Neuroscience Letters 585 (2015) 82–87

Contents lists available at ScienceDirect

Neuroscience Letters

journal homepage: www.elsevier.com/locate/neulet

Behavioral inflexibility and motor dedifferentiation in persons with Parkinson's disease: Bilateral coordination deficits during a unimanual reaching task

Shinichi Amano[a], S. Lee Hong[a], Jacob I. Sage[b], Elizabeth B. Torres[b,*]

[a] Department of Biomedical Sciences, Ohio University, Athens, OH, USA
[b] Rutgers Robert Wood Johnson Medical School, Piscataway, NJ, USA

HIGHLIGHTS

- We examine movement slowing and bilateral coordination deficits in Parkinson's disease (PD).
- When reaching, PD patients exhibited slowness and velocity control deficits on the less affected arm.
- Unlike healthy peers, PD patients exhibited excessive synchrony between shoulders.
- Inflexibility in PD was accompanied by reduced difference across left and right limb (arm).

ARTICLE INFO

Article history:
Received 23 May 2014
Received in revised form 1 October 2014
Accepted 4 October 2014
Available online 14 October 2014

Keywords:
Parkinson's disease
Bradykinesia
Motor freezing
Phase synchrony
Behavioral inflexibility
Motor dedifferentiation

ABSTRACT

We evaluated kinematics of people with Parkinson's disease (PD) and age-matched controls during cued and uncued reaching movements. Maximum hand velocity, its variability and shoulder-to-shoulder coupling, quantified by phase locking value (PLV), were compared between PD ($n=14$) and Control ($n=4$). The PD group achieved significantly lower maximum hand velocities during the reaching movement in comparison to the Control group ($p=0.05$), whereas the Control group exhibited significantly greater variability (i.e., larger SDs) of maximum hand velocities across the blocks than the PD group ($p=0.01$). Persons with PD exhibited higher PLVs than the healthy elderly individuals when performing reaching movements with their dominant side ($p=0.05$), while the PLVs did not differ between groups when the movements were performed with their non-dominant hand. The present study suggests that persons with PD have a reduced ability to: (1) modulate maximum reaching velocity; and (2) alter coordination across the shoulders to different reaching actions. In persons with PD, the velocity-oriented (dominant) limb becomes slowed and less flexible, to the point that its movement dynamics are effectively similar to that of the position-oriented (non-dominant) limb.

Published by Elsevier Ireland Ltd.

1. Introduction

When required to perform bimanual tasks, persons with PD appear to compensate for unilateral bradykinesia by facilitating the movement of the more affected side at the expense of the less affected side [8]. This compensatory strategy in persons with PD is a particularly important and intriguing phenomenon, given the fact that the dominant and non-dominant limbs perform specialized functions [21]. The loss of specialization is known in the literature as a process of dedifferentiation, wherein systems that normally serve specific functions lose this specificity and become simplified [2]. This process of dedifferentiation can occur at various levels: neural [16], muscular [13,17] and behavioral [18] level. As a result, a compensatory slowing of the dominant hand might reflect dedifferentiation in the dynamic functions of the dominant and non-dominant limbs.

To date, studies of motor coordination during unimanual reaching in PD have focused exclusively on the reduced control and modulation of limb segments [1,11,19], whereas studies examining bilateral coordination deficits in PD have generally employed a bimanual paradigm where both limbs are engaged in the performance of the task [4,7,10]. However, bilateral coordination during unimanual tasks has yet to be explored as a test of the potential that *dedifferentiation* in limb dominance might be a problem in PD. Effectively, dedifferentiation in PD motor behavior could be

* Corresponding author at: Department of Psychology, Rutgers University, Busch Campus, 152 Frelinghuysen Road, Piscataway, NJ 08854, USA. Tel.: +(848)445 8909.
E-mail address: ebtorres@rci.rutgers.edu (E.B. Torres).

http://dx.doi.org/10.1016/j.neulet.2014.10.007
0304-3940/Published by Elsevier Ireland Ltd.

indicative of reorganization of the neuromuscular system, such that coordinated, yet specialized, subsystems (e.g., left and right limb) become less distinctive. In addition, the manner in which the proximal joints are stabilized through coupling may also become more similar across dominant and non-dominant reaches.

Another important issue in PD is the effect of instruction and visual cues on motor output. Instructional cues have been shown to have a facilitative effect [12,20]. For instance, freezing of gait can be resolved with a visual cue, such as a transverse line or another person's foot to step over [5,14,15]. However, when sensory cues allow persons with PD to alter their motor behavior, their bradykinesia is exacerbated [11]. The aforementioned studies suggest inflexibility in PD, potentially owing to increased neural noise [3] that would be consistent with the hypothesis of a loss of specialization or dedifferentiation in neural signaling [6]. Effectively, neurobehavioral adaptations are made more difficult for the neuromotor system in persons with PD.

