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Finger force changes in the absence of visual feedback in patients with Parkinson's disease

Hang Jin Jo [a], Satyajit Ambike [a], Mechelle M. Lewis [b,c], Xuemei Huang [a,b,c,d,e], Mark L. Latash [a,*]

[a] Department of Kinesiology, The Pennsylvania State University, University Park, PA 16802, USA
[b] Department of Neurology, Pennsylvania State University – Milton S. Hershey Medical Center, Hershey, PA 17033, USA
[c] Department of Pharmacology, Pennsylvania State University – Milton S. Hershey Medical Center, Hershey, PA 17033, USA
[d] Department of Radiology, Pennsylvania State University – Milton S. Hershey Medical Center, Hershey, PA 17033, USA
[e] Department of Neurosurgery, Pennsylvania State University – Milton S. Hershey Medical Center, Hershey, PA 17033, USA

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HIGHLIGHTS

- Patients with Parkinson's disease (PD) show an accelerated drop in total force in accurate two-finger force production tasks performed without visual feedback.
- Sharing of the total force between the two fingers drifts towards a 50:50 pattern without a difference between the PD patients and control subjects.
- The accelerated force drop in PD may reflect adaptive changes to the documented loss of action stability.

ABSTRACT

Objectives: We investigated the unintentional drift in total force and in sharing of the force between fingers in two-finger accurate force production tasks performed without visual feedback by patients with Parkinson's disease (PD) and healthy controls. In particular, we were testing a hypothesis that adaptation to the documented loss of action stability could lead to faster force drop in PD.

Methods: PD patients and healthy controls performed accurate constant force production tasks without visual feedback by different finger pairs, starting with different force levels and different sharing patterns of force between the two fingers.

Results: Both groups showed an exponential force drop with time and a drift of the sharing pattern towards 50:50. The PD group showed a significantly faster force drop without a change in speed of the sharing drift. These results were consistent across initial force levels, sharing patterns, and finger pairs. A pilot test of four subjects, two PD and two controls, showed no consistent effects of memory on the force drop.

Conclusions: We interpret the force drop as a consequence of back-coupling between the actual and referent finger coordinates that draws the referent coordinate towards the actual one. The faster force drop in the PD group is interpreted as adaptive to the loss of action stability in PD. The lack of group differences in the sharing drift suggests two potentially independent physiological mechanisms contributing to the force and sharing drifts.

Significance: The hypothesis on adaptive changes in PD with the purpose to ensure stability of steady states may have important implications for treatment of PD. The speed of force drop may turn into a useful tool to quantify such adaptive changes.

* Corresponding author at: Department of Kinesiology, Rec.Hall-268N, The Pennsylvania State University, University Park, PA 16802, USA. Tel.: +1 814 863 5374; fax: +1 814 863 4424.

E-mail address: mll11@psu.edu (M.L. Latash).

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1. Introduction

Stability of action is paramount given the unpredictable external conditions typical of natural everyday motor behavior. The idea of task-specific stability (Schöner, 1995) implies that the central nervous system (CNS) is able to organize redundant (actually, abundant, Latash, 2012) sets of elements taking part in all natural movements into groups (synergies, Latash et al., 2007; Latash, 2008) that provide stability with respect to salient, task-specific variables. Analysis of inter-trial variance within the space of elemental variables has been used to provide a quantitative index of stability: Assuming that individual trials start from somewhat different internal states, variance in directions of low-stability is expected to be large whereas variance in directions of high stability is expected to be low. Within the uncontrolled manifold (UCM) hypothesis (Scholz and Schöner, 1999), the difference between the former (variance within the UCM, V_{UCM}) and the latter (variance orthogonal to the UCM, V_{ORT}) has been used as an index of synergy (ΔV) stabilizing the corresponding performance variable.

Problems with stability of posture and movement are among the most common consequences of Parkinson's disease (PD), and postural instability is one of the cardinal features of PD (Fahn and Jankovic, 2007). In a recent series of studies, we used the framework of the UCM hypothesis to quantify stability of multi-finger pressing and prehensile actions (Park et al., 2012, 2013; Jo et al., 2015). Across tasks and analyses, patients with early-stage PD showed significantly lower synergy indices, ΔV, stabilizing the multi-finger steady-state actions compared to controls.

