NEURO-DEGENERATIVE DISEASE DIAGNOSIS USING HUMAN GAIT

A Dissertation

Submitted in partial fulfillment of the requirements for the award of degree of

Master of Engineering
in
Electronic Instrumentation and Control

Submitted by

Paramjeet
Roll No: 801151017

Under the Guidance of

Mr. Mooninder Singh
Assistant Professor,
Thapar University,
Patiala

Department of Electrical and Instrumentation Engineering
Thapar University
(Established under the section 3 of UGC act, 1956)
Patiala, 147004, Punjab, India

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DECLARATION

It is certified that the work is being presented in the dissertation work entitled "**Neuro-degenerative Disease Diagnosis using Human Gait**" in fulfillment of award of degree of **Master of Engineering** in **Electronic Instrumentation and Control** submitted in Electrical and Instrumentation Engineering Department, Thapar University, Patiala is an authentic record of my own work carried under the supervision of Mr. Mooninder Singh, Assistant Professor, Department of Electrical and Instrumentation Engineering , Thapar University, Patiala, Punjab.

Paramjeet

Paramjeet

801151017

Date:

15/07/2013

I certify that the above statement made by the student is correct to the best of my knowledge and belief.

Mooninder Singh

Mr. Mooninder Singh
Assistant Professor
Department of Electrical and
Instrumentation Engineering
Thapar University, Patiala
Punjab

S. Ghosh

Countersigned By

Dr. Smarajit Ghosh
Professor & Head of Department
Department of Electrical and Instrumentation Engineering
Thapar University, Patiala
Punjab

Dr. S.K Mohapatra
Dean of Academic Affairs
Thapar University,
Patiala,
Punjab

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ABSTRACT

Falls are one of the most serious implications of the gait disturbance in neuro-degenerative disease. Neurodegenerative diseases affect the ability to control muscle movements. Muscle tone, involuntary movements and smoothness of movement are significantly impacted while range of motion and muscle mass remain unaffected. Some of the major neuro-degenerative diseases include Parkinson's Disease (PD), Amyotrophic Lateral Sclerosis (ALS), and Huntington Disease (HD). These diseases are generally unpredictable in their rate of progression and exhibition of degeneration. Neuro-degenerative diseases are caused by loss or death of neurons. These diseases are characterized by progressive nervous system dysfunction. This dissertation reviews how the human gait is related to neuro-degenerative diseases. Gait is basically the pattern of movement, means how we move or walk. For comparison of the gait pattern of patients suffering from neuro-degenerative disease, a healthy control group is taken. Heel and Toe strike detection and computation for gait analysis using computer aided programming for patients and healthy control was done After computing heel and toe strike intervals of each left and right foot, Mean and Standard Deviation (SD) were calculated to obtain the Coefficient of variation (CV) and compared with healthy control.The gait pattern of both left and right foot is recorded, analyzed and compared for detection and computation of neuro-degenerative disease diagnosis, using several techniques. Three phases of classification were used to classify the data more appropriately. First phase classifies normal and neuro-degenerative subjects. Second phase classify Parkinson and non-Parkinson subjects. Third phase classify Huntington and ALS subjects. Coefficient of Variation of left and right foot heel and toe strike intervals is taken as input vector to Artificial Neural Network (ANN) for these classifications. In phase 1, we obtained accuracy of 94%. In phase 2, accuracy was 100%, and in phase 3, we obtained accuracy of 88%.

ORGANIZATION OF THESIS

The dissertation begins by introducing Neuro-degenerative diseases, various type of diseases like Parkinson's disease (PD), Huntington's disease (HD) and Amyotrophic Lateral Sclerosis (ALS) Gait, Phases of Gait in Chapter 1. This is followed by Literature review. In Literature review, the previous work related to neurodegenerative diseases using gait has been discussed in Chapter 2. Methodology has been explained in Chapter 3. It described the whole procedure step by step. Chapter 4 displays the results in tabular form with bar graphs. Chapter 5 concludes the dissertation and outlines directions for future work. The dissertation ends with references and publications from the present research.

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LIST OF ABBREVIATIONS

PD	Parkinson's Disease
HD	Huntington's Disease
ALS	Amyotrophic Lateral Sclerosis
SCPG	Super Central Pattern Generator
ITW	Idiopathic toe Walking
ITUG	Instrumented Timed Up and Go test
FOG	Freezing of Gait
SD	Standard Deviation
CV	Coefficient of Variation
ANN	Artificial Neural Network

CHAPTER 1: INTRODUCTION

1.1 Neuro-degenerative Diseases

Neuro-degenerative disease produces changes in neuromuscular control. Muscle movements control, Muscle tone, involuntary movements and smoothness of movement are affected due to neuro-degenerative disease. One of the important diagnostic methods for determining Neuro-degenerative disease is study of human gait. Gait is basically the pattern of movement of limbs. Human locomotion can be described by three distinct stages: 1. Development stage (from resting position to some velocity) 2. Rhythmic stage (at some constant position) 3. Decay stage (back to the rest position) [1]. A step in human has two distinct parts. The first part begins when the foot strikes the ground and ends when the foot is lifted. The second part begins when the foot is lifted and ends when it strikes the ground again. Aging is the great factor for neuro-degenerative disease. As the age increases, the disease progresses due to loss of neurons. Mostly neuro-degenerative diseases are caused by genetic mutation.

As the age increases, it affects balance and gait including declining strength, muscle mass and bone density. Impaired respiratory capacity also occurs. Central nervous system age-related changes include shrinkage of neural soma and processes of the central cortex. As the degree of neurologic impairment increases, the gait variability is affected. Young healthy children have an immature gait. As the growth increases, their walk becomes more stable and close to the adult one. Apart from the age, human gait is also affected by Neuro-degenerative diseases like Parkinson's disease (PD), Huntington's disease (HD) and Amyotrophic Lateral Sclerosis (ALS).

