found on tests such as the WAIS-R Block Design and Object Assembly subtests, but not on tests such as the Judgment of Line Orientation or Embedded Figures test. However, it should be noted that tasks such as the Block Design and Object Assembly subtests are considered to be cognitively complex, likely

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reflecting the summation of several cognitive processes in the production of an overt behavioral response (see 33 for a discussion). Consequently, it should not be surprising that the Block Design subtest shows a high correlation with verbal ability ($r = 0.61$), as does the Object Assembly subtest to smaller extent ($r = 0.49$) (29). Thus, findings of deficits on these tasks, in the absence of converging data, may not reflect isolated deficits in visual-spatial ability, but rather, deficits in cognitive function other than visual-spatial ability being tapped by these measures as well.

Similarly, visual-spatial ability is likely not a single process, but rather, involves several distinct cognitive processes (31, 44, 45). For example, Ekstrom et al. (44) identify six different cognitive factors that predominantly involve visual-spatial processes: 1.) Closure Flexibility (e.g., the ability to disembed target information from distracting background information), 2.) Figural Fluency (e.g., the ability to generate different figural designs), 3.) Spatial Orientation (e.g., the ability to perceive/maintain spatial patterns from different visual perspectives), 4.) Visualization (e.g., the ability to transform spatial patterns/visual images into different images or patterns), 5.) Spatial Scanning (e.g., visual exploration of a complex visual stimulus), and 6.) Visual Memory (e.g., memory for visual-spatial information). Notably, these visual-spatial processes have been identified empirically as distinct abilities through factor analysis (44). Because visual-spatial ability involves different cognitive processes, it is possible that individuals with PD may exhibit deficits on some visual-spatial tasks, but not others. Thus, findings of visual-spatial deficits in individuals with PD may appear inconsistent due to the different types of tests being used that may or may not be sensitive to cognitive dysfunction in PD.

Another issue that needs to be taken into consideration in the study of visual-spatial ability in PD is the limited understanding of the dysfunctional neuropsychological mechanisms that produce this cognitive presentation. As noted above, cognitive deficits in PD are commonly thought to be due, either directly or secondarily, to frontal-executive deficits resulting from frontal-striatal dysfunction (10, 11). Alexander and colleagues (46, 47) identify five distinct neural circuits that incorporate the basal ganglia. These parallel circuits include: 1.) the motor circuit which appears to be involved in movement preparation and execution, 2.) the oculomotor circuit which is involved in eye movements, 3.) the limbic circuit which is thought to be involved in emotional and motivational processes, and the prefrontal circuit which is comprised of two subcircuits, 4.) the dorsolateral prefrontal circuit and 5.) the lateral orbitofrontal circuit. For the purposes of this paper, the dorsolateral prefrontal and lateral orbitofrontal circuits appear to be the most relevant to the study of visual-spatial ability in PD, and only this circuit will be discussed further.

Alexander and his colleagues (46, 47) indicate that the dorsolateral prefrontal circuit is comprised of the dorsolateral prefrontal cortex, dorsolateral head of the caudate nucleus, the globus pallidus, subthalamic nucleus,

and the substantia nigra reticulata, as well as the ventral anterior, medial dorsal, and parafascicular nuclei of the thalamus. The dorsolateral head of the caudate also receives input from the posterior parietal cortex that is interwoven with the connections from the dorsolateral prefrontal cortex. The lateral orbitofrontal circuit consists of the lateral orbitofrontal cortex, the ventromedial region of the caudate nucleus, substantia nigra reticulata, and the globus pallidus, as well as the ventral anterior and medial dorsal nuclei of the thalamus. The ventromedial caudate also receives input from auditory and visual association regions of the temporal lobe.

Frontal dysfunction is typically associated with deficits in executive skills (see 33 for review). And as noted by Alexander et al. (46) in their review, dysfunction in the dorsolateral prefrontal region has been associated with working memory deficits, whereas dysfunction in lateral orbitofrontal regions has been associated with set-shifting deficits. Support for the frontal-executive dysfunction theory was presented in a study that found a significant relationship between executive dysfunction and visual-spatial deficits in individuals with PD (48). In a group of 19 individuals with mild to moderate PD, these investigators found that statistically controlling for the deficits in executive skills (e.g., Wisconsin Card Sorting Test, California Sorting Test) through analysis of covariance eliminated the visual-spatial deficits (e.g., WAIS-R Picture Arrangement, Benton Facial Discrimination Test) in PD subjects, but statistically controlling for the visual-spatial deficits did not alter the abnormal measures of executive function. Thus, according to these data, frontal-executive dysfunction can account for the visual-spatial deficits seen in PD.

It should be noted, however, that the relationship between frontal-executive dysfunction and visual-spatial deficits has been less than consistent. For example, Cronin-Golomb and Braun (49) provide evidence for a visual-spatial deficit in PD that is independent of executive skills. In a group of 50 non-demented, non-depressed, individuals with mild to moderate PD, these investigators found deficiencies on Subtest A of Raven's Colored Progressive Matrices (RCPM) compared to control subjects matched for age and education. Because Subtest A of the RCPM has a greater visual-spatial component than the remaining portions of the RCPM, these researchers concluded that PD was associated with a visual-spatial problem-solving deficit. Further, Cronin-Golomb and Braun (49) found that the PD subjects' RCPM-A performance was related to other measures of visual-spatial ability, but there was no relationship between the PD patients' RCPM-A performance and measures of executive function. It should also be noted that qualitative difference in frontal executive dysfunction have been found between individuals with PD and those with frontal lobe damage (10, 50, 51, 52), suggesting that somewhat different cognitive processes are involved. Thus, frontal-executive dysfunction may not account entirely for the visual-spatial deficits seen in PD. As such, findings of visual-spatial deficits in PD that are independent of frontal-executive dysfunction would suggest that PD affects cognitive

function in other brain regions. This supposition is consistent with other findings in the literature that indicate that posterior brain regions, usually involving the right hemisphere, are dominant for visual-spatial ability (see 33, 53, 54 for reviews).

