Spectral Analysis of Hand Tremors induced during a Fatigue Test

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***Abstract*—In this paper, we analyze various kinds of hand tremors induced by performing hand actions in the time and frequency domains. Tremor data was collected using a simple, wearable accelerometer from 15 healthy individuals with varying levels of athleticism. The overall mean results presented here show that the physiologic tremors that lie in the frequency range of 8-14 Hz are most noticeable when fatigue is being induced.**

***Keywords*-Hypoglycemia, hand tremor, wearable non-invasive sensor, fatigue.**

I. Introduction

Tremor is a rapid back and forth movement of one or more parts of the body which can be quantified in healthy individuals and considered a pathological symptom [1]. It affects the hands, arms, head, face, voice, trunk, and legs. Tremor either occurs naturally without any underlying cause or may indicate a symptom associated with disorders, medicines, alcohol use, mercury poisoning, anxiety or panic. The tremors can be classified into two main categories: resting and action tremor. The resting tremor (3 Hz to 6 Hz) occurs when the affected body part is completely supported against gravity (e.g. hands resting on the lap), while the action tremor is produced by voluntary muscle contraction. There are further sub-classifications of action tremor: postural, kinetic, intention tremor, task-specific tremor and isometric [2]. Postural tremor (4 Hz to 12 Hz) occurs when the affected body part maintains position against gravity (e.g. arms extended away from the body). Isometric tremor results from muscle contraction against stationary objects (e.g. holding a heavy object in one hand). Kinetic tremor, which occurs with voluntary movement, is either simple kinetic tremor or intention tremor. Simple kinetic tremor (3 Hz to 10 Hz) is associated with the movement of extremities (e.g., pronation-supination or flexion-extension wrist movements). Intention tremor (<5 Hz) occurs during visually guided movement toward a target (e.g. finger-to-nose or finger-to-finger testing), with significant amplitude fluctuation on approaching the target. Task-specific tremor (4 Hz to 10 Hz) occurs with specific action (e.g. handwriting tremor) [2]. Tremor is most commonly classified by its appearance and the cause or origin. Some of the most common forms of tremor include essential, dystonic, cerebellar, psychogenic, physiologic, Parkinsonian and orthostatic [3], [4]. Tremor is usually examined using an accelerometer and/or with electromyography. Through the accelerometer, the total force measured in postural finger tremor is proportional to the acceleration. Acceleration reveals the high-frequency components well because faster oscillations generate more power within higher frequencies [5].

Physiologic tremor (PT) is defined as an oscillatory, roughly sinusoidal involuntary movement of a body part [5]. All normal persons exhibit PT, a benign, high-frequency, low-amplitude postural tremor. It is invisible to the naked eye and can be amplified by doing some action as holding a piece of paper on the outstretched hand or pointing a laser at a screen. Enhanced PT is a visible, high-frequency postural tremor that occurs in the absence of neurologic disease and is caused by medical conditions such as thyrotoxicosis, hypoglycemia, the use of certain drugs, or withdrawal from alcohol or benzodiazepines. It is usually reversible once the underlying cause is addressed [2]. According to Galinsky et al. [6], a PT consists of arrhythmic movements occurring at frequencies predominantly in the range of 7 Hz to 12 Hz. PT occurs in specific body areas of a healthy person resulting from an interaction of mechanical and nervous factors. It is composed of oscillations which stem from two principal components; the mechanical reflex and the central neurogenic [7], [8]. The mechanical reflex component is the larger of the two oscillations and its frequency is governed by the inertial and elastic properties of the body [9]. When examining tremor on the index finger, frequencies below 7 Hz are mainly associated with mechanical-reflex components [10], which is driven by the resonance properties of a segment and could be influenced by reflex activities. The stretch reflex response to mechanical oscillation can be increased by fatigue, anxiety, and some medications, producing a modulation of motor-unit activity [10]. The central-neurogenic component of the PT is associated with modulation of motor-unit activity and comprises oscillations at frequencies between 8 and 12 Hz. Frequencies in this range are associated with oscillations generated within the central nervous system whereas frequencies within the 16 Hz to 30 Hz range are associated with the mechanical resonance of the finger [10], [11], [8], [9].