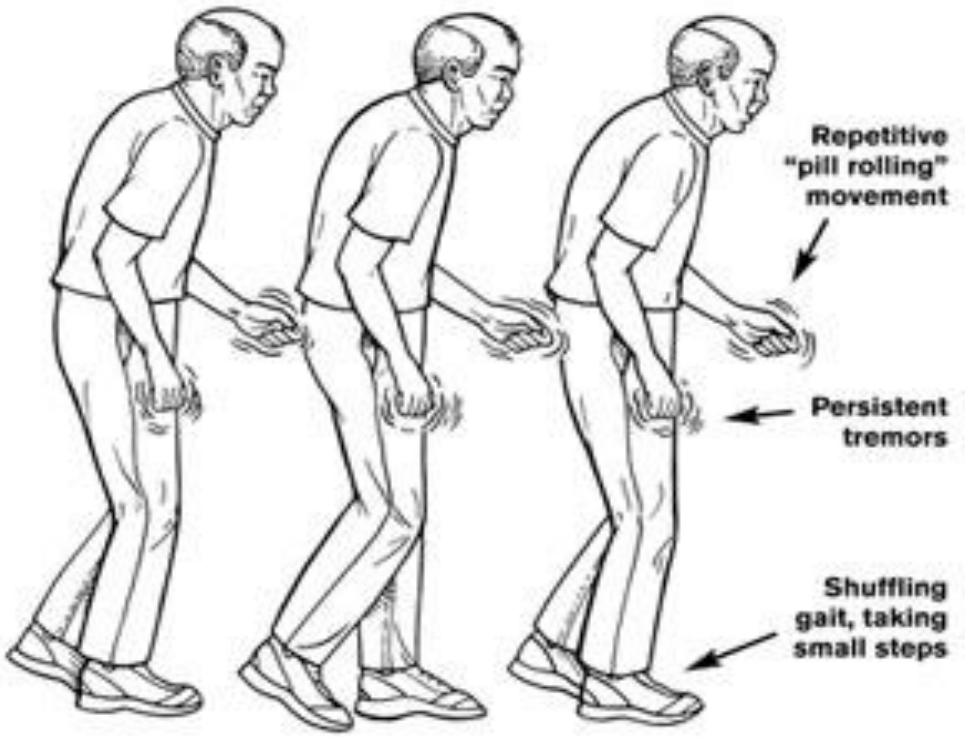

Figure 1.1: Symptoms of Neuro-Degenerative Diseases [2]

1.2 Parkinson's disease

Parkinson's disease (PD) is a degenerative disorder of the central nervous system. It was first described in 1817 by James Parkinson, a British who published a paper on what he called "the shaking palsy." Parkinson's disease belongs to a group of conditions called movement disorders. The main symptoms are trembling in the hands, arms, legs, jaw, and face, stiffness the limbs and trunk, slowed movement, and impaired balance and coordination. After Alzheimer, PD is the second most common neurodegenerative disease and usually affects people over the age of 50. There is currently no accurate test for diagnosis of PD and it is highly uncertain in the early stages of disease. These symptoms usually begin gradually and worsen with time. Symptoms of Parkinson's disease usually come on gradually and affect people over the age of 50, although there are rare forms that progress more quickly and strike at a younger age. PD is also called primary Parkinsonism or idiopathic PD. Parkinson's disease is both chronic, meaning it persists over a long period of time, and progressive, meaning its symptoms grow worse over time. Parkinson's disease occurs when nerve cells, or neurons, in an area of the brain known as

the substantia nigra die or become impaired. Normally, these neurons produce an important brain chemical known as dopamine. Dopamine is a chemical messenger responsible for transmitting signals between the substantia nigra and the next "relay station" of the brain. As the disease progresses, the shaking or tremor that affects the majority of Parkinson's patients may begin to interfere with daily activities. Affected people may feel mild tremors or have difficulty getting out of a chair [3]. They may notice that they speak too softly or that their handwriting is slow and looks cramped or small. They may lose track of a word or thought, or they may feel tired, irritable, or depressed for no apparent reason. Friends or family members may be the first to notice changes in someone with early PD. Patients may not be able to hold utensils steady or they may find that the shaking makes reading a newspaper difficult. Parkinson's disease does not affect everyone the same way, and the rate of progression differs among patients. Tremor is the major symptom for some patients, while for others; tremor is nonexistent or very minor. PD symptoms often begin on one side of the body. Sometimes people suffering with PD become fearful and insecure. They lose their confidence and motivation and don't want to travel, going in parties and socialize with friends. They become fully dependent on family members [4].

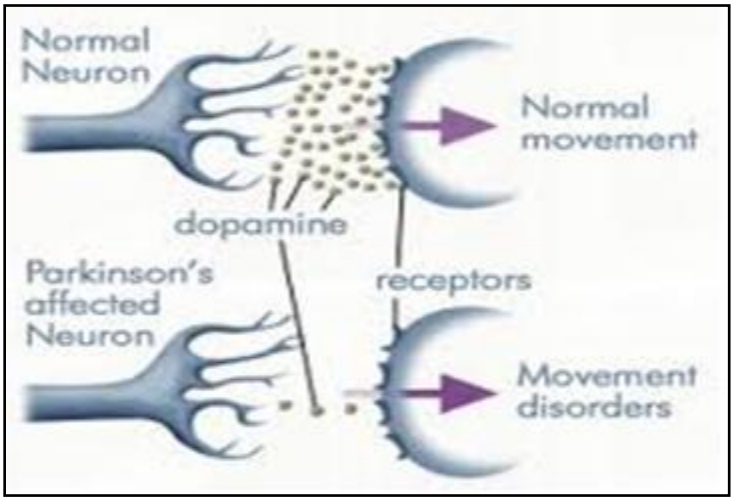

Figure 1.2: Dopamine levels in a Normal and Parkinson's affected Neuron [5]

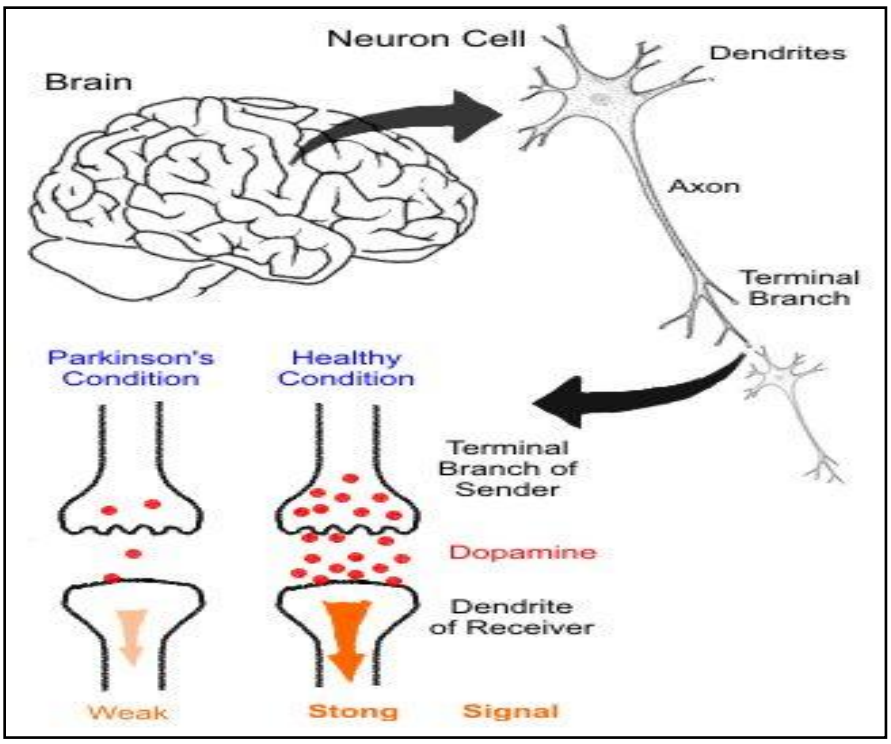

Figure 1.3: Affected brain [6]

