Impaired Reach-to-Grasp Actions during Barrier Avoidance in Individuals with Parkinson's Disease

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Objective: *To determine the kinematics and coordination while performing reach-to-grasp (RTG) actions under barrier avoidance condition in individuals with Parkinson's disease (PD).*

Material and Method: *Right handed idiopathic PDs (Hoehn and Yahr stage 2-3) (n = 20) and age-matched controls (n = 10) without dementia and psychological impairment were recruited. They were asked to perform RTG "as soon as you see the light and as fast as you can" with their right hands under barrier condition. The RTG performance were assessed in three domains, planning, execution (or kinematics), and coordination. The planning was measured by reaction time. The kinematics variables were movement time, maximum velocity, time to maximum velocity, deceleration time, maximum aperture, time to maximum aperture, aperture closure time, and aperture closure distance. The coordination was assessed using a cross correlation analysis between transport velocity and aperture size, which consisted of maximal correlation coefficient (r_{max}) and associated time lag (T_{max}).*

Results: *Compared to the controls, the PD group had delayed planning. In execution domain, they showed decreased maximum velocity, smaller amplitude of maximum aperture, and prolonged all raw times comparing to controls. When considering the coordination, they had only prolonged T_{max} than controls.*

Conclusion: *PD participants with mild to moderate impairment showed poorer RTG planning, execution, and coordination during barrier avoidance when compared to age-matched controls.*

Keywords: *Reach to grasp, Parkinson's disease, Barrier task, Manual coordination*

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Reach-to-grasp (RTG) movement requires precise control in two components, transport component for bringing hand to a specified object, and grasp components for shaping the hand to grasp the object[1,2]. These two components are coordinated spatially and temporally[3,4].

Previous evidence showed that patients with Parkinson's disease (PD) had deficits in central processing or planning[5], RTG execution, and transport-grasp coordination[6-8]. Some studies showed controversial results, which might partly be due to various factors. Some studies have recruited PD participants with mild involvement[9] who demonstrated normal grasping[10] and some were tested on the less affected side. The task condition has shown to influence the movement deficits when the difficulty of the task increases[6,7,9,11,12]. Considering the task demand in the studies of RTG movement, the common methods to measure transport-grasp coordination include perturbation of transport or grasp component and then observe the alteration in another components. Instances of these perturbation tasks are the changes in object location, varying object size, and altered hand path[1] e.g., reach over or around barrier[3]. A barrier task has a high degree of difficulty to investigate a RTG kinematics and coordination[3,13]. However, this task has not been used in the PD population. Another factor is the measurement. Previous studies quantified the RTG coordination in PD by investigating the intervals synchronization some points of arm trajectory and some points of hand trajectory. A sensitive measure of transport-grasp coordination is a cross correlation analysis. This technique quantified the correlation coefficient between two components at every single point of time[13-15]. Therefore, it would be more sensitive than previous technique.

The present study aimed to measure RTG planning, kinematics and coordination in PD participants with moderate impairment (Hoehn and Yahr stage 2-3). They performed the task with their

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more affected (right) hand and usinga challenging RTG task with barrier avoidance. The cross correlation analysis of transport velocity and aperture size was employed to analyze the transport-grasp coordination.

Material and Method

Study design and participants

An experimental study with matched-pairs was conducted. Participants were right handed idiopathic PDs (Hoehn and Yahr stage 2-3) and age-matched controls without dementia or psychological problems. The two PDs were matched in age to each control for receiving adequate data from PD patients without wastefulness of frequency matching[16]. The PD participants had more impairment in their right hand. Volunteers were excluded if they had severe action, resting tremor or rigidity (score 3-4 in domain of UPDRS), marked wearing-off and history of treatment by deep brain stimulation. A written informed consent form approved by Siriraj Institutional Review Board (SIRB, COA: Si038/2014), Faculty of Medicine Siriraj Hospital, Mahidol University was read and signed prior to enrollment.