Fatigue is a factor influencing the characteristics of the PT. In healthy adults, significant increases in the amplitude of the 8 Hz to 12 Hz neural component are reported following simple task manipulations such as voluntarily stiffening of a limb, changing whole body postural position, and following exercise-induced fatigue [12]. The exercise-induced fatigue results in explicit changes in the time and frequency characteristics of the tremor output. The most notable effect is an increased peak amplitude of the generated 8 Hz to 12 Hz frequency component [13]. Moreover, the onset of fatigue produces enhanced PT (EPT), characterized by irregular or monorhythmic amplitude oscillations [6], [2]. A temporary decrease in the tremor amplitude right after a strong brief effort period is followed by its gradual increase above a pre-fatigue level [14], [6].

The purpose of this investigation is to examine the effect of fatigue on PT. In order to assess its impact on the tremor, resting, postural and loaded tremors were recorded from wrist and finger in healthy young adults using a non-invasive, wearable, cost-effective, and continuous proactive system. The frequency and amplitude of the finger/wrist tremor were measured by compact a high-precision accelerometer.

II. Methods

A. Fatigue Test

Fifteen healthy subjects, comprising of 8 males and 7 females, aged between 18 and 33 years participated in this study which was approved by the institutional review board of Texas A&M University, College Station. The study subjects displayed varying levels of physical activity and athleticism. The participants were non-diabetic with no history of diabetes in their family, and were also confirm no history of cardiovascular disease or autonomic neuropathy or that they were not taking drugs affecting the cardiovascular system. The data was collected from the middle finger and the wrist of the right hand. Other information such as age, gender, blood pressure and pulse were also recorded.

B. Experimental Apparatus

A non-invasive, wearable, and cost-effective system was used to detect the finger and wrist tremors. To capture the low-frequency PTs, compact high-precision accelerometers with two configurations supporting wrist and finger were used. A small, low-power, 3-axis accelerometer, ADXL 335 (Analog Devices, Inc., Massachusetts, United States) with a sensitivity of 270 mV/g to 30 mV/g, was put on 3D printed platform (21x21x6 mm) and calibrated using three reference SETRA (piezoelectric) accelerometers. Accelerometer output was transmitted to a computer where the signal analysis software mapped the hand tremor levels. A microcontroller, Arduino UNO R3 (Adafruit) was wire connected to a computer and an accelerometer. The illustration of the hand tremor sensors is shown in Fig. 1. The tremor detection was based on quantification of movement over a time period.

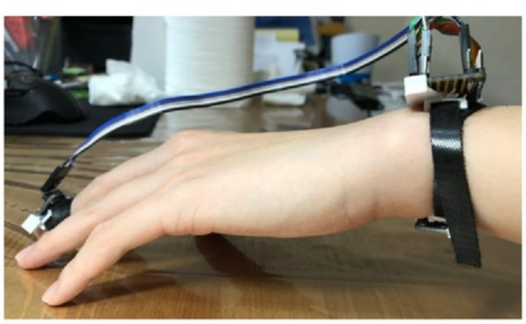


Fig. 1: The hand tremor sensor developed for this study.

C. Experimental Protocol

This study took place in a quiet/private lab environment at Texas A&M University, College Station. During the experiments, participants were seated comfortably on a chair. All experimental procedures were performed by appropriately trained personnel, following standard operating procedures. The participants wore finger- and wrist- based accelerometer fixed to the terminal phalanx of the index finger. The subjects were asked to estimate the intensity of exercises using the rated perceived exertion (RPE) scale ranging from 1 to 10 and whether their left- or right-hand is dominant. Tremor was assessed in three stages (Fig. 2).

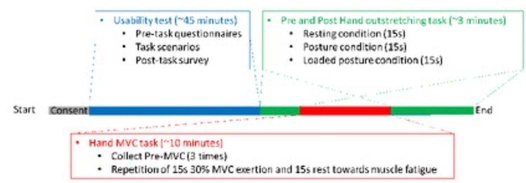


Fig. 2: The fatigue test protocol.