1.3 Huntington's disease

It is a neurodegenerative genetic disorder that affects muscle coordination and leads to cognitive decline and psychiatric problems. Huntington's disease is a progressive, degenerative brain disorder that produces physical, mental and emotional changes. The disease was named after George Huntington, who first described the illness in 1872 [7]. The people affected by disease are not able to think, talk and move properly. As shown in figure, it destroys the cells in the basal ganglia, the part of the brain that controls these capacities. It is also a hereditary problem. Huntington's disease usually develops in adulthood and can cause a very wide range of symptoms every child has a 50% chance of inheriting the abnormal gene. Because Huntington's disease affects the mind, body, and emotions, symptoms often mimic other conditions. The general symptoms in early stages can include poor memory; difficulty in making decisions; mood changes such as depression, anger or irritability; a growing lack of coordination, twitching or other uncontrolled movements; difficulty in walking, speaking or swallowing. It is more common in people of Western European descent than in those of Asian or African ancestry. Symptoms of the disease may vary between individuals and even among affected members of the

same family, but usually progress predictably. This disease also occurs due to mutation on the fourth chromosome. It primarily affects certain nerve cells of the striatum known as medium-sized "spiny" neurons [8]**.**

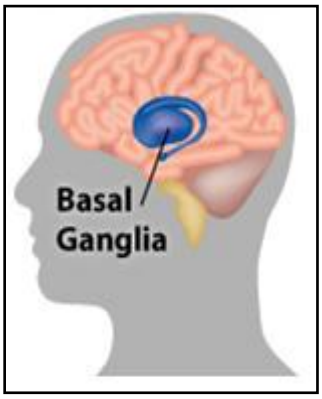

Figure 1.4: Huntington's disease affects the brain's basal ganglia [9]

1.4 Amyotrophic Lateral Sclerosis (ALS)

This disorder is referred to as motor neuron disease. It is also related to muscles problem. The disease is characterized by progressive weakness, difficulty in speaking, swallowing, breathing, muscle twitching (involuntary muscle contraction and relaxation), muscle stiffness etc. when the motor neurons get damaged in any part of body, that part gets affected by amyotrophic lateral sclerosis disease. It does not affect the sensory nerves and involuntary nervous system. It means most of the patient will maintain touch, hearing, smell, sight, and taste. The patients suffering from ALS are not able to regulate normal locomotion. The earliest symptoms of ALS are the weakness of muscles in arms and legs. Eventually, the patient will not be able to walk, talk and be bedridden. As the respiratory muscles weaken, the patient and family must decide whether to use artificial respirators, or go into palliative hospice care. The researchers say that most of the US patients go for palliative hospice care and the Japanese choose respirators. The disease is 1 to 2 per 100,000 each year suffer from ALS, most cases of which are Sporadic while 5%-10% are inherited. The treatment of ALS is very limited. It becomes necessary to understand the pathological mechanism of this disease. As the time passes the patients experience increasing

difficulty moving, swallowing and speaking or forming words. Disease progression is slower in the patients who are younger than 40. ALS symptoms typically spread to the arms before the legs and it spreads from affected limbs to the opposite limbs before affecting the other parts of body. Maintaining a healthy weight gets difficult due to eating problem. The patients find difficulty swallowing and chewing [10].

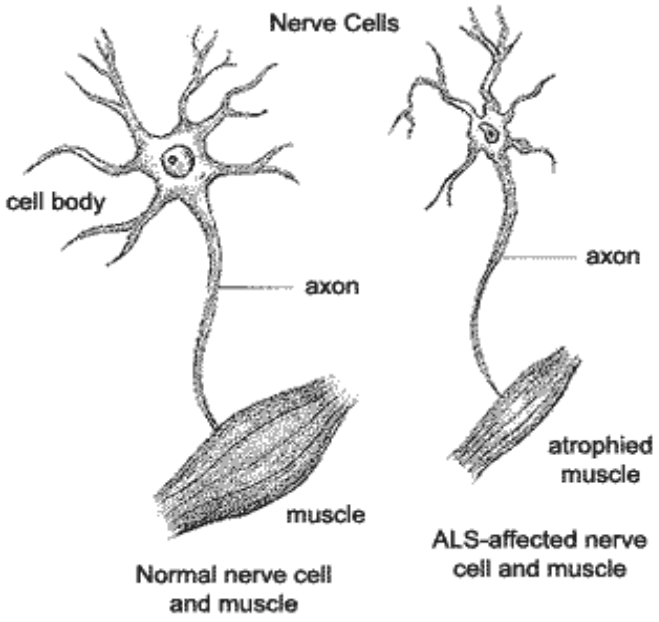

Figure 1.5: ALS affects the nerve cell [11]

1.5 Gait

Freezing of gait is the most disabling symptom of neuro-degenerative disease. Freezing of gait means the feet are stuck to the floor. Patients take small shuffling steps and movement gets slower. Patient faces difficulty to start moving and also faces difficulty while stopping. Gait is basically the pattern of movement means how we move or walk. There are basically two types of gait. The symmetrical and asymmetrical and it is based on the limbs movement. In the symmetrical gait both left and right limbs move alternate while in asymmetrical gait limbs move together. The movement of each limb was divided into two phase first one is the stance phase, where the foot strikes the ground, and the swing phase, where the foot was lifted and moved forward. Gait pattern depend on the different limbs movement pattern. It is characterized by

differences in limb movement patterns. The deviation from normal gait is called gait abnormality. The gender difference in gait is female walk with lesser steps and hip sway and male with longer steps and swagger in shoulder [12].

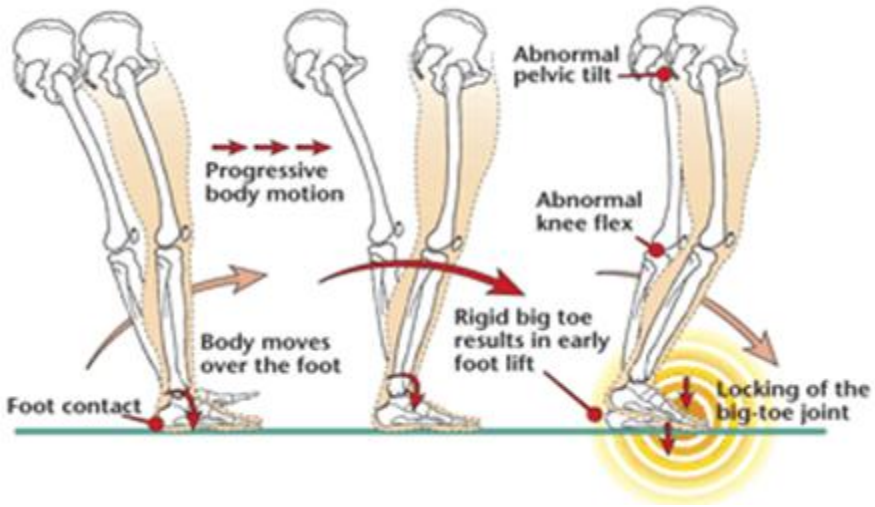

Figure 1.6: Improper foot function resulting in abnormal walking [13]

The gait disturbances can be classified into two parts, the one is continuous and the other one is episodic. The episodic gait disturbances occur occasionally and very rarely. The main symptoms include festinating, start hesitation and freezing of gait. The continuous type gait disturbances are most commonly in patients. The age factor also contributes in neuro-degenerative diseases, as the age increases, the fall and impairment also progresses.

