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A Novel Experimental Method to Evaluate Motor Task Control in Parkinson's Patients*

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Abstract—**In this paper, a novel experimental method was developed to study planar arm movement control in tremor dominant Parkinson's (PD) patients. The method utilized a ball-bearing supported fiberglass brace apparatus against gravity to maintain the upper extremity in the horizontal plane. Subjects can perform postural and movement tasks with minimum damping effects. Arm movements were recorded using the MotionMonitor II system concurrently with EMGs of multiple muscles. Testing results in normal subjects with and without the brace support showed that the inertia and damping effects were negligible for oscillatory arm movement at maximum voluntary frequency (MVF). The tremor behaviors in horizontal posture maintenance and reaching movement in three PD subjects were also obtained with this method. The average frequency of postural tremor was 4.34±0.15 Hz in all arm positions tested. However, the tremor magnitudes changed significantly with posture locations. In performing reaching movements, the tremor was inhibited prior to reaching, but resumed after reaching. These results may provide interesting insights into the pathological mechanisms of Parkinsonian tremor, as well as the modular nature of neural control of movements.**

I. Introduction

It has been hypothesized that the control of arm position and movement is planned and executed separately by different modules of the brain [1, 2 and 3]. Exploring the sensorimotor performance under pathological conditions may provide insights as to how the impairment of sensorimotor system affects the functions in motor task control. This is demonstrated in the study on deafferented subjects, in which the role of afferent feedbacks in motor control has been investigated [4, 5]. Parkinson's patients display typical motor dysfunctions with resting tremor, rigidity, bradykinesia, and postural instability [6]. A large body of work on molecular biological, electrophysiological, and neural imaging approaches were used to reveal the pathophysiology of Parkinson's disease (PD) [7, 8], as well as the effectiveness of deep brain stimulation (DBS) to treat PD patients [9, 10 and 11]. Behavioral tests were also performed to implicate contributions of basal ganglia to motor control [12], but were not studied as intensively as other aspects [13]. The purpose of this paper is to develop a novel method to evaluate the behavioral features of PD patients in task performance.

Existing experimental apparatus for studying motor behaviors of upper extremity of Parkinson's patients included horizontal movement platform [12], robot arm [14], and wearable accelerometer system [15]. However, these methods provided nether anti-gravity support for upper extremity, nor friction reduction of the damping effects introduced by bracing robot's inertia and friction, which may interfere the tremor behaviors of PD patients. To achieve a more reliable evaluation of tremor behavior, we developed a novel experimental method for upper extremity posture and movement measurement in horizontal plane. A fiberglass brace with ball-bearing base apparatus sliding on a frictionless surface was design to facilitate PD patients performing arm posture and reaching tasks.

We tested the performance of the brace apparatus on healthy subjects by performing oscillation movement at maximum voluntary frequency (MVF). Then we evaluated posture maintaining and reaching tasks in tremor dominant Parkinson's patients with this experimental platform. The results proved that this experimental method is an effective approach to evaluate motor task control of Parkinson's patients.

II. Materials and Methods

A. Subjects

The Ethics Committee of Animal and Human Subject Studies in School of Biomedical Engineering, Shanghai Jiao Tong University, approved this study. 3 Parkinson patients with tremor dominant symptoms were recruited from the Department of Neurology, Ruijin Hospital, School of Medicine, and 3 healthy subjects were enrolled as control subjects. All subjects signed the informed consent before the initiation of experimental procedures and have the right to quit whenever they want. All Parkinsonian subjects were attending experiments at 9 a.m., meanwhile taking medications as usual. All healthy subjects are right handed and perform motor tasks using right upper limb. All Parkinsonian subjects perform motor tasks using upper limb on the tremor-originated side.