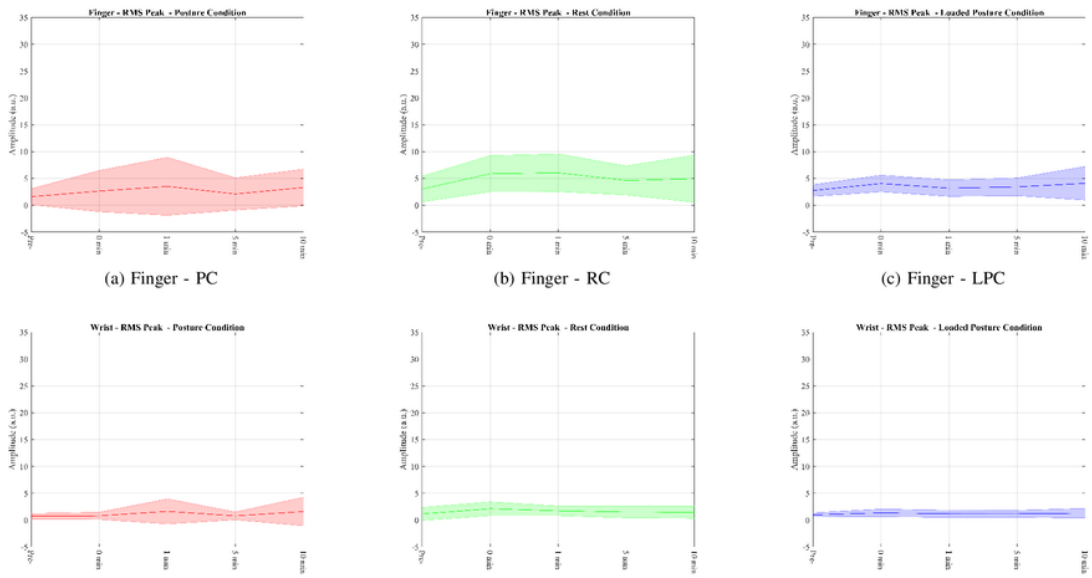
In the first stage, pre-fatigue test (3 min), the participants were tested in three conditions: rest (resting tremor), unloaded posture (posture tremor), and loaded posture (posture tremor) positions. In the rest position, the participant's forearm was fully supported with the hand and fingers completely relaxed so that there was no voluntary muscle activity in the forearm and hand. In the postural condition, the participants were asked to raise their dominant arm horizontally in front of them, parallel to the floor by maintaining a flexion of 90° at the shoulder, an extension of the elbow, pronation of the forearm and an extension of the index finger while the other fingers remained at rest. In the loaded postural condition, the postural tremor when participants were holding 300 g weight (Jamar Hydraulic Hand Dynamometer) in the distal half of their horizontally extended hand was measured. Each exercise was with duration 15 s followed by 30 s rest.

The second stage, fatigue test (10 min), started with pre-maximum voluntary contraction (pre-MVC) repeated 3 times in which each episode lasted about 5 s followed by a 60 s rest. To determine the preMVC, a hand dynamometer was used. The fatigue tasks, a sustained contraction at 30% MVC, consisted of the repetition of 30% MVC exertion (15 s) and 15 s rest towards muscle fatigue. The RPE was performed every 4 minutes and at the end of exhaustion.

In the third stage, post-fatigue test (3 min), a cycle which consists of Post-MVC (5 s), posture, resting and loaded posture condition tests each with duration 15 s without rest between exercises was repeated 4 times. The rest period after each cycle of the tasks was progressively increased from 0, 2 and 4 min. The tremor was measured 0, 1, 5 and 10 min after the exhaustion. In this stage, the participant performed the RPE before and post-MVC after 1, 5 and 10 min tasks.

D. Data Analysis

The output signals obtained from the accelerometer were sampled at 45 Hz, and digitized using a 14-bit analog to digital converter. The signals were then fed to a microcontroller placed on the wristband and then transmitted to a



(a) Finger - PC (b) Finger - RC (c) Finger - LPC

(d) Wrist - PC (e) Wrist - RC (f) Wrist - LPC

Fig. 3: RMS values of the different actions obtained from the finger and wrist

computer using a serial cable. All signals were processed using Matlab (release 2018b; The MathWorks, Natick, MA). The acceleration data was synchronized with EMG event markers and split into episodes (65 episodes per person) according to event markers. Each episode data was then passed through a highpass filter to remove static content. Fast Fourier transforms (FFTs), and power spectral densities (PSDs) were then calculated for the acceleration data.

