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Atypical task-invariant organization of multi-segment tremors in patients with Parkinson's disease during manual tracking

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Abstract

The objective of the study was to investigate the interplay between involuntary tremulous activities and task performance under volitional control for patients with Parkinson's disease (PD) during position tracking. A volunteer sample of nine untreated patients and nine age-matched healthy subjects participated in this study. They performed a sinusoidal tracking maneuver with a shoulder and a static pointing task; meanwhile, a position trace of the index and accelerometer data in the upper limb were recorded to characterize tracking performance and postural–kinetic tremors. In reference to postural tremor, the kinetic tremor of control subjects during tracking was considerably modulated, leading to a lower regularity and greater spectral deviation. In contrast, patients with PD demonstrated greater postural and kinetic tremors than control subjects, and tremulous movements of the patients were comparatively task-invariant. The prominent coherence peak, which occurred at 8–12 Hz in control subjects, was atypically presented at 5–8 Hz for PD patients with poorer tracking performance. Functionally, congruency of position tracking was related to amplitude of kinetic tremor after subtracting from amplitude of postural tremor. In conclusion, task-dependent organization of tremulous movements was impaired in patients with PD. The inferior tracking performance of the patients correlated implicitly with kinetic tremor, signifying some sharing of neural substrates for manual tracking and tremor generation.

Keywords: Parkinson's disease; Kinetic tremor; Postural tremor; Position tracking; Coherence

1. Introduction

Tremor is one of the most recognizable motor symptoms of Parkinson's disease (PD). Following progressive loss of nigrostriatal neurons, the initial symptom of PD, resting tremor, begins distally in one arm at 4–6 Hz due to altered oscillations within the pre-existing interconnection of neural networks (Beuter and Edwards, 2002; Feger, 1997). Different forms of tremulous movements can be observed in patients with PD during postural maintenance (Jankovic et al., 1999; Vaillancourt and Newell, 2000), force exertion (Forssberg et al., 2000; Vaillancourt et al., 2001), or alternate movements (Duval et al., 2004), in relation to altered central–peripheral interplay for diverse task needs (Burne, 1987; McAuley and Marsden, 2000). The presentation of kinetic tremor in PD is thought to impair task performance (Carey et al., 2002) because the temporal and amplitude controls of skilled movements could be undermined by tremor-associated muscle weakness and pacing disturbance (Brown et al., 1997; Logigian et al., 1991). However, based on movement fluctuation in distal limb segments or task errors, several researchers have reported only a weak linkage between resting/kinetic tremors and disability stage (or motor dysfunction) in patients with PD (Duval et al., 2004; Louis et al., 1999; O'Suilleabhain, 2006).

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Recently, inherent correlation among tremulous movement in different limb segments has been considered to be of functional value in understanding coordinative control of human movements (Hwang and Wu, 2006; Morrison and Newell, 1996; Morrison and Newell, 2000). Our previous study revealed task-dependent tremor modulation by contrasting inter-segmental oscillatory activities between postural holding and position tracking. There was a lower coherence between the finger and hand at 8–12 Hz during finger tracking than that during postural holding, and task precision during tracking was inversely proportional to the amplitude of kinetic tremors in finger and hand (Hwang and Wu, 2006). Moreover, Hurtado et al. (2000) reported task-related tremor coupling in PD by demonstrating a higher intralimb coherence of EMG activity during a mental arithmetic task than a finger-to-nose task. Although a number of studies have been conducted on functional correlates between motor deficits and kinetic tremor of a single segment, those works may simplify the conclusion by overlooking the evidence that any coordinative movement entails collaboration of several limb segments, while kinetic tremor in those segments may not be equally modulated in a task. Additionally, because tremor is not under volitional control, attention may be profitably directed to decouple impaired performance of PD patients from the errors contributed by tremor, and then to reassess whether PD-related tremor and impairment of volitional control are correlated (Spirduso et al., 2005).