B. Experimental Setup

The experimental setup is illustrated in Figure 1A. Subjects were seated comfortably in front of a custom built wooden table with adjusted height, performing upper extremity motor tasks in the horizontal plane. A large piece

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of transparent and smooth acrylic glass with a thickness of 5 *mm* was placed on top of the table, while dot targets with 10 *mm* diameters were marked under the glass plate. Subjects wearing the ball-bearing supported fiberglass brace apparatus on the forearm can slide on the glass plate, with wrist joint fixed, and shoulder and elbow joint moved freely. A target pointer was mounted on the front end of the brace at hand to help the subjects align to the start position and targets. Jelly lubricant was smeared on the glass surface to reduce friction between glass and the brace apparatus.

The ball-bearing supported fiberglass brace apparatus shown in Figure 1B was fabricated with specific considerations of friction-free and lightweight design that can minimize rotational inertia and damping during joint movements. It was assembled from a fiberglass cast and a brace by nylon screws and nuts. The forearm shaped cast was made of rapid prototyping fiberglass material, and the brace was made of Plexiglas and installed with 5 ball-bearing wheels, which were assembled by nylon shell and silicon nitride (Si_3N_4) ceramic balls. Cotton-padded lining was added to the cast to make it comfortable and well fitted for the subjects. The ergonomically designed ball-bearing supported fiberglass brace apparatus was capable of supporting the upper extremity of subjects rest on the table effortlessly and move in horizontal plane without apparent resistance. In addition, since we employed a magnetic motion tracking system, the wooden table and the brace apparatus have to be built without metal materials.

C. Kinematic and EMG Measurements

We employed a commercialized MotionMornitor^{TM} II system for planar movement monitoring and recording. An Ascension^{TM} wide range transmitter was placed 1.5 *m* in front of the subjects (Figure 1), produced a sphere magnetic field with a radius of about 3 *m*. Three magnetic sensors (Ascension^{TM} trakSTAR, Model 800) were attached to corresponding body segments (forearm, humerus, and thorax) of the subjects, respectively. Each sensor can measure 6 channels of position signal corresponding to 6 degrees of freedom (DOFs) of rigid body: 3 DOFs of Cartesian coordinates and 3 DOFs of rotational coordinates. The position signals detected by sensors were sampled at 120 *Hz*, and then linearly interpolated to align to the EMG sampling rate for synchronization.

Surface EMG of biceps brachii (Biceps), triceps brachii (Triceps), flexor carpi radialis (FCR), and extensor carpi radialis (ECR) were collected using Norotrode^{TM} silver/silver chloride (Ag/AgCl) bipolar electrodes (Model BS-24SAF) and a copper reference electrode. Electrode placement was standardized as per [16] and the EMG signals were pre-amplified by 5000 times and band-pass filtered between 1-1000 *Hz* using Grass^{TM} amplifiers. Then the EMG signals were A/D converted at the sampling rate of 2410 *Hz* using a 16-channel Computing Measurement^{TM} USB-BNC A/D card.

D. Data Processing and Analysis Toolkit

The data processing and analyzing toolkit were developed in Matlab^{TM} (Version: R2010a, MathWorks Inc.), involving zero-phase filters designed for noise elimination and principal component analysis (PCA) tool for tremor evaluation and motion variability analysis. Raw kinematic

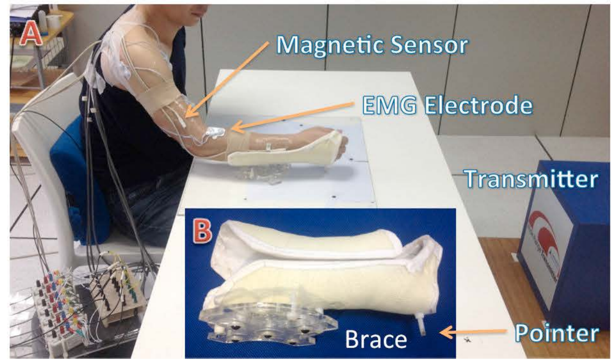

Figure 1. A. Schematic illustration of experimental setup for horizontal movement recordings of upper extremity of Parkinson's patients. B. The ball-bearing supported fiberglass brace apparatus.