III. Results and Discussion

A. Pre-fatigue

For pre-fatigue conditions, the amplitude of the tremor in terms of root mean square (RMS) value and its variance at the finger are greater than at wrist (Fig. 3).

The frequency analysis revealed tremor with higher frequencies of the finger compared with the wrist in rest, posture and loaded posture condition. The PSD distribution analyses in the 3-8, 8-14 (Fig. 4), and 14-22 Hz intervals show that most of the peaks are in the first frequency range, especially for the finger tremor. For the rest condition, the values for PSD distribution are 48 % (finger) and 38 % (wrist), 30 (finger) and 33 % (wrist), 18 % (finger) and 24 % (wrist) in the 3-8 Hz, 8-14 Hz and 14-22 Hz ranges, respectively. For posture and loaded posture condition, these values are 49 % and 41 % (3-8 Hz), 26 % and 30 % (8-14 Hz), 19 % and 30 % (14-22 Hz); 54 % and 30 % (3-8 Hz), 24 % and 34 % (8-14 Hz), 18 % and 31 % (14-22 Hz) for finger and wrist, respectively. In the case of rest condition, the variance of the PSD distribution on finger tremor is bigger than on the wrist in all three frequency ranges. When the participants do posture and loaded posture condition, the variance of the wrist is almost equal or bigger than of the fingers, which could be explained with their physical status and ability to do simple exercises without fatigue.

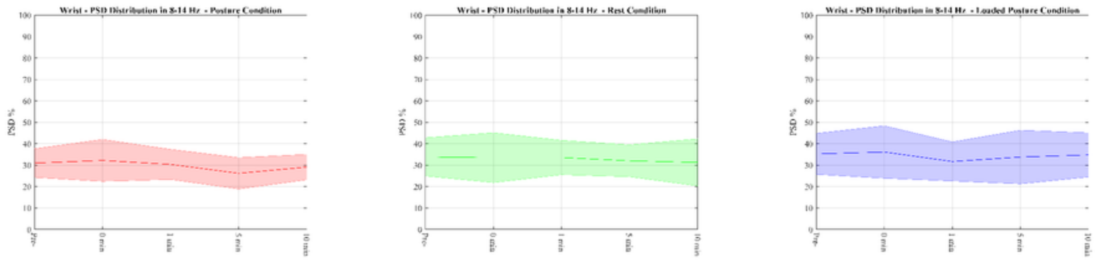
For the finger tremor in rest and posture condition, the most notable changes of the post-fatigue mean PSD distribution and its variance are in the 3-8 Hz range.

B. Post Fatigue

As each person has an individual level of fatigue the variance of the amplitude depends on personal physical condition. Exact after the exercises (0 min), the mean tremor's amplitude is almost the same as the pre-fatigue amplitude for finger and wrist in rest, posture and loaded posture conditions but changes their mean PSD distribution.

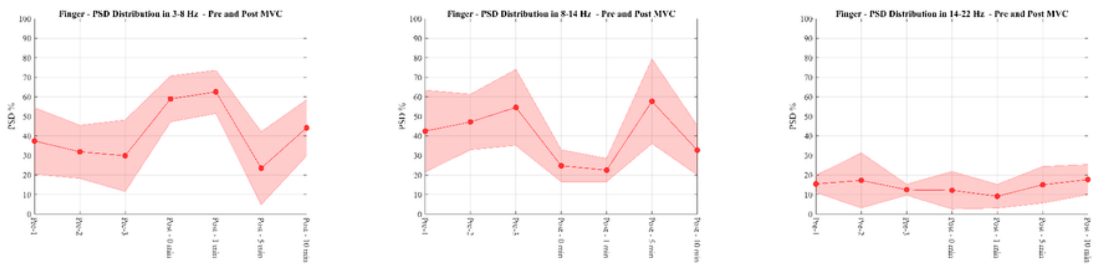
As the participants continue with the exercises in posture and loaded posture condition, their fatigue increase. As the rest time 1 min after the fatigue in rest condition case is 0 s, the finger and wrist fatigue are most notable which is proved by the max variance of the tremor amplitude while the mean PSD distribution is almost the same. The rests after the second and third post MVC are 120 and 240 s, respectively. This gives the opportunity of the participants to rest and the mean PSD distribution and its variance weakly decrease. For PSD distribution in rest, posture and loaded posture conditions, the variance of the mean post-fatigue value is $\pm 5\,\%$ compared with the pre-fatigue value. These small variances do not allow determining the fatigue influence on the PSD distribution.

