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Tremor Suppression Orthoses for Parkinson's Patients: A Frequency Range Perspective

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Abstract— **While the majority of tremor-afflicted Parkinsonian (PD) patients suffer from rest tremors, which is not considered highly disabling, a portion of these PD patients also demonstrate action tremors that interfere with their daily lives. Two main considerations in designing an orthosis that aims at suppressing the tremor, are the frequency bands of the tremor and the joints tremor affects. Nine subjects,which included six healthy people, two PD patients with typical tremor afflictions, and a PD patient with severe tremor of not only in her fingers and wrist, but also in her elbow, participated in this study. The highly afflicted patient displayed the need for tremor suppression in action as well as when in rest. The study focuses on uncommon elbow tremors and demonstrates that, for typically afflicted patients, tremor amplitudes are comparable to healthy subjects, but the frequency distribution of the tremors are different at high levels of elbow torque. For the highly afflicted patient, both tremor amplitude and its frequency distribution are different at all levels of elbow torque. The study further investigates the tremors in two bands of frequency on both hands of the highly troubled patient before, and after medication. The two bands are those of classical Parkinsonian tremor (4-6 Hz) and physiological (or enhanced physiological) tremor (8-12 Hz). Power spectrum and tremor amplitude comparisons reveal that, for part of tremulous PD patients, both tremors coexist and, depending on the level of affliction, the designed orthosis needs to suppress tremors in both bands, even at more proximal joints, such as the elbow.**

I. INTRODUCTION

Parkinson's disease (PD) is associated with bradykinesia, rigidity, tremor, and postural instability. Tremor represents a particularly interesting symptom because its responsiveness to dopamine therapy is quite variable [7]. Although 4-6 Hz rest tremor with pill rolling is typical, many researchers have reported additional action and postural tremors, occurring in a varying range of 40% to 93.4% depending on the study ([13], [5], [12], [15]). Part of the challenge in distinguishing and recognizing the differences is whether the frequency is the same or higher than rest tremor (5-12 Hz) [14], [4], [3]. Action tremor occurs during any voluntary muscle contraction, and is a more comprehensive term for postural, kinetic, isometric, and task specific tremors [1]. Because PD action tremor interferes with daily activities, it is more disabling than rest tremor. Yet, its underlying pathophysiology remains unclear [15]. A group of researchers have proposed that action tremor (just during movement) might represent an enhancement of physiologic tremor in PD patients [21]. Both physiological tremor and enhanced physiological tremor (EPT) are essentially twice as fast as classical Parkinsonian rest tremor (RT), and, while the former is barely noticeable unaided, the latter can produce clinical symptoms [10]. EPT is a weak and rapid (with single peak frequency in 8-12 Hz) tremor which is minimal or absent at rest. It appears or intensifies in posture and remains present during movement with no increase in amplitude [10]. RT is a rest tremor of 4-6 Hz that subsides with any deliberate muscle activation [14]. However, it has been reported to remain visible even during posture or movement [6], [9], [21] or re-emerge in posture after a delay [11]. Similarities that are often observed between PD action tremor and EPT have led to the assumption that Parkinson's action tremor is, in fact enhanced (or alternatively known as exaggerated) physiological tremor [9], [17], [13], [8], [18]. Few researchers demonstrate the coexistence of physiological and PD action tremors in patients without visible rest tremors [2].

Many of the current wearable tremor suppression devices, such as the Double Viscous Beam (DVB) [16] and the Wearable Orthosis for Tremor Assessment and Suppression (WOTAS) [20], are intended to suppress essential tremor. Examining the coexistence of the two aforementioned tremors and their dominance during action in PD patients with different levels of tremor affliction would be a necessary step to apply the current or similar devices to suppress the tremor in these patients.

The aim of this pilot study is to test the coexistence hypothesis on a small group of PD patients and to compare the amplitude of physiological or enhanced physiological tremor in these patients with a group of healthy people in rest and in all levels of generated torque at elbow flexion.

II. METHODS

Nine people participated in this study. Six were healthy students with a mean age of 31.7 years (SD=5.8). Two PD patients (with a mean age of 76.5 years, SD=2.1) had typical tremor afflictions. A 53 year old, right-handed PD patient with a high degree of tremor affliction also participated in the study. The latter subject had strong rest and action tremors on the dominant (right) side, which was highly disabling even at elbow level, and responded positively to L-dopa medication.

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A. Experimental device and data acquisition

The apparatus in the experiment measured the isometric elbow flexion-extension torque using a reaction torque sensor (OMEGA® TQ301, 45±0.09 N.m). Each participant was seated upright in a chair, facing the device with the shoulder fully adducted, lower arm fully supinated, and palm facing up. All the trials were performed at an elbow angle of $\theta = 135°$.