Experimental setup

The task was to reach around a barrier to grasp and lift the object. Participants sat in front of a table and were asked to place their index and thumb on a start switch before each trial. The object to be grasped was a square shape (2.5 centimeters wide and long, and 10 centimeters high) located 30 centimeters directly in front of the body and where the index and thumb are positioned on the start switch. The barrier was a cylinder shape (2 centimeters round and 30 centimeters high) located half way to the target object and 2.5 centimeters to the right. Participants were instructed to reach as soon as they saw a LED light and as fast as possible without a collision of the barrier, grasp the object with the thumb and index finger, lift it off the table and return it to the same location with right hand. Ten successful trials were collected. Participants in PD group were tested under on-drug condition (90 minutes after medication).

Data acquisition and analysis

Kinematic variables were recorded by using an electromagnetic tracking motion system (MotionMonitor, Innsport, Inc.) with the sampling rate 100 Hertz. Three sensors were attached on right radial styloid process, the nail beds of the thumb and index fingers. The kinematics variables (Fig. 1) included 1) reaction time (RT), 2) movement time (MT), 3) maximum velocity (V_{max}), 4) time to V_{max} (TV_{max}), 5) deceleration time (DT), 6) maximum aperture (A_{max}), 7) time to A_{max} (TA_{max}), 8) aperture closure time, and 9) aperture closure distance. The transport-grasp coordination was assessed by cross correlation analysis between transport velocity and aperture size, which consisted of maximal correlation coefficient (r_{max}) and associated time lag (T_{max}). This technique was investigated the similarity in the patterns of transport velocity and grasp aperture size by measuring the correlation coefficient (r) between these two components at every single point of time. The transport velocity trajectory was shifted until reach the time at highest r_{max}, which indicate the T_{max}. In Fig. 1C, upper left corner represents transport velocity trajectory (gray) and aperture (black) at zero time lag (T_{max} = 0 ms) with the r_{max} was 0.36. Lower left corner shows the highest correlation coefficient (r_{max} = 0.97) after shifting the transport velocity trajectory for 200 ms (T_{max} = 200 ms) to achieve the most similar pattern with grasp aperture trajectory. The positive T_{max} indicate that grip aperture start to open after the onset of hand's transporting and vice versa.

Statistical analysis

Mann-Whitney U test was used to compare the each variable's median of 10 successful trials from PD and age-matched controls groups. Significant level was set at *p*-value less than 0.05.

Results

Participants' characteristics

Twenty individuals with Parkinson's disease and 10 age-matched controls were enrolled to the study. Participants in PD group was aged 63.3±6.7 years and had mild to moderate impairment assessed by the motor section of Unified Parkinson's Disease Rating Scale (UPDRS-III) upper extremity domains (6±2 scores) and Hoehn and Yahr stage (2-3). Non-disabled control group participants had comparable mean age (62.6±6.8) to PD group. Participants in both groups were not different in cognitive capability which measured by the Mini Mental State Examination Thai version (28±2 for control group and 27±2 for PD group).

Reach-to-grasp planning

Planning performance was measured by movement initiation. In the PD group, initiation was significantly delayed when compare to the control group (Table 1).