1.1.1 Phases of Gait

The heel strike is defined as the heel first touches the ground and ends until the whole foot touches the ground. As shown in figure 1, the early flatfoot strike occurs, when the whole foot is on the ground. The late flatfoot stages ends when the heel lifts off the ground. The rise begins when the heel starts to leave the ground. The toe off phase occurs, when the toe leave the ground. 60% of the walking consists of stance phase. The Stance phase occurs when the whole foot is on the ground. Swing phase is basically defined as the one foot is on the ground and the other is in the air

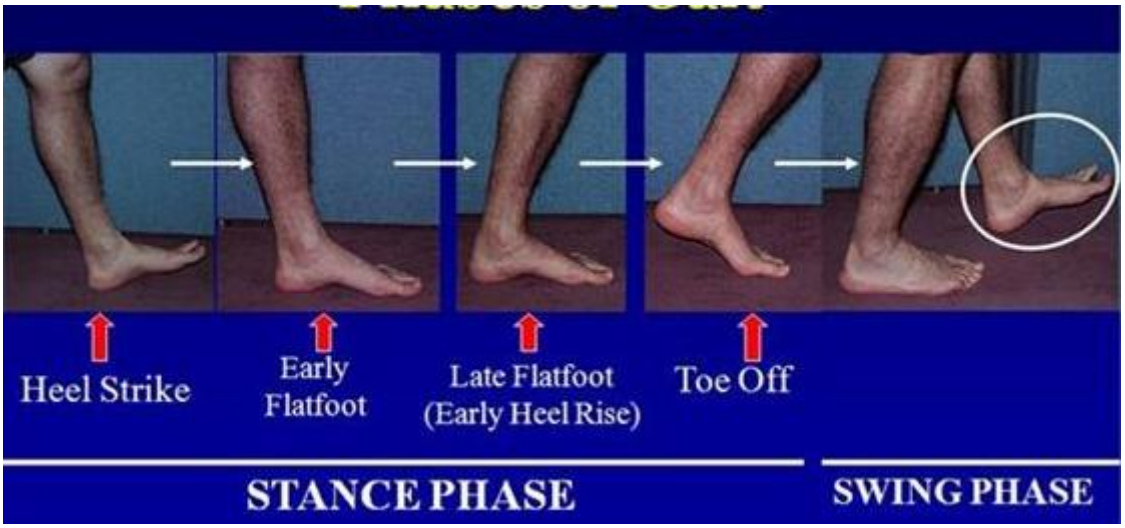

Figure 1.7: Phases of Gait [14]

J. West *et.al* developed a super central pattern generator (SCPG) for both fractal and multifractal properties of the gait. SCPG is used to simulate the stride interval of human gait and determined the basic frequency, average period of normal human gait, frequency of both slow and fast gaits. Amplitude (A=1) was chosen for normal gait, A=2 for both slower and faster gaits. For metronomically constrained gait, A=4 is used for normal gait and A=8 for both slower and faster gaits. Amplitude is lower in normal gait because it is the most relaxed position and higher in metronomically constrained because it increases the stress on subject. The histogram of distributions of the holder exponent (h) is shown in figure 2.1. Lower the holder exponent, the higher randomness in sequences. [12]

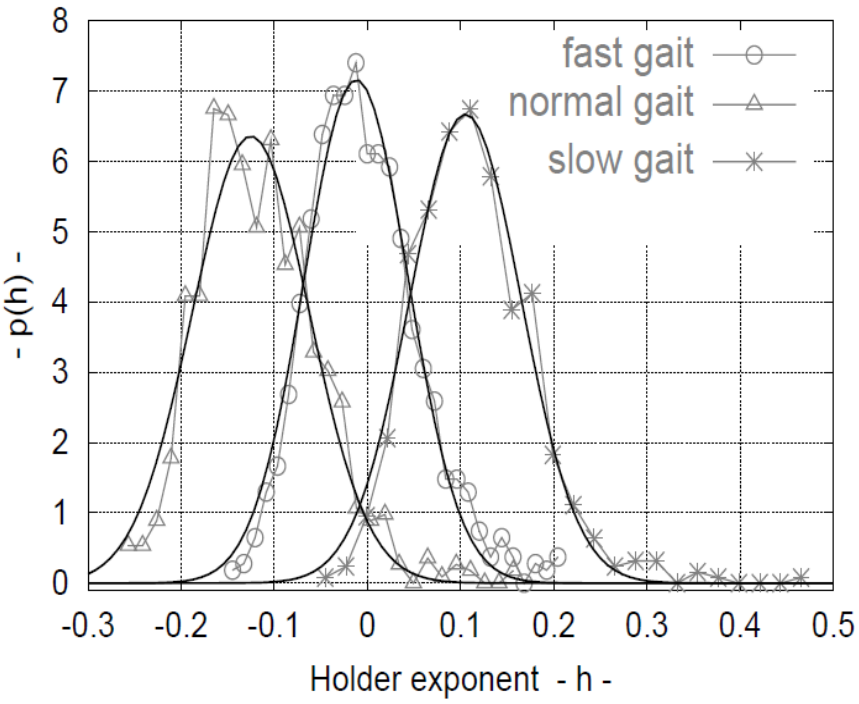

Figure 2.1: Histogram and Probability Density estimation of the Holder exponents [12]