The applied torque was collected along four channels of bipolar EMG signals with a 16-bit data acquisition card (National Instruments, PCI-6221) at a sampling frequency of 1 kHz. EMG signals were used in another study, but were examined in this one to avoid muscle fatigue. The torque signal was amplified using a full bridge amplifier (Entran® PS-A, calibration was performed once with amplifier included). Software user-interface was written in LabVIEW®8.0 (Laboratory Virtual Instrumentation Engineering Workbench). The software interface provided the experimenter with online information about the acquired signal, facilitating different stages of the experiment. It also provided the subject with real-time visual feedback of the applied torque in addition to the target torque pattern, which the participant was supposed to follow.

B. Experimental Procedure

Subjects provided informed consent to the experiment procedure, approved by the Office of Research Ethics at the University of Waterloo. For severely afflicted patient, the experiment was run in two sessions. Anti-Parkinsonian medication was withheld for 18 hours (Off condition) and Unified Parkinson's Disease Rating Scale (UPDRS) was administered before the first session and, then again, two hours post administration of medication. In each session, the subject sat at the experimental apparatus and performed the experiment with both hands, one at a time, and with a short break in between. For the rest of the participants, the experiment was done in one session and only on the dominant hands. Before each data collection session, noise signal was recorded (2 s) for session-to-session comparisons. Two Maximum Voluntary Torques (MVTs) were collected from each limb in flexion direction (5 s), with a 2-minute rest in between to avoid fatigue. Two rest segments were also recorded (5 s) to analyze rest tremor. Then main data collection was carried out in five trials of forty seconds each. In each trial, the subject attempted to exert torques according to a randomly chosen pattern displayed on the computer monitor. Each pattern included ± 50%, ± 20% and 0% MVT (or rest) intervals of eight seconds each.

C. Data analysis

Frequency analysis was applied on torque signal as well as on EMG signals acquired from related flexor and extensor muscles. All the analyses were done off-line using MATLAB®2007b (MathWorks) and STATISTICA™7.0 (StatSoft). The power spectrum of EMG signals of all muscles were checked for possible fatigue during the trials. Before working with the torque signal, rest torque averages were subtracted to account for gravitational components. To find the tremor, the DC value was removed from the signal. Then, the signal was padded symmetrically with an appropriate length at the ends to eliminate the transient effects of filtering. Assuming that drift and all other non-tremor movements have frequencies below 1-2 Hz [3], any component in the range 3 to 17 Hz is related to tremor. Therefore, a band-pass filter (discrete-time FIR filter using a least-squares minimization error) in the mentioned range was used to obtain all tremor related fluctuations in the torque signal. For each trial (rest, target tracking, or MVT), power spectral densities (PSDs) for the tremor signals were estimated after they passed through the 3-17 Hz filter. The resulting signals were subsequently digitally differentiated to provide the torque-rate signals, and their PSD were estimated with periodogram. The main advantage of such a differentiation (using torque-rate dT/dt instead of T) was suppressing non-tremor low-frequency oscillations in torque or force signals and is discussed further in [19], [9]. There are different measures of predominant frequency in the tremor, each of which can help identify the tremor's nature. The most trivial ones are spectrum's peak frequency and median frequency.

To compare tremor amplitudes, three bands were considered and the corresponding band-pass filterings were applied on all signals. The root mean square (RMS) values were calculated as the most obvious measure of tremor amplitude [3], [9], in each band. RMS value in 3-17 Hz band represented the amplitude for the total tremor. Similarly, RMS value in 3.5-6.5 Hz band (B1) represented the tremor amplitude in RT range and RMS value in 7.5-12.5 Hz band (B2) represented the tremor amplitude in EPT range.

III. Results

Total tremor amplitudes are compared in boxplots of Fig. 1 for all the participants and all the situations (rest, target tracking, and MVT). Boxplots are graphical means of summarizing the data through five numbers (of smallest and largest observations, lower and upper quartiles, and median) and possible outliers. For PD patients with typical tremor

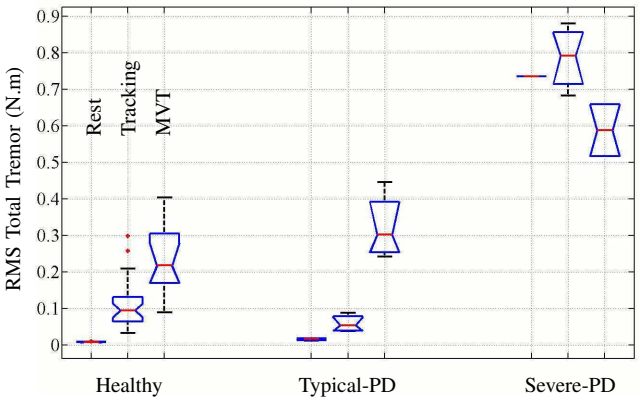

Fig. 1. Comparison of total tremor amplitudes for all groups of participants and all three situations

affliction, rest tremor was significantly higher than those of

healthy people, and tremors during target tracking and MVT were comparable to those of healthy people. For the severely afflicted PD patient, total tremors were mush higher than those experienced by the other two groups in all situations. To compare the frequency distribution of the mentioned total tremors, relative RMS amplitudes of tremors in each band (B1 and B2) with respect to the total RMS amplitude were calculated for each signal (Fig. 2).