This study tested the hypothesis that PD leads to motor dedifferentiation using a simple reaching task. Additionally, we tested the effects of orientation-related cues to examine inflexibility in the modulation of motor behavior as a function of task demands and external visual information. We measured movement speed of the reaching hand and bilateral coordination across the proximal joints, i.e., the shoulders. We hypothesized that dedifferentiation would be apparent in PD patients in when compared to matched controls, reflected by: (1) reduced difference in maximal movement velocity between dominant and non-dominant hand; (2) reduced modulation of movement velocity; and (3) similar patterns coupling of bilateral shoulder coordination for dominant and non-dominant reaching movements.

2. Materials and methods

2.1. Participants

A total of 18 right-handed (14 PD and 4 healthy elderly Controls; Table 1) participants signed an informed consent approved by the University's Internal Review Board. All participants with PD were diagnosed as having idiopathic PD by a trained neurologist using standard criteria. Participants were excluded if they could not follow instructions given in this study. All participants with PD were tested while off of their usual anti-movement disorder medications. The level of motor impairment was evaluated by the neurologists using the Part III of the Unified Parkinson's Disease Rating Scale (UPDRS). An independent t-test confirmed that the level of motor impairment, quantified by the UPDRS III subscore (from item 20 to 26), did not significantly differ across the limbs ($p = 0.55$; Table 1).

2.2. Procedures

Participants were asked to perform a unimanual reaching task with or without a hand-arm orientation cue while being seated comfortably and facing a computer monitor placed at their eye level. The reaching task used here simplifies the study of grasping actions because it focuses on the rotations of the hand to match the target orientation without the further complexity that arises when the fingers actually grasp the object. This virtual version of the veridical grasping task has proven useful to study persons with PD [29]. A mathematical model of this task involving the recruitment and co-articulation of the arm's degrees of freedom has also been implemented [26] and studied in normal controls [27]. We have also studied other subjects with PD under this simplified version of the grasping task [25,29] in order to investigate the feasibility of the new questions that we addressed here. For example, in the present task there are different joints recruited in the arm for each of the orientations evoked by how the hand is oriented to hold the rod (Fig. 2).

Participants were instructed to hold a cylinder-shaped wooden rod (approximately 70 g) in their hand, resting it on the table prior to the start of each trial. The task was to move their hand toward a virtual rod displayed on the monitor and match the principal axis of orientation of the virtual rod with their hand-held rod. They would then return the hand to an uninstructed resting position. This study focuses only on the reaching segment toward the target, which is a simplification of the conventional reach-to-grasp paradigm.

Participants were tested in two conditions: CUED and UNCUED. In the CUED condition, participants were asked to match their final hand orientation as if they were going to grasp a cup displayed next to the virtual rod on the computer monitor and drink from it (Fig. 1). This orientation cue evokes different arm and hand postures, which tests an individual's ability to modulate their motor plan and output in order to achieve the final hand orientation. In the UNCUED condition, participants were free to select any final hand orientation and simply reach their hand toward the screen. The desired movement speed was shown on the rod with text and prompted with color (red for slow and green for fast).

In each condition (i.e., CUED and UNCUED), participants completed five 20-trial blocks for each side. The sequence of trial speed and orientation was randomly presented and balanced for each participant. Kinematic data were collected at 240 Hz using a Polhemus Liberty system (Polhemus, Colchester VT) with markers placed on the ipsilateral shoulder, upper arm, forearm, and hand, as well as the contralateral shoulder. Further details regarding the experimental setup and procedures are described in our previous report [29], which used an identical experimental setup.

2.3. Outcome measures

Three main outcome measures: (1) maximum hand velocity, (2) inter-block variability of maximum hand velocities (i.e., standard deviation across the blocks), and (3) shoulder-to-shoulder phase locking value (PLV) were obtained in the present study. PLV is a statistic used to quantify the phase coupling between two biological nonlinear signals in time-series, such as time-series electroencephalographic signals [9,22]. In the present study, PLV was employed to quantify the level of coupling (phase synchrony) in left-right shoulder coordination. Briefly, the instantaneous phases of left and right shoulder acceleration were estimated and compared with each other in time-series. In cases where the instantaneous phases of left and right shoulder accelerations are synchronized, PLV = 1. If the accelerations are unsynchronized, then PLV = 0. Greater detail regarding the procedure for computing PLV can be obtained elsewhere [9,28]. Hence, motor dedifferentiation (or reduced lateral specialization) could be evidenced by lack of difference between the limbs in PLV. It is important to note here that the individual outcome measures do not denote dedifferentiation per se. Rather, reduced difference between the dominant and non-dominant hand reaches would be indicative of dedifferentiation.

Table 1
Mean (±standard deviation) values of demographic and clinical characteristics of the study participants.

		PD	Control
N		14	4
Gender	(M/F)	10/4	2/2
Age	(year)	64 (±13)	56 (±11)
Disease duration	(year)	8 (±6)	–
Age at first Diagnosis	(year)	56 (±13)	–
UPDRS motor			
Total	(–)	25.0 (±12.4)	–
Left subscore (item 20–26)	(–)	7.3 (±5.9)	–
Right subscore (item 20–26)	(–)	6.1 (±3.9)	–

Abbreviation: UPDRS, Unified Parkinson's Disease Rating Scale.