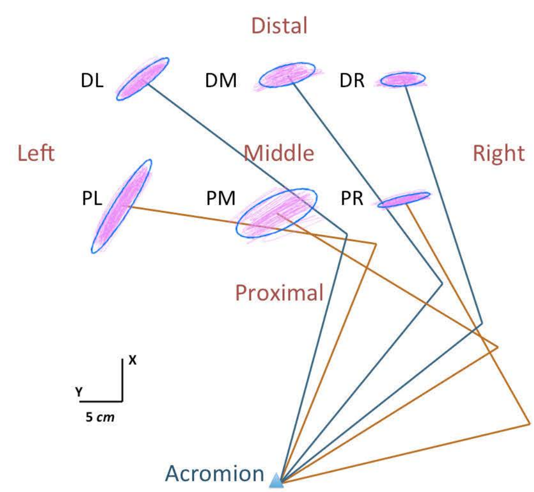

Figure 2. Posture maintaining tasks with visual feedback performed by a Parkinsonian subject. The subjects were asked to maintain at 6 endpoint positions, Distal Left (DL), Distal Middle (DM), Distal Right (DR), Proximal Left (PL), Prox imal Middle (PM), and Proximal Right (PR), respectively. The pink traces indicate the endpoint trajectory of posture tremor in horizontal plane, and the blue ellipses represent 95% confidence ellipse of the endpoint variation.

and EMG signals needed to be off-line notch filtered to eliminate AC power noise (50 *Hz* and higher harmonic) and harmonic noise generated by the dynamic magnetic field produced by the magnetic transmitter (120 Hz and higher harmonic). In order to prevent nonlinear phase shift that general digital IIR (infinite impulse response) filters may introduce, we designed third order Butterworth notch filters that filtered the data in both forward and reverse directions, to achieve sixth order zero-phase distortion performance. The kinematic signals were low-pass filtered by a FIR (finite impulse response) median filter to eliminate sampling noise.

EMG features including root-mean-square (RMS) amplitude, bursting initial time, bursting duration, bursting area, and the maximum value during bursting, were extracted from the pre-processed data. Kinematics including trajectory, velocity and acceleration, and the correlation between acceleration and EMG signals were calculated. Principal component analysis (PCA) method was established to evaluate tremor movement variability, which was represented by the 95% confidence ellipse of the endpoint distribution. The axes lengths of variability ellipse were determined by 1.96 times the square root of eigenvalues of the covariance

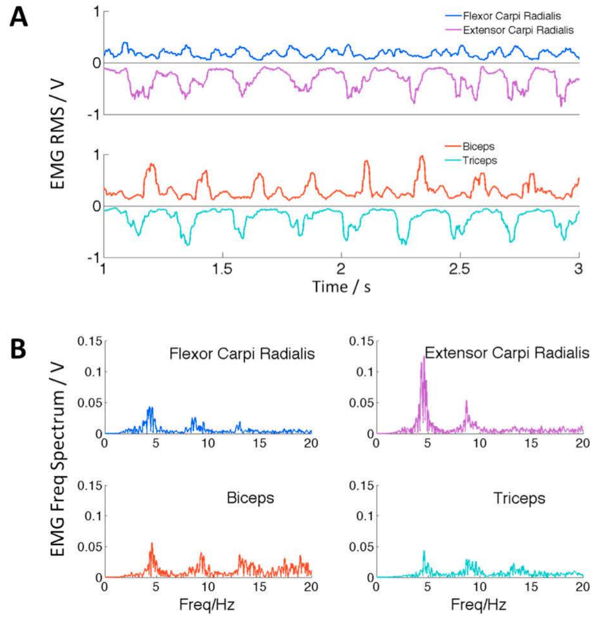

Figure 3. A. RMS (root mean square) EMG of two pairs of antagonist muscles during posture tremor. B. Frequency spectrum diagrams of above muscles.

matrix of the endpoint distribution. The details of PCA method were described elsewhere [17].