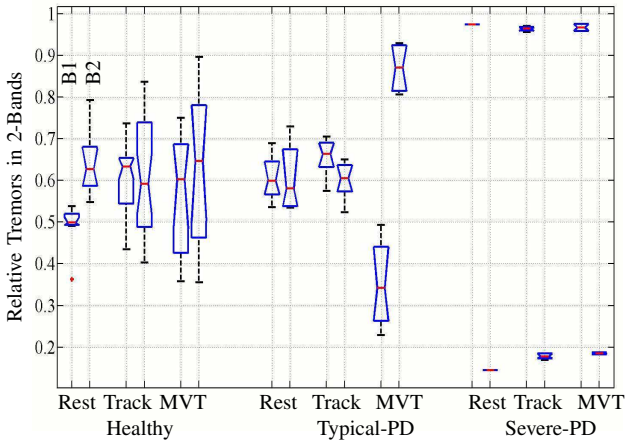

Fig. 2. Comparison of relative tremor amplitudes in two bands of RT (B1) and EPT (B2) for all groups of participants and all three situations

Healthy people demonstrated tremors with an almost equal power in each band (disregarding the fact that B2 is wider) that did not change in different situations. PD patients with typical tremor afflictions, demonstrated tremors that were different from those of healthy people only in higher torque levels (MVT). Their tremors tended to be more evident in EPT band (B2) at higher torque levels. Severely afflicted PD patient, had a dominant tremor only in the RT band (B1) and the tremor characteristics did not change in different situations.

For the highly afflicted patient, more details were investigated on both hands, and before and after medication. The total score on the UPDRS (motor section III) was 32 when "off" and 21 when "on medication". The dopaminergic medication effect was evident on the tremor-dominant (TD) hand. Before taking medication, the subject was virtually incapable of following the pattern on the monitor because of a high amplitude tremor of oscillation at 4.5 Hz, whereas when "on medication", tracking was improved in following the same pattern with smaller amplitude of oscillation at a higher ($\approx$ 9 Hz) frequency.

In the TD hand, while "off medication", EMG from antagonist muscles exhibited alternating pattern of bursts and had peak frequencies that often closely followed the peak frequency in tremor PSD. Tremor peak frequency at rest was 3.9 Hz and during action ($\pm 20\%, \pm 50\%, and \pm 100\%$ isometric MVT) was between 4-5 Hz, and its RMS amplitude, which was not significantly different between rest, tracking, and MVT ($p > 0.05$), was between 0.4 and 0.7 N.m.

Analyzing the same (TD) hand's data, while "on medication", it appears that the rest tremor frequency has increased

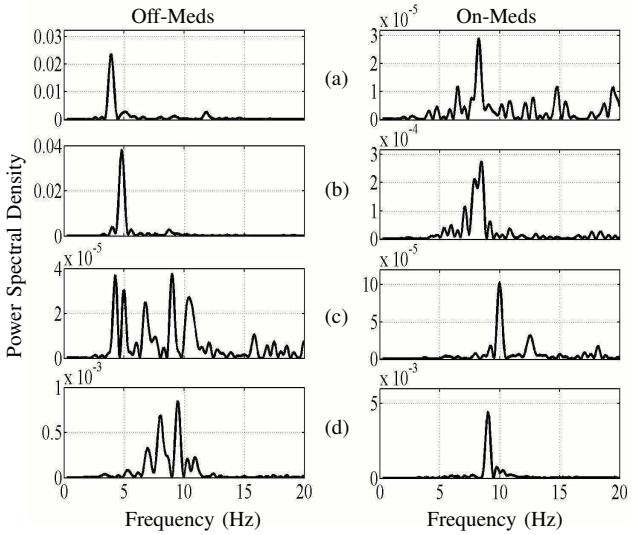

Fig. 3. Comparison of tremor signals' PSDs (from TD hand's torque rate signals, rows a-b) and NTD hand (rows c-d). Left column presents the results "off medication" and the information in the right column corresponds to similar trials after medication. Rows a) and c) correspond to rest trials, and rows b) and d) correspond to one of the MVT trials (flexion #2)

to 8.2 Hz (compared to "off medication") and action tremor frequency was between 7.2-10.5 Hz (almost physiological tremor band). Tremor amplitude was drastically reduced, both at rest and in action, to 0.02-0.06 N.m, and was significantly lower when at rest ($p < 0.01$). The sample PSDs presented in Fig. 3, reveals co-existing tremors (peaks in two different bands) for both hands in rest and also in action.