M. Yang *et.al* worked on a paper. The gait data of the patients suffering from neurodegenerative diseases was recorded using foot switches. Four types of feature selection and feature construction method: maximum signal-to noise ratio based feature selection method, maximum signal-to noise ratio combined with minimum correlation based feature selection

method, and maximum prediction power combined with minimum correlation based feature selection method and principal component analysis. Support vector machine (SVM) classifier was applied. SVM was used to classify gait patterns of patients using knee osteoarthritis before and after knee replacement surgery. Right Stride, Right Swing, Right Stance, Left Stride, Left Swing, Left Stance, Double Support were extracted. Right stride is the period of time from right heel contacting with the ground to the same heel contacting with the ground again .Right stance is the period of time for right foot contact with the ground (from right heel contact to right toe off) . Right swing is the period time for right foot leave form the ground (from right toe off to right heel contact again). Double Support is the period of time for two feet contact with the ground in a cycle. Feature was extracted by comparing PD versus control group, HD versus control group, ALS versus control group, PD versus HD, PD versus ALS, ALS versus HD, HD+PD+ALS versus control group. The classification results that ALS can be more easily distinguished from PD with accuracy of 85.47%, HD with accuracy of 86.52% and the control group with accuracy of 93.96%. PD and HD can be distinguished from the healthy control with accuracy of 86.43% and 84.17%. The accuracy of PD versus HD is only 79.04%, because their gait pattern has similar characteristics and both diseases occur due to the impairment of basal ganglia. [15]

Jeffrey M. Hausdorff has done a research. This research consists of long range correlation properties of gait in PD. The stride length, Gait variability and Fractal scaling of gait are impaired in PD. In study of 230 patients with PD, 43% reported falling at least once in 12 months. They examined the effects of several experimental conditions on these gait properties in order to probe common and feature-specific responses and the neural mechanisms that contribute to these different gait properties. [16]

Y. Balash *et.al* worked on a paper. Patients with PD are unable to generate sufficient stride length. The swing time series from a patient with PD and a control subject under usual walking conditions and when performing serial 7 subtractions were calculated. Coefficient of variability (CV) is larger in patient with PD (CV=2.7*%)* compared to the control (CV=1.3%). Coefficient of variability increases during dual tasking (serial 7 subtractions) in the subject with PD CV=6.5% but not in the control CV=1.2% [17].

Leo Ota *et.al* worked on a paper. In recent years fluctuations of time series data is becoming more important. Detrended Fluctuation Analysis (DFA) is one of the methods for

analyzing the fluctuation of the gait cycle. The DFA analysis of gait cycle in 200 meters walk of 17 PD patients and 12 healthy young people was performed. PD patients was divided based on the Hoehn and Yahr (HY) scale into an HY2 group (n=9) and an HY3 group (n=8) to examine the relation to disease severity. It results that the fractal exponent is lower for PD patients in compare to the healthy control. Wireless headset was used to generate acoustic cues to unfreeze the gait. [18]

Scientist Grimbergen YA *et.al* worked on a paper. They have done the analysis on fall and gait disturbance. Falls were recorded in 45 early to mid stage Huntington's disease patients. Falls rate were measured using Unified Huntington's Disease Rating Scale (UHDRS) and quantitative measures of balance (using angular velocity Sensors) and gait (using a pressure-sensitive walkway). Comparison between healthy control and patients suffering from Huntington's disease was done. He found that the Huntington's patients had decreased stride length and decreased gait velocity as compare to control subjects. Because both characteristics were found in fallers so he concluded that falls are the common symptom of Huntington's disease. [19]

Yunfeng Wu *et.al* downloaded the data via physionet.org. The least-squares support vector machine (LS-SVM) was used to distinguish the stride patterns between the ALS patients and healthy controls with an accuracy of 82.8% [20].

Hausdorff *et.al* proposed an algorithm to detect stride interval for both left and right foot in his paper "A PDF-Based Classification of Gait Cadence Patterns in Patients with Amyotrophic Lateral Sclerosis." The least-squares support vector machine (LS-SVM) was used to distinguish the stride patterns between the ALS patients and healthy controls with an accuracy of 82.8% [21].

Lakshmi Sugavaneswaran *et.al* proposed ML (Machine learning) based TF kernels to obtain one-step discrimination between different non-stationary patterns. An accuracy of 93.1% was obtained for neurological gait data base from the signals (16 controls and 13 Amyotrophic lateral sclerosis subjects). Gait signal was downloaded from physionet. Comparison was made between ALS and healthy control by placing force sensitive insole under the subject's foot. Subjects were asked to walk at their comfortable walking speed. Stride to stride measurements were recorded [22].

A. Mufioz-Diosdado *et.al* used a method proposed by chhabra and Jensen to calculate the multifractal spectra of a database with 50 gait time series of children, ten long-term recording of gait dynamics from healthy young persons and another databases with gait time series of healthy adults and persons with Parkinson, Huntington and amyotrophic lateral sclerosis (ALS) diseases. He found that the spectra of the healthy young persons are almost monofractal. The spectra of little children are wider and they narrow as the children age increases. The spectra of ill persons are wider than the spectra of healthy persons. The statistical properties of the different subsets characterized by these different exponents can be quantified by the function f(h) or f(a), (a is the Lipschitz-Holder exponent), *f(a)* is the fractal dimension of each subset, so multifractals require many exponents to characterize their scaling properties. The gait time series of healthy individuals are less complex than those of ill persons. In the same way the time series of young individuals are less complex than that of little children [10].

B. Sridhar *et.al* worked on a paper. They focused on the mechanical aspect of the Huntington's disease. The disease progresses due to nerve degeneration. He designed and tested the neural networks to simulate and progression of the disease. Three basic networks were created and tried to simulate this network using program and then obtained a desired behavior and found the change in behavior before and after the death of neurons [23].

Y. Han *et.al* has extracted features from the gait signals in Parkinson's disease patients and control subjects for comparison and realization of automatic recognition. In the comparison process, we also give our own definition to Associated Discrete Index (ADI) in order to measure the discrete degree at a same frequency. 93 patients with PD and 72 healthy controls were selected. Foot pressure was analyzed including vertical ground reaction force. Power spectra were obtained to compare gait signals of PD and control subjects. Compared with PD patient, the frequency features of gait in control subject are more random, since the spectral lines are loose as well as different with others. On the other hand, those lines in PD patient are comparatively closer to each other. This feature can be indicated by ADJ, which shows that PD patients always possess larger ADI than that of control subjects [24].

Y. Rakhshani Fatmehsari *et.al* presented a new algorithm to analyze a gait pattern in Parkinson's disease patients using deep brain stimulation (DBS) on and off. Features were extracted to classify the PD subjects from healthy control subjects with deep brain stimulation

(DBS) on and off. Four uni-axial gyroscopes were used to obtain the angular velocity. The angular velocity signals of the right side of body are more informative than those of the left side in the classification of PD subjects and normal subjects. We also found that the data of only one gyroscope has enough information to separate two groups of PD and normal subjects correctly [25].

C. Pongmala *et.al* examined the effect of cueing device by using visual, auditory or somatosensory stimuli during walking in Parkinson's disease patients. The use of cueing can improve the gait pattern of patients. Patients pay attention to the stimuli during the walk. Visual, auditory and somatosensory cues can improve gait of Parkinson's disease patients. 3 cues (visual, auditory and somatosensory) were effectively used to increase gait velocity, average step length, average stride length and gait cadence. All cues also decreased ambulation time and gait cadence in case of Parkinson's disease patient having short shuffling gait. Auditory cue was more effective among all cues. Patients were able to hear the sound without earphone. According to the earlier researchers it was also confirmed that the visual cue can improve gait velocity, average step length and average stride length [26].