Taken together, findings of visual-spatial deficits in individuals with PD appear to be inconsistent, likely due to methodological issues in the study of this phenomenon, as well as a limited understanding of the pathological processes in PD that affects this higher cognitive function. Two studies were recently conducted at this institution to further examine the relationship between visual-spatial ability and PD, taking into consideration the methodological issues discussed above. Findings from these studies will now be reviewed.

5. RECENT FINDINGS

In the first study, we attempted to examine visual-spatial ability in PD using the Piagetian Water Jar Test which measures visual-spatial perception and disembedding (55). In this task, the subject is presented with a drawing of an empty water jar that is either tilted or upright, and the subject's task is to draw a line to show what the water level would look like if the glass were half full. Because vestibular dysfunction is also thought to accompany PD and because this dysfunction may impact visual-spatial ability (56, 57), we also examined the influence of manipulating vestibulo-proprioceptive input by having the subjects complete the Water Jar Test with their head tilted as well as upright. In this study, we found that the medicated, non-demented PD subjects were less accurate than control subjects on the tilted jars but not the upright jars, indicating that tilting the stimulus interfered with the PD subjects' ability to determine horizontal. No effect was found for head tilt, indicating that vestibulo-proprioceptive processes did not contribute to the visual-spatial deficits in PD. Further, in a correlational analysis between Water Jar Test performance and clinical neuropsychological test measures in the PD subjects, we found no relationship between the Water Jar Test scores and measures of frontal-executive function (e.g., WAIS-R Digit Span, Stroop Test, Trail Making Test) or the other neuropsychological tests (e.g., language, memory). We also found no relationship between Water Jar Test performance and parkinsonian symptom presentation. Notably, in their Water Jar Test performance, the PD subjects showed a tendency to draw the water level as perpendicular to the sides of the jar stimulus, thus exhibiting some utilization, approach-type behavior (58, 59).

In the second study, we examined visual-spatial ability in PD using the Mental Rotations Test which assesses visual-spatial orientation (60). This task requires the subject to recognize a target stimulus in different two- and three-dimensional spatial orientations. This task was selected because visual-spatial orientation is believed to be a basic component of visual-spatial ability (31, 45, 61, 62). In this study, we found that the medicated, non-demented PD subjects were less accurate than the control subjects.

We found no relationship between Mental Rotation Test performance and symptom presentation in the PD subjects. Consistent with previous findings of a sex difference on this task, we found a group by sex interaction. Post-hoc analyses revealed that the men with PD were significantly less accurate than male control subjects, whereas both PD and control women performed poorly at around chance level. Notably, men with PD showed no difference in mental rotation accuracy from either PD or control women. Further, a correlational analysis between Mental Rotation Test performance and clinical neuropsychological measures (e.g., language, memory, frontal-executive function) in the PD subjects revealed that men with PD showed a significant relationship between mental rotation ability and measures of frontal-executive function (e.g., Stroop test, WAIS-R Digit Symbol), whereas women with PD exhibited a significant relationship between mental rotation ability and measures of verbal memory (e.g., WMS-R Logical Memory). These findings indicate that men with PD perform mental rotations differently than women with PD.

6. CONCLUSIONS

In summary, findings from these recent studies indicate that PD is associated with deficits in visual-spatial ability involving visual-spatial closure and visual-spatial orientation. Further, these findings indicate that the relationship between visual-spatial ability and frontal-executive function in PD is likely complex. Whereas no relationship was found between Water Jar Test performance and traditional measures of frontal-executive function, the PD subjects exhibited a pattern of utilization, approach behavior on this task that is indicative of frontal-executive dysfunction (58, 59). Moreover, findings from the study of mental rotation in PD suggest that the relationship between frontal-executive function and visual-spatial ability may also depend on the sex of the individual with PD.

Additional research on visual-spatial ability in PD will be needed to confirm these findings, as well as elaborate on the dysfunctional neuropsychological mechanisms in PD. The various aspects of visual-spatial ability (e.g., Figural Fluency, Visualization, Spatial Scanning, Visual Memory) need to be further evaluated to determine if PD affects these abilities as it does with visual-spatial closure and orientation. The relationship between visual-spatial ability and frontal-executive function also requires further study to elaborate the nature of this complex relationship. Whereas frontal-executive dysfunction that accounts for the visual-spatial deficits found in PD would be consistent with current theories of cognitive deficits in PD, findings of visual-spatial deficits in PD that are independent of frontal-executive dysfunction would suggest that other neuropsychological processes are being affected by PD. Additional study is needed to elucidate the influence of sex on visual-spatial ability in PD, and the implications this relationship may have on daily function. Further study is also needed in examining the relationship between visual-spatial ability and dopamine function in PD. Findings that dopamine function

directly influences visual-spatial ability would be consistent with current theories on PD, whereas findings that visual-spatial ability is not affected by dopamine would suggest that other neurological processes are involved in the cognitive deficits in PD. This research is needed to clarify the underlying mechanisms associated with PD that affect cognition, as well as identify those factors that mediate these effects, hopefully leading to better treatments for this medical condition.

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