E. Experiment Procedures

We set up 6 endpoint positions in horizontal plane as shown in Figure 2. We first tested the performance of the ball-bearing supported fiberglass brace apparatus on 3 healthy subjects. They were seated in front of the table and asked to perform right arm flexion/extension movement at maximum voluntary frequency (MVF) for 10 *seconds* between two dot targets separated by 60 *mm* at each position. Each participant completed 4 trials at each position with or without the cast-brace apparatus, and the average MVFs were listed in Table I.

Secondly, we evaluated posture maintaining and reaching capacity of 3 Parkinson's patients, two of them with tremor originated on the right side and one on the left side. Subjects were instructed to maintain at 6 positions for 10 *seconds* with visual feedback in posture tasks as shown in Figure 2, and the distribution of endpoint tremor trajectory was evaluated using PCA method. Then they were asked to perform reaching task from position PM to DL, between 2 posture maintaining tasks, triggered by a vocal instruction.

III. Results

First, we tested the performance of the ball-bearing supported fiberglass brace apparatus on 3 healthy subjects by

TABLE I. CAST'S EFFECT ON MOVEMENT AT MVF

Subjects	MVR Frequency / *Hz*		Difference
	Without Cast	With Cast	
LYT	5.02±0.24	4.75±0.17	-5.34%
XYJ	4.83±0.21	4.63±0.15	-4.14%
QHE	5.35±0.35	5.08±0.23	-5.05%
Average	5.07	4.82	-4.84%

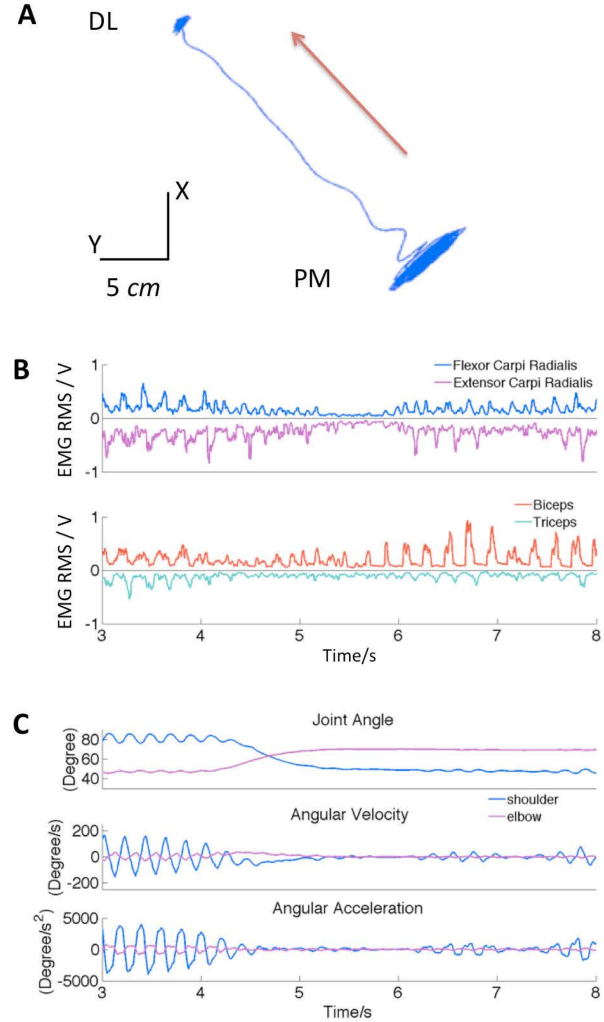

Figure 4. A. Reaching task performed by a Parkinsonian subject from PM to DL with visual feedback. The blue trace indicates the endpoint trajectory in horizontal plane and the red arrow indicates the reaching direction. B. RMS (root mean square) EMG of two pairs of antagonist muscles and C. kinematic features of shoulder (blue line) and elbow (pink line) joints during reaching task in A. The tremor is significantly suppressed during and shortly after reaching movement.

performing movement at maximum voluntary frequency (MVF). The testing results are listed in Table I. The average MVF of 3 healthy subjects without and with cast-brace apparatus are 5.07 *Hz* and 4.82 *Hz*, respectively. So the ball-bearing supported fiberglass brace apparatus reduced the MVF by less than 5% due to damping and inertia effects. This difference is acceptable because cast's effect at this level will not affect the tremor evaluation significantly.