G. Solas *et.al* used a monitoring system of the motor status of patients. The people affected by neurodegenerative diseases for example Parkinson's disease, Huntington's disease was monitored, based on a series of sensors distributed all over the patient's body, which send the collected information to a Personal Remote Monitoring Device that the patient takes with himself. This device is in charge of carrying out a preliminary processing of the data and sending these measures wirelessly, for their processing and study in a hospital [27].

S. Santaniello *et.al* developed a two-stages modeling study. They focused on those nuclei involved in the genesis of PD motor symptoms and, for them, develops a conductance-based electrical model able to mimic quantitative data from different in vitro physiological analyses. Such models show how several highly nonlinear electrical behaviors can stem from the interaction between specific ionic currents as particular parameters change. Cellular models are inserted in a network scheme to reproduce the main actual anatomical connections and the resulting macroscopic behaviors reported in literature for normal and Parkinsonian conditions. [28]

J. Barth *et.al* applied a mobile, lightweight and easy applicable sensor based gait analysis system to measure gait patterns in PD and to distinguish mild and severe impairment of gait. Gait

test was performed using sport shoes equipped with inertial sensors. Two categories were taken for measurement one is healthy control and the other is patients suffering from PD. The signals were recorded for both left and right foot, and then features were extracted and classified using different classification algorithm. The sensitivity and specificity were obtained 88% and 86% respectively. The Unified Parkinson`s Disease Rating Scale (UPDRS) was used to rate motor symptoms in PD [29].

G. M. Pendharkar *et.al* evaluated the severity of toe-walking in idiopathic toe walking (ITW) children from the measurement of the ankle range of passive movement. It was also evaluated by observation of parents. For a normal child the foot is stationary on the ground during the stance phase, and the angle of inclination of the foot with respect to the ground is zero, whilst for an ITW child the foot is plantar flexed, and is always inclined at an angle with respect to the ground. Gait monitoring boots fitted with dual axis accelerometer in the heel have been developed, which would serve as long term gait monitoring device for ITW children. They detected the stance phase from the acceleration signals obtained from the dual axis accelerometer for a normal gait and a toe-walking gait and then determine the percentage of toe-walking steps in the gait of ITW children. [30]

M. Mancini *et.al* tested 21 PD with freezing of gait (FOG), 27 PD without FOG, and 21 healthy elderly people in a clinic with the Instrumented Timed Up and Go test (ITUG). Frequency Ratio was calculated as the square of the total power in the 3-8 Hz band, divided by the square of the total power in the 5-3 Hz band. The Frequency Ratio was significantly larger in freezers than in non-freezers or control subjects. It better differentiated gait disorders between PD subjects with and without freezing of gait (FOG) than traditional gait measures such as stride length, strides velocity and double support time. The subjects were chosen for testing, did not have any neurological disorders other than PD, or any orthopedic disorders or other impairments that could interfere with gait, and all patients had to be able to walk independently [31].

M. Pansera *et.al* used a Multi-parametric system for the continuous assessment and monitoring of motor status in Parkinson's disease. Four PD patients were compared to four healthy controls using a set of five wireless sensors located in the limbs and trunk. They initiated the assessment of gait based on Entropy Analyses. Entropy of information allows evaluating the complexity of human gait. Analyzing data collected from PD’s patients, it has been proved that the variability of gait parameters like stride length, step frequency, speed of locomotion is higher

compared to healthy subjects. Motion data was collected using the SHIMMER platform. SHIMMER is a small cordless sensor platform designed as a wearable device for health-sensing applications. All sensors provide 3-axis accelerometer signals large storage, and low-power standards based communication capabilities [32].

A. Ashoori *et.al* performed a series of manual pursuit tracking tasks on 10 normal and 14 PD subjects: three tasks were first performed separately, then as a merged sequence with sudden, task changes. The tasks differed in whether the tracking errors appeared amplified, attenuated or unaltered. From the discrete block experiments, subject- and task-specific second-order, linear time invariant models were derived, with the trajectory subjects are asked to track as input and the subject's motor response as output. Multiple model adaptive estimation was employed on the merged sequences to determine whether, and with what delay, each subject modified their performance after a task change. Although all normal subjects detected the task change, less than one-third of PD subjects did (and with longer delay). Further, those PD subjects who detected the task change had estimators with higher damping ratio than those PD subjects who did not [33].

H. Uchitomi *et.al* mainly focused on interpersonal synchrony and locomotors control. They have constructed an interpersonal synchrony emulation system between a human subject and a biped virtual robot that generates pacing signal cues using nonlinear oscillators. An interpersonal synchrony emulation system synchronizes the stride interval times of a human and the robot. They evaluated the effectiveness of the system in gait stabilization of 21 subjects suffering from Parkinson's disease (PD), who previously displayed disturbances in rhythm formation and festinating gait. It resulted that the festinating gait, as measured as stride time Reduction rate significantly stabilized and accelerated less with the system compared to unassisted walking [34].

3.1 Data source

All data were downloaded from www.physionet.org through PhysioBank ATM using Gait in Neurodegenerative disease database (gaitndd) [35]. Data was downloaded in Microsoft excel form. One minute data was recorded for both left and right foot signals in standard form were considered. The data had 300 samples/sec sampling rate.

3.2 Procedure to detect and compute heel and toe strike interval

13 subjects of Parkinson's disease (PD), 13 subjects of Huntington's disease (HD), 13 subjects of Amyotrophic lateral sclerosis (ALS) and 13 healthy control subjects were selected for analysis.