Recently, a complementary mechanism of ensuring stability of action has been hypothesized based on the observations of unintentional changes in the motor output when subjects were instructed to keep the output constant (Vaillancourt and Russell, 2002; Zhou et al., 2014; Ambike et al., 2015). In particular, when a healthy person is asked to press with a finger and maintain constant force, turning the visual feedback off leads to a slow drop in the produced force, up to 40% of the initial force level over 20 s (Slifkin et al., 2000; Vaillancourt and Russell, 2002; Shapkova et al., 2008; Ambike et al., 2015). Active force production may be viewed as a consequence of a discrepancy between the actual (AC) and referent (RC) coordinates of the finger multiplied by a gain (apparent stiffness, cf. Latash and Zatsiorsky, 1993). Within this view, the unintentional force drop reflects a slow drift of RC towards AC, which is fixed in isometric conditions. This drift reduces the difference between the AC and RC and hence moves the effector closer to the minimum of its potential energy (reached when AC = RC), which is also a state of high stability.

A recent study explored accurate total force production by the two index fingers pressing simultaneously while the shares of the total force produced by the two fingers varied across trials within a broad range (Ambike et al., 2015). Turning the visual feedback off led to two phenomena: The aforementioned drift of the total force was accompanied by a drift in the sharing pattern towards more equal force distribution between the two fingers. The time profiles of the two drifts were similar leading to a conclusion that they reflected a single neurophysiological mechanism.

In this study, we explored the unintentional force drift during accurate force production without visual feedback in patients in early-stage PD. Our main hypothesis was that PD patients could use an adaptive strategy to compensate, at least partially, for their loss of stability reflected in the reduced synergy index (Park et al., 2013, 2014). Hence, we expected the patients to show a stronger coupling between the AC and RC of the fingers resulting in a faster unintentional drop in the finger force when the visual feedback was turned off (cf. Vaillancourt et al., 2001). We also explored the effects of varying the initial sharing pattern of force between the two fingers based on the mentioned observations that the sharing drifts towards a preferred pattern, close to 50:50 (Ambike et al., 2015). In that study, Ambike and colleagues suggested that a single neurophysiological process could be responsible for the observed drifts of finger forces to lower values and sharing towards a preferred pattern. Both were supposed to reflect a drift within the UCM, which also affected total force because of the coupling between the UCM and orthogonal to the UCM sub-spaces. Therefore, our second hypothesis for the present study was that the adaptive changes leading to a faster drop in forces in PD patients (as in the first specific hypothesis) would also lead to a faster drift in the sharing pattern.

2. Methods

2.1. Subjects

Ten patients with PD (aged 63.1 ± 4.6 years; 6 males) and 10 age-matched control subjects (CS; aged 63.3 ± 3.1 years; 7 males) were tested. The participants were selected from a larger pool of subjects of an ongoing clinical and neuroimaging correlation study in which all PD subjects were recruited from a movement disorder clinic and diagnosed by movement disorder specialists. CS were recruited from spouses and friends of the patients, as well as through flyers posted in the local community. All participants were right-handed according to their preferential hand use during writing and eating. None of the CS had any known neurological disorders or arthritis in their upper extremities.

Descriptive data for all subjects are presented in Table 1. For PD subjects, Unified PD Rating Scale part III – motor scores (UPDRS-III) ranged between 3 and 24. The median duration of illness since diagnosis was 2.2 years (ranging from 0.1 to 8.1 years); none of the patients showed postural instability and/or signs of drug-induced dyskinesia. PD subjects were tested while on their prescribed anti-parkinsonian medication. The levodopa equivalent daily dose (LEDD) was estimated for PD subjects according to a published formula (Tomlinson et al., 2010). The study protocol followed the Helsinki principles and was reviewed and approved by the Pennsylvania State University-Hershey Medical Center Institutional Review Board. Written informed consent was obtained from all subjects.

2.2. Apparatus and procedure

Subjects were seated comfortably in a chair with their forearms resting on top of a table and facing a 19-in. computer monitor positioned at eye level. They performed a set of tasks with two fingers pressing on individual force sensors (1) right and left index fingers (*BOTH* condition); (2) right index and middle fingers (*RIGHT* condition); and (3) left index and middle fingers (*LEFT* condition). Two piezoelectric force sensors (model 208A03; PCB Piezotronics, Depew, NY) were used to measure the vertical forces produced by the fingers. Each sensor was covered with sandpaper (100-grit) to increase the friction between the fingertips and the top surface of the sensors. Prior to each trial, all sensor signals were set to zero when subjects placed their fingertips on the sensor centers and relaxed their hands. As a result, the sensors measured only active downward forces. A customized LabVIEW program was used for the data acquisition at 100 Hz with 16-bit resolution and for subject feedback.

For the *BOTH* condition, subjects' shoulders were flexed at approximately 30°, abducted at approximately 30° and internally rotated approximately 45° with the elbows flexed approximately at 90° (Fig. 1A). The mid-point between the two sensors was aligned with the midline of the body, and the distance between