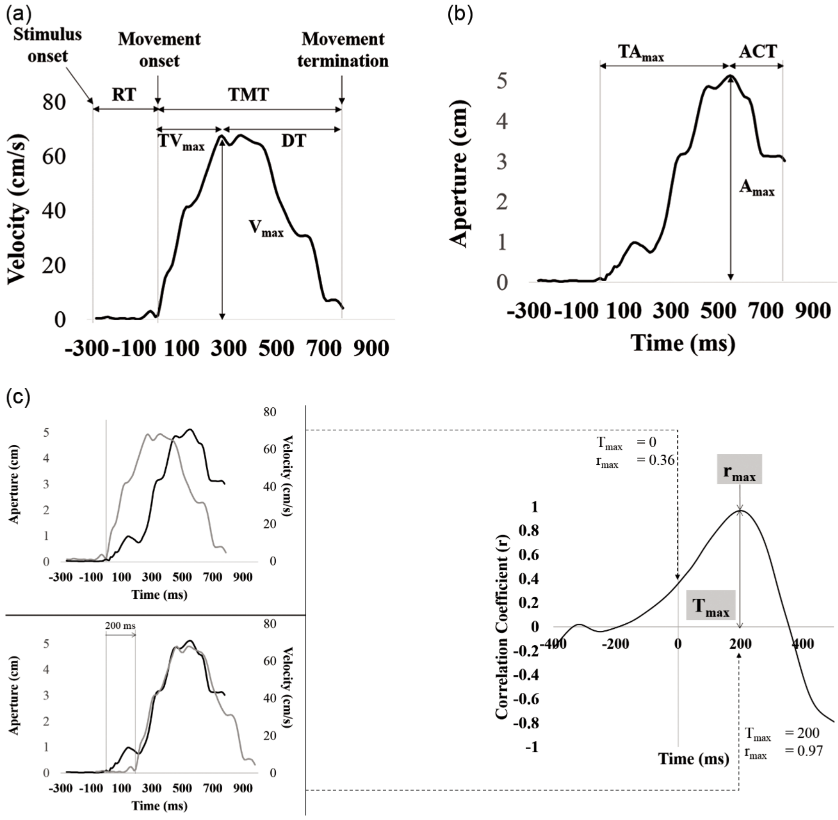

Fig. 1 Key kinematic variables: (a) reaction time (RT), movement time (MT), maximum velocity (V_{max}), time to maximum velocity (TV_{max}), and deceleration time (DT), (b) aperture with marked maximum aperture (A_{max}), time to maximum aperture (TA_{max}), and aperture closure time (ACT), (c) transport-grasp coordination expressed by cross correlation coefficient (r_{max}) as a function of time lag (T_{max}).

Transport and grasp kinematics

Table 1 summarizes the 25, 50, and 75 percentiles of each variable in transport and grasp kinematics and coordination from PD and control groups. The PD group had a prolonged transport component, encompassing MT and absolute TV_{max}, and absolute DT and decreased V_{max}. In the grasp component, the PD group had smaller A_{max} and later TA_{max} by approximately 270 milliseconds.

Transport-grasp coordination

The spatial coordination which measured by r_{max} was not significantly different between PD and control groups. In contrast, T_{max} which measured temporal coordination in PD group was significantly longer (p-value <0.01).

Discussion

The current study used a challenging and complex RTG action with fast speed avoiding a barrier to investigate movement deficits in PD patients with mild to moderate impairment of upper extremity. RTG performances are measured by kinematics in transport and grasp component, and transport-grasp coordination. We chose the sensitive cross correlation analysis to detect impaired coordination(13,15,17). Although PD patients, who had mild impairment on UPDRS, are tested in ON-medication state, the RTG deficits are detected. This finding indicates that the barrier task and cross correlation analyses is appropriate and suggestive measurement to investigate RTG impairment in PD population. The results were interpreted that PD patients had deficient kinematics and coordination in both temporal and spatial aspects.

Reach-to-grasp planning

Prior studies using simple reaction time (SRT) assessment found equivocal and contradictory results for patients with PD(5,6,18). Participants in the present study demonstrated delayed response to visual stimulus

Table 1. Comparison of reach-to-grasp between patients with Parkinson's disease (PD) and control

Reach-to-grasp variables	Control (n = 10), percentile			PD (n = 20), percentile			*p*-value
	25th	50th	75th	25th	50th	75th	
Reaction time (ms)	122.00	138.06	170.00	205.00	251.13	318.50	<0.01*
Transport component							
Movement time (ms)	516.67	558.50	587.78	800.72	914.50	1,154.50	<0.01**
Maximum velocity (cm/s)	97.03	105.94	113.22	59.25	64.56	73.16	<0.01**
Absolute time to maximum velocity (ms)	167.78	210.63	237.00	309.95	395.50	450.00	<0.01**
Relative time to maximum velocity (%)	32.80	35.66	47.19	35.80	40.04	45.26	0.35
Absolute deceleration time (ms)	292.00	356.94	388.57	429.78	528.50	744.00	<0.01**
Relative deceleration time (%)	52.81	64.34	67.20	54.75	59.97	64.21	0.35
Grasp component							
Maximum aperture (cm)	6.44	7.45	8.63	5.07	5.91	6.92	0.02*
Absolute time to maximum aperture (ms)	366.00	416.86	446.00	556.61	703.89	812.50	<0.01**
Relative time to maximum aperture (%)	73.37	75.03	77.98	69.53	73.93	77.66	0.65
Absolute aperture closure time (ms)	124.00	132.61	171.11	171.00	225.00	318.50	<0.01**
Relative aperture closure time (%)	22.02	24.97	26.63	22.34	26.07	30.01	0.65
Aperture closure distance (cm)	0.70	2.07	2.52	0.54	0.94	1.68	0.10
Transport-grasp coordination							
Maximal correlation coefficient (r)	0.78	0.85	0.89	0.78	0.83	0.89	0.88
Associated time lag (ms)	117.00	151.67	174.00	243.00	314.17	366.67	<0.01**