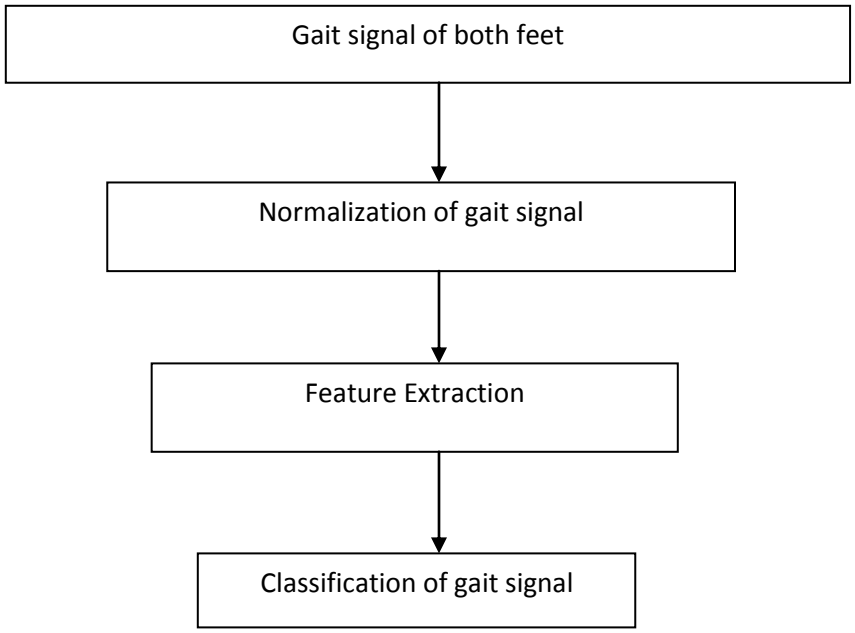

Figure 3.1: Flow chart of the methodology for Classification of Gait

The aim here is to compute heel to heel and toe to toe strike intervals. The data of force sensor is available in text file format on physionet.org. This text file is exported to MATLAB for analysis. In order to compute heel to heel interval, it is necessary to first detect the exact moment at which the heel strikes the ground. It is taken as the first, maxima as shown in figure 1. Similarly toe strike is detected as second maxima, again shown in figure 1. Detecting the heel strike means find the exact time when first maxima occurs .from two subsequent heel strike times, heel strike interval is calculated. Hence to compute heel strike interval, it is required that heel strike time is identified accurately. Similarly toe strike interval requires accurate identification of toe strike time.

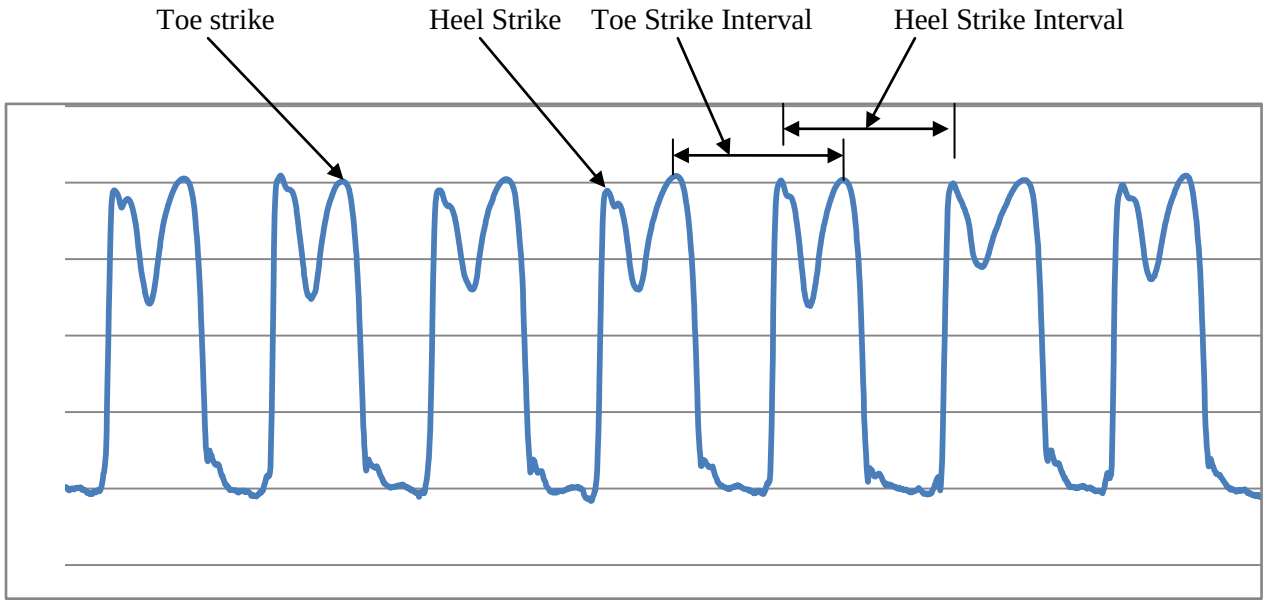

Figure 3.2: Signal taken from Huntington's left foot

The MATLAB program is based on the algorithm which identifies heel strike time and toe strike time. This algorithm was developed by the authors operates in the following sequences:

1. The average of the downloaded signals is taken.
2. The average is subtracted from each sample.
3. The minimum value of the entire set is computed.
4. 40% of this minimum value is added to the signal so as to elevate the signal appropriately.
5. When the waveform cuts the zero axis and move towards positive axis that is called rise point.

6. When the waveform crosses the zero axis from positive value towards negative, called fall point.
7. Moving towards right from the rise point, the first maxima are taken as heel strike point.
8. Similarly, Moving towards left from the fall point, the first maxima is taken as toe strike point.
9. The corresponding time, where the heel strike occurs, is recorded as heel strike time.
10. Similarly, where the toe strike occurs, is recorded as toe strike time.
11. Heel strike interval is taken by subtracting two subsequent heel strike times.
12. Toe strike interval is taken by subtracting two subsequent toe strike times.
13. The heel strike intervals and toe strike intervals are presented.

3.3 Procedure to calculate Coefficient of Variation (CV)

The following steps are:

1. Mean of all heel to heel intervals is taken.
2. Standard deviation for all heel to heel point intervals is also calculated.
3. The values above and below the range "mean ± 2 *(standard deviation)" are rejected.
4. Step 1 and 2 are repeatedly performed until all the values lie within "mean ± 2 *(standard deviation)".
5. Mean of all toe to toe intervals is taken.
6. Standard deviation for all toe to toe point intervals is also calculated.
7. Step 5 and 6 are repeatedly performed until all the values lie within "mean ± 2 *(standard deviation)".
8. Coefficient of variation (CV) for heel strike and toe strike interval is calculated using the formula "C_V = Standard deviation / Mean".
9. CV for both heel strike and toe strike interval is presented.