On a multi-segmental basis, the first objective of the study was to reinvestigate the effect of kinetic tremors on tracking performance in patients with PD. The second objective was to compare the differences in temporal/spectral features of tremors associated with postural holding and position tracking in PD patients versus those in healthy participants. It was hypothesized that (1) amplitudes of kinetic tremor are relevant to the degree of disruption in tracking performance, and (2) the capacity of task-related modulation on tremor for patients with PD is reduced in contrast to healthy adults. We focused attention on tremor interplay among various limb segments because atypical tremor structures may shed light on impairments of intra-limb coordination in PD in achieving the goal of a task.

2. Methods

2.1. Subject and procedures

Nine selected patients (aged 72.1 ± 5.1 years; 5 male, 4 female), who first visited a neurological clinic because of tremor syndrome and were later diagnosed with idiopathic Parkinson's disease (PD), participated in this study. The diagnosed PD patients had never taken any anti-Parkinson's medication before the experiment. Patients were classified as Stage I–II on the Hoehn and Yahr scale (Hoehn and Yahr, 1967), and they all presented visible postural tremor in the most affected side (the dominant arm). The nine age-matched subjects with no neurological abnormality in the control group (aged 71.1 ± 4.9 years; 3 male, 6 female) were volunteers from a local community. There was no gender and age difference between the two groups studied (gender: $\chi^2(1) = 0.90$, $p = .637$; age: $Z = 0.796$, $p = .426$). All participants were right-handed by self report and signed written informed consents in accordance with the institutional guidelines concerning the protection of human subjects.

The present study measured postural tremor in a research laboratory, where the patients and control subjects performed a pointing task with their dominant arm while sitting. All subjects outstretched their right arms and pointed the index finger directly ahead in parallel to the ground for 20 s. The positions of the upper limb were shoulder flexion at 90 degrees with the elbow at full extension and forearm pronation. The wrist remained at 0 degrees of flexion with the fist closed, but the index finger was extended horizontally at the metacarpophalangeal (MCP) joint. Next, kinetic tremor was recorded three times for a consecutive 20 s during position tracking. The subjects were encouraged to pursue target sinusoidal curves with the shoulder in the sagittal plane in a range of ±2.5 cm at a 0.6 Hz, generated by a functional generator (33220A, Agilent, Malaysia). It was necessary that the wrist and elbow be kept in the relatively same position and move in accordance around the shoulder joint. Hence, subjects produced the tracking motion with a "stiff" arm. The success of the tracking task requires meticulous control of joint stiffness in the elbow, wrist, and index against additional gravitational and rotational accelerations in the movement. A displacement-transducing laser (ZX-LD100, Omron, Japan) was placed 4 cm from the fingertip to monitor the position of the fingertip. The subjects controlled shoulder movement to couple the position trace of the fingertip to the target line on the screen of the oscilloscope (GOS-620, Instek, Taiwan). The middle position of the position tracking (horizontal reference line) was identical to the position for recording postural tremor. Limb oscillatory activities were measured with four accelerometers (ADXL202, Analog Devices Inc., Norwood, USA, sensitivity = 312 mV/g, measurement range = ±2 g, bandwidth = 0.01 Hz–5 kHz) by placing the accelerometers on the following anatomical landmarks: (1) the index finger: dorsal aspect of the distal index finger; (2) the hand: middle shaft of the third metacarpal bone; (3) the forearm: belly of the brachioradialis; (4) the arm: 3 cm lateral to the belly of the biceps brachii (Hwang et al., 2006; Morrison and Newell, 2000). Index displacements, transformed from voltage outputs of the laser system, were conditioned with a low pass filter (cut-off frequency: 1 Hz) to separate involuntary limb oscillation (>1 Hz) from position trace. Hence, the filtered index displacement (<1 Hz) containing negligible involuntary tremulous movements signified the capacity of volitional control over the upper limb. Accelerometer data, displacements time series of the index, and target sinusoidal signals were digitized at 400 Hz using a computer program constructed on the Labview platform (National Instruments, USA).

2.2. Data processing and statistical analyses

Offline analyses included average intensity/regularity, power density function, and inter-segment correlation/coherence of the accelerometer data. The intensity of tremulous activities was represented with the root mean square (RMS) of the conditioned accelerometer data following a high pass filter (cut-off frequency = 1 Hz) to preclude possible low frequency components of cardioballistics and sinusoidal motion artifacts. Regularity of the limb tremulous movements was assessed with approximate