* Significant level was set at *p*-value <0.05, ** Significant level was set at *p*-value <0.01

relative to controls. The task assessed in this study required participants to generate complex goal-directed movement[19]. The prolonged RT or difficulty in initiating movement is termed akinesia similar to previous studies that examined initiation time during RTG in PD patients[19,20]. Goodrich et al concluded that persons with PD have impaired recruitment attentional resources to prepare and speed their RT[21].

Transport and grasp kinematics

Participants with PD demonstrate slower transport time and lower peak velocity termed bradykinetic movement. This may be the result of internal programming deficits[12]. Patients with PD have a slower force development[22], which leads to impair scaling of movement parameters, bradykinesia. PD participants demonstrate deficits in all measures of spatial and temporal transport and grasp. The impaired movement execution of persons with PD was also found in other studies[6,7,9,23]. However, there are conflicting results regarding maximum aperture size, which might be due to different degrees of PD involvement and different task demands. The present study excluded patients with Hoehn and Yahr stage 1 and used a challenging task (the barrier task with small object, and rapid movement). This resulted in significantly smaller aperture than controls. Reduced maximum grasp aperture amplitude reflects hypometric movement that commonly occurs in patients during performing pretension and writing. These deficits indicate the important role of the basal ganglia in controlling movement amplitude[2,19]. Previous studies also suggested another controversial result regarding relative time to maximum velocity. A study reported normal relative time to maximum velocity[9] while another found significantly decreasing[7] and another found significantly increasing[24]. All relative values of both transport and grasp components in this study are similar to those of the non-disabled controls. The possible reason why all relative values were not changed after suffering PD is that they prolonged in all time parameters including movement time, absolute time to maximum velocity, deceleration time, time to maximum aperture, aperture closure time for preserving their motor programming by consistent ratio of duration in each component relative to total movement time or relative values[25].

Transport-grasp coordination

The control group demonstrated tight temporal coupling between the components of transport and grasp. In contrast, in the PD group it was delayed by approximately 150 milliseconds. Thus, individuals with PD showed disrupted temporal coordination. This impaired coordination might result from a failure to execute the reach and grasp components in a parallel manner. Previous neurophysiological studies have reported that the basal ganglia integrates somatosensory and visual information[26]. Thus, deficient integration of proprioceptive information derived from the transport component and visual information regarding object recognition form the grasp component would occur in persons with PD. However, our participants preserved spatial coordination. This finding could be explained by "Speed/accuracy trade-off" theory[27]. PD participants spent a longer time coordinating transport velocity and grasp aperture in order to have a perfectly coupled pattern of movements.

Conclusion

The current preliminary assessment of participants with mild to moderate PD demonstrates deterioration of RTG planning capability, kinematics and coordination during a barrier avoidance task. The findings indicate that although patients received medicine, the RTG performance could not be regained to normal level when compare to non-disabled adults. This information might be advantage for exploring the optimal rehabilitation program for PD patients. For example, clinical goals might include improving reaction time, reversing hand opening and closing, coordinating arm and hand movements. Various technique could be apply to solve these impairment including the specific instructions, feedback regarding their movement quality (knowledge of the performance), or other facilitation technique such as practicing with training BIG technique or auditory cue. The task and analysis is sensitive enough to detect the deficient kinematics and coordination in Parkinson's disease patients with mild to moderate impairment.

What is already known on this topic?

Parkinson's disease patients after taking their normal dose of dopaminergic drug still have impairments in reach-to-grasp actions.

What this study adds?