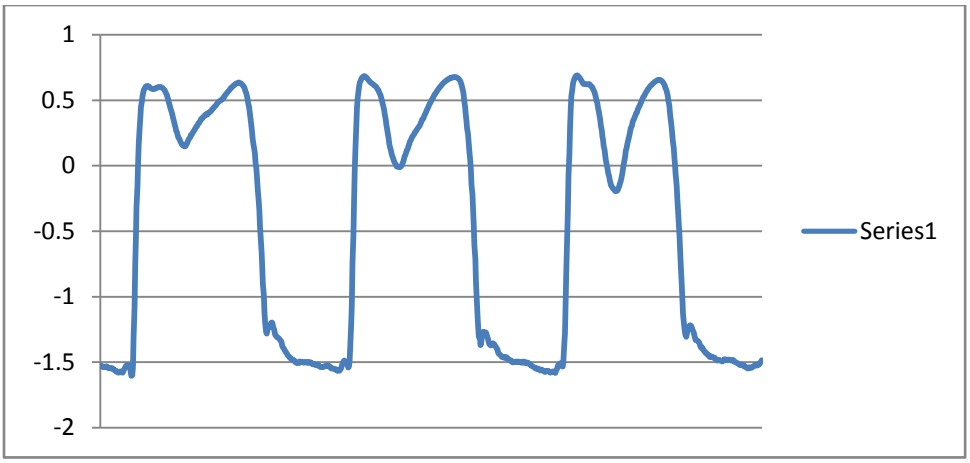

Figure 3.3 (a): Original Signal taken from Huntington's left foot

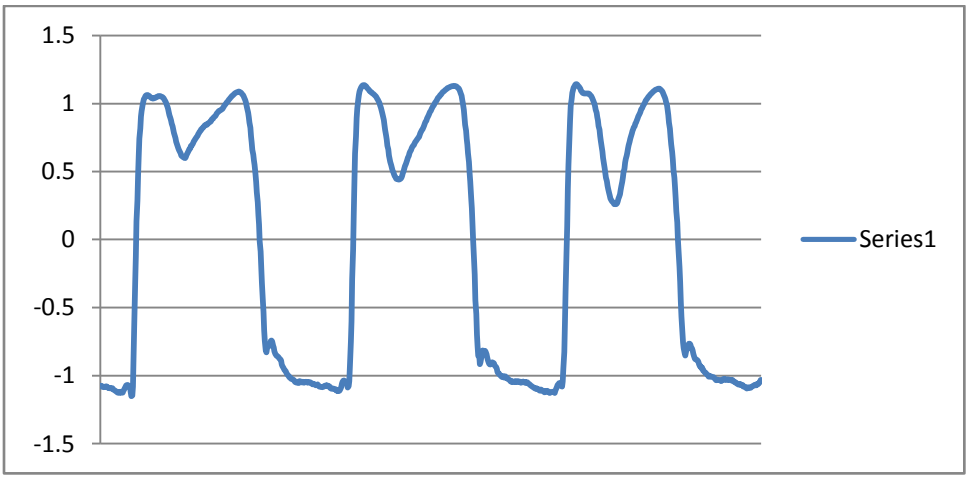

Figure 3.3 (b): Signal after Subtracting Mean Value

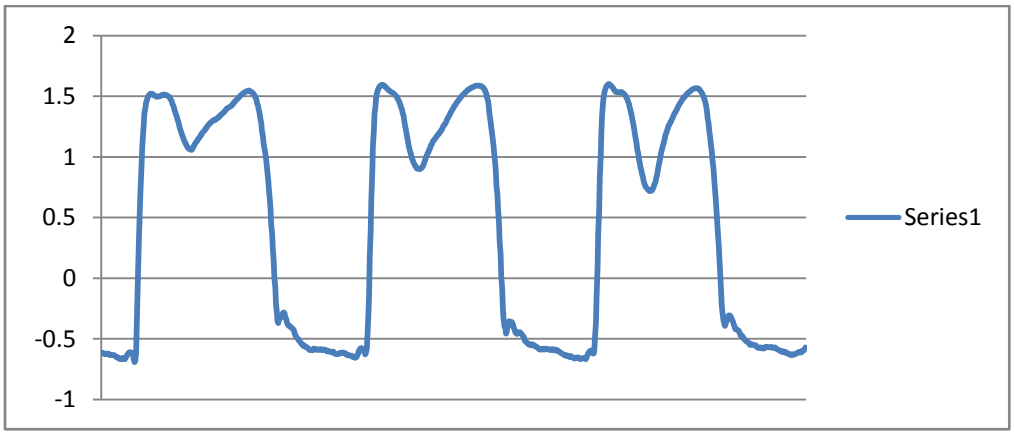

Figure 3.3 (c): Signal after adding 40% of minimum value

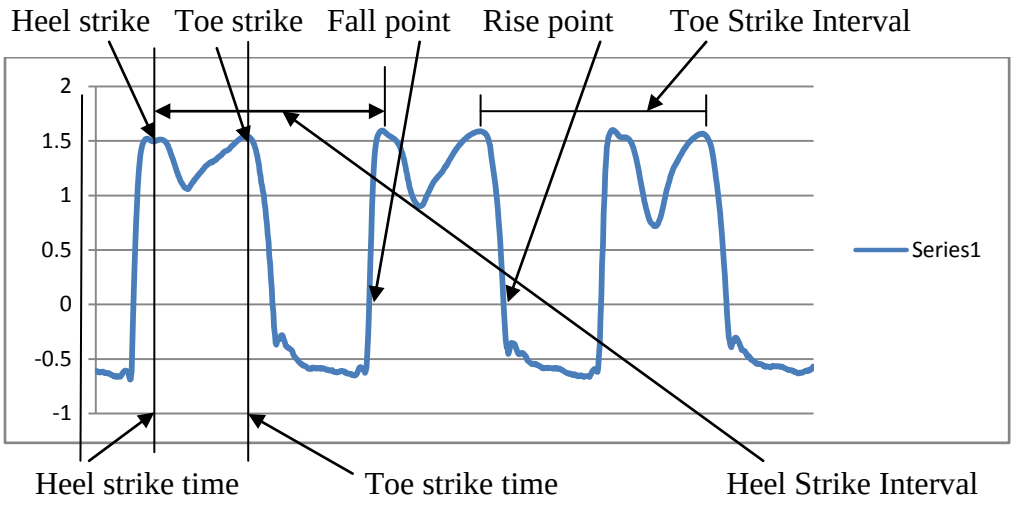

Figure 3.3 (d): Signal showing Identified Parameters

3.4 Comparison between manually detected and computationally detected strikes

To cross check the detection efficiency of MATLAB program, signals from the subject 1 of Huntington's disease, left foot was analyzed manually, wherein 60 heel strikes and 60 toe strikes were detected. The MATLAB program for this signal gives 61 heel and 61 toe strikes. Of these 61 strikes, 60 strikes are correctly detected; none of the strike is missed while one falsely detected strike is reported. If we compute accuracy of the algorithm for this signal comes out to be 98.33 %, which is highly satisfied. The accuracy can be calculated by the formula: "(Actual detection - Missed strikes - False detection) / (Actual detection)"

Table 3.1: Confusion Matrix (Comparison of Manual Gait detection with Computational Gait)

Output / Desired	Manually detected heel strikes	Computationally detected heel
Computationally Detected Heel Strikes	**60**	**0**
Manually detected heel strikes	**1**	**60**

3.5 Classification

The two-layer feed-forward back propagation Artificial Neural Network (ANN) is used for classification. It has one hidden layer with 10 neurons. Tan-Sigmoid function is used in hidden layer. The MATLAB Neural Network (nntool) opens the Network/Data Manager window, which is helpful to create, train and export the data. The collected data consists of two sets for the classification of normal and Neuro-degenerative subjects. The normal set contains 13 healthy control subjects whereas