For the rest, posture and loaded posture conditions, the tremor can be detected better on the finger as around 50 % of the tremors are in 3-8 Hz range.



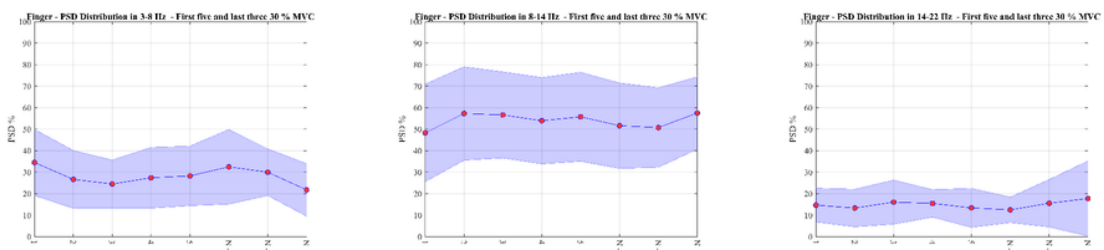
(a) Wrist - PC (b) Wrist - RC (c) Wrist - LPC

Fig. 4: PSD values of the different actions obtained from the wrist in the 8-14 Hz range



(a) Finger: 3 - 8 Hz (b) Finger: 8 - 14 Hz (c) Finger: 14 - 22 Hz

Fig. 5: Pre and post MVC PSD distribution in different frequency ranges.



(a) Finger: 3 - 8 Hz (b) Finger: 8 - 14 Hz (c) Finger: 14 - 22 Hz

Fig. 6: 30% MVC PSD distribution in different frequency ranges.

C. *Maximum Voluntary Contraction*

In pre and post MVC case, the fatigue influence on the tremor amplitude is more notable on finger than on the wrist tremor as well as for the pre and post 30 % MVC. Observing the first five and last three 30 % MVC, the PSD distribution is more than 50 % for the finger and wrist when in the frequency range 8-14 Hz. For the rest two ranges, the values are between 20 and 30 %. All participants do 3 cycles of MVC with 60 s rest between them. It seems that this time is not so short and the finger and wrist mean PSD distribution changes weakly.

The post MVC cycles include consecutive execution of rest, posture and loaded posture condition. The rest time increase from 0 to 4 min 1 min. From the Fig. 5, it can be noticed that the range 8-14 Hz mean PSD distribution increase between post 1 min and post 5 min as the fatigue increase. The decreasing in the interval post 5 min to post 10 min shows that the number of tremors with frequency 8-14 Hz also decrease at the expense of tremors in the 3-8 Hz, which are typical for the rest condition. These changes are not so notable for wrist tremor. For the MVC and 30% MVC conditions (Fig. 6), the tremor can be detected better on the wrist because the mean PSD distribution values in the 8-14 Hz range are with almost 20 % bigger than values in the 3-8 and 14-22 Hz, i.e. the main part of the tremors is with frequency typical for PT.

There was not dependence found between the rest and action tremor frequency or amplitude based on the gender of participants as well as on their age.

IV. Conclusion

This paper presents the spectral analysis of hand tremors recorded from the finger and the wrist. For the study, a low-cost and wearable hand tremor sensing device was designed using a 3 axis accelerometer. It was observed that the physiologic tremor in the frequency range of 8-14 Hz was most noticeable during the fatigue inducing tasks involving maximum voluntary contraction. Moreover, the power spectral density showed a uniform distribution during the tasks that did not involve any physical exertion. The outcomes of this study show encouraging results that low blood sugar or hypoglycemic events can be recorded as enhanced physiologic tremors in the 8-14 Hz frequency range.

V. Acknowledgment

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