This is the first study to use a challenging task for disturbarm transport and used a cross correlation analyses between transport velocity and grasp aperture size to evaluate the RTG kinematics and coordination in individuals with Parkinson's disease. Moreover, this study controlled all possible influential factors, which might affect the results of investigating RTG impairments. Therefore, these designs are sensitive enough to detect the deficient kinematics and coordination in individuals with Parkinson's disease.

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Potential conflicts of interest

None.

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ความบกพร่องของการเอื้อมมืออ้อมสิ่งกีดขวางเพื่อหยิบจับวัตถุในกลุ่มผู้ป่วยโรคพาร์กินสัน

สุวีณา ค้าเจริญ, จารุกูล ตรีไตรลักษณะ, ภครตี ชัยวัฒน์, อภิชาติ พิศาลพงศ์

วัตถุประสงค์: *การศึกษานี้มีวัตถุประสงค์เพื่อประเมินความสามารถของแขนและมือขณะเอื้อมมือหยิบวัตถุที่มีสิ่งกีดขวางกั้นอยู่และประเมินการประสานสัมพันธ์ของการเอื้อมและการหยิบจับในกลุ่มผู้ป่วยพาร์กินสัน*

วัสดุและวิธีการ: *ผู้ป่วยพาร์กินสัน (ระยะ 2-3 เมื่อประเมินด้วย Hoehn and Yahr stage) 20 ราย และคนปกติที่มีอายุใกล้เคียงกับผู้ป่วยพาร์กินสัน 10 ราย ที่ถนัดมือขวาและไม่มีภาวะความจำเสื่อมหรือโรคทางจิตเวช เข้ารับการประเมินทางความสามารถของแขนและมือในขณะที่เอื้อมมือขวาอ้อมสิ่งกีดขวางเพื่อหยิบจับวัตถุทันทีที่เห็นสัญญาณไฟด้วยความเร็วที่สุดเท่าที่จะทำได้ โดยความสามารถของแขนและมือถูกวัด 3 ด้าน คือ การวางแผน การสั่งการหรือไคเนมาติกส์ และการประสานสัมพันธ์ของการเอื้อมและการหยิบจับ การวางแผนถูกวัดด้วยเวลาในการตอบสนองต่อสัญญาณไฟตัวแปรทางไคเนมาติกส์ ประกอบไปด้วยเวลาที่ใช้ในการเอื้อมมือจนกระทั่งหยิบจับวัตถุ ความเร็วสูงสุดในการเอื้อม ระยะเวลาที่ใช้ในการเร่งความเร็วของแขน ระยะเวลาที่ใช้ในการชะลอความเร็วของแขน ความกว้างของการเปิดนิ้วมือ เวลาที่ใช้ในการเปิดนิ้วมือ เวลาที่ใช้ในการหุบนิ้วมือ และระยะทางที่ใช้เพื่อหุบนิ้วมือในขณะที่การประสานสัมพันธ์ของการเอื้อมและการหยิบจับจะประเมินด้วยการวิเคราะห์สหสัมพันธ์แบบไขว้ประกอบด้วยการประสานสัมพันธ์ด้านรูปแบบและเวลา*

ผลการศึกษา: *กลุ่มผู้ป่วยพาร์กินสันใช้เวลาในการวางแผนช้ากว่าคนปกติและยังมีความบกพร่องในส่วนการสั่งการคือความเร็วสูงสุดในการเอื้อมน้อยลง ความกว้างของการเปิดนิ้วมือแคบลง และตัวแปรทางด้านเวลาทุกตัวยังช้าลงกว่าคนปกติ นอกจากนั้นการประสานสัมพันธ์กันของการเอื้อมและการหยิบจับก็ยังพบว่านานกว่าคนปกติอีกด้วย*

สรุป: *ผู้ป่วยพาร์กินสันที่มีอาการของแขนระดับน้อยถึงปานกลางมีความบกพร่องในการวางแผนการเคลื่อนไหว การสั่งการ และการประสานสัมพันธ์ขณะเอื้อมมือหยิบวัตถุที่มีสิ่งกีดขวางกั้นอยู่เมื่อเปรียบเทียบกับคนปกติที่มีอายุใกล้เคียงกัน*