A typical group of results for 6 posture maintaining tasks performed by Parkinson's patients is shown in Figure 2. All subjects show conspicuous tremor at each position while trying to maintain at the target position. The pink trace indicate the endpoint trajectory during 10 *s* posture maintaining task, and the blue ellipses cover 95% of endpoint variability, which represent the tremor magnitude at each position. The major and minor axes varied tremendously among 6 positions possibly due to biomechanics and different psychological states. The RMS EMG patterns illustrated in Figure 3A demonstrate typical alternating bursting in paired antagonists. The frequency spectrum diagram of each EMG channel is presented in Figure 3B, indicating the muscle bursting frequency or tremor frequency is 4.36 *Hz* at the peak of spectrum. The average frequency of postural tremor of 3 PD patients is 4.5 *Hz*, and no significant differences in the tremor frequency are observed in different postures.

A reaching trajectory in horizontal plane from PM to DL is illustrated in Figure 4A. Subjects were asked to maintain posture both before and after reaching movement. The blue line trace the planar endpoint trajectory of two posture maintaining stages and one reaching section in between for 10 *s*, and the red arrow indicates reaching direction. RMS EMG of two pairs of antagonists were displayed in Figure 4B, and joint kinematics of shoulder and elbow were plotted in Figure 4C. Tremor correlated EMG bursting was significantly suppressed during and shortly after reaching, as well as oscillations in joint kinematics. Apparently the tremor was switched off at the initiation of reaching movement, and then switched on shortly after movement.

IV. Discussion and Conclusion

EMG and movement measurements have usually been utilized for diagnostic investigations of Parkinson's disease [14]. In this study, we recorded EMG and movement for evaluation of motor task control of Parkinson's patients. Our experimental setup is different with [12], in which arm movement control of advanced PD patients with bradykinesia was studied without gravity compensation. In our study, the goal was to evaluate delicate tremor behaviors of tremor dominant PD patients, and we designed the ball-bearing supported fiberglass brace apparatus to provide anti-gravity support for the arm and to facilitate subjects performing planar motor tasks. Fixing the wrist joint by the apparatus did limit hand tremor to a large extent. However, since we were more interested in the tremor behaviors in the elbow and shoulder joints for posture and reaching, the interference of hand tremor did not change the tremor behaviors at the elbow and shoulder joints.

There is a clear alternating burst pattern of EMGs in the antagonistic muscles in the arm (Fig.3) at the same tremor frequency. This may suggest that the oscillatory signals of the arm muscles may come from a single source of central oscillation. This phenomenon may further imply that the basal ganglia circuitry may output an oscillation signal that is passed down to muscles in parallel via the normal spinal motor system.

Preliminary results also revealed that Parkinson's subjects could maintain arm positions with a superimposing tremor at the hand, but may also make a reaching movement despite the dysfunction of basal ganglia circuitry. The amplitude of the tremor was found to be dependent on the location of the hand. This may be caused by the different inertia of the arm in different arm configurations. The reaching movement was slower than that of normal subjects. The tremor was suppressed before the initiation of reaching, and returned after reaching. These experimental results imply that separate control mechanisms for posture and movement may be implemented in the brain independently.

In future studies, we will design more specific tasks to evaluate the motor performance in PD patients. This experimental method could also be combined with computational approach [18, 17] to test hypotheses concerning neural control of movement, and to develop computational model to understand deep brain stimulation (DBS) for treating Parkinsonian symptoms.

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