For non-tremor-dominant (NTD) hand, while "off medication", rest tremor PSD exhibited two, almost equal, peak frequencies (Fig. 3-c, one in 4-6 Hz and the other in 8-12 Hz band) with RMS amplitude of 0.03 N.m. In action, tremor frequencies were between 7.7-11.7 Hz (physiological tremor band) and their amplitudes were between 0.05-0.11 N.m, which were significantly higher compared to rest tremors ($p < 0.01$). After medication, the rest tremor's peak frequency was 10 Hz and those of action tremors were between 8.7-12.7 Hz. The tremor amplitude for rest was 0.02 N.m and those in action were between 0.04-0.11 N.m (significantly higher $p < 0.01$).

Peak frequency and RMS amplitude for tremors during the trials in four different states are compared in boxplots (Fig. 4). In each state, three columns represent rest, MVT, and target tracking trials respectively, from the left.

IV. Discussion and Conclusions

The purpose of this study was to investigate the hypothesis of coexisting RT and EPT at typical and high levels of PD tremor affliction, which would be beneficial in designing tremor suppression orthosis for these patients. In patients with typical affliction, EPT was exhibited predominantly in higher levels of elbow flexion torque. The highly afflicted patient had a strong action and rest tremors in TD-OFF (tremor-dominant hand when "off medication") state, and sub-clinical tremors in all other three states (TD-ON, NTD-OFF, and NTD-ON). For this patient the action tremor was not EPT,

but co-existing tremors were confirmed in both hands when in rest and also in action. Amplitude comparisons revealed that tremors in TD-OFF state were almost ten times stronger on average than tremors in other states (whether at rest or in different levels of isometric contraction). This low-frequency tremor (of 3.9-5.1 Hz) was not apparent after dopaminergic medication was administered, and was replaced with a high-frequency (of 7.2-10.5 Hz), and barely visible tremor. We expected RT to have its highest amplitude at rest, but there was not a significant difference between the amplitudes at rest, in tracking trials, and in applying MVTs. The RT had a slight decrease in amplitude on average in MVT and a slight increase on average during tracking tasks. The mental stress or contralateral movements (where the subject was not able to track the patterns in TD-OFF state) could explain this increase.

For the NTD hand, frequency, and amplitude comparisons revealed that the only noticeable change caused by medication was one low-frequency rest tremor component that disappeared when on medication. The remaining tremors were all high-frequency (7.7-12.7 Hz) in both "on" and "off medication" cases and whether at rest or in isometric contraction. In either hand, EPT had significantly lower amplitudes at rest which was expected.

In conclusion, the coexistence of RT and EPT for both groups of PD patients could be verified. While the severely afflicted patient had disabling tremors only in the RT band, the typically afflicted patients exhibited noticeable tremors in the other band (EPT). Therefore, if a tremor suppression device is designed for such patients, it is recommended to be capable of suppressing the tremors in both bands, even for the elbow joint to cope with the needs of different groups of PD patients. However, further studies with a larger sample of participants, should investigate the practical significance of these recommendations.

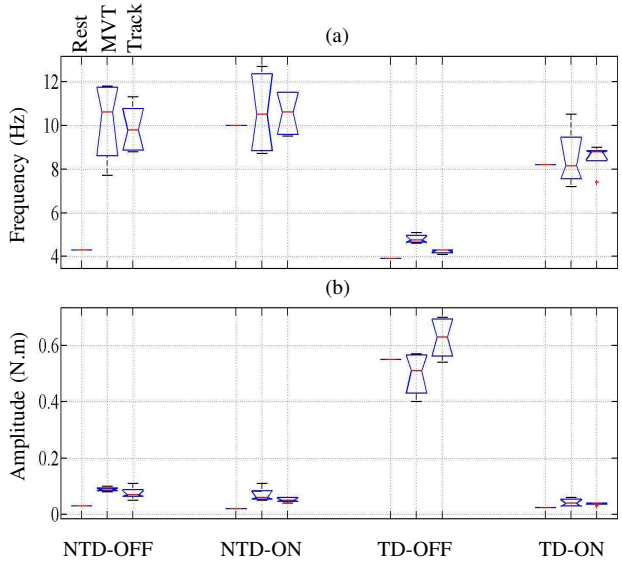

Fig. 4. Frequency and amplitude of tremors in all four cases: TD and NTD hands, "off" and "on medication". a) represents peak (or dominant) frequencies for each trial's PSD. b) represents RMS amplitude of all tremors in 3-17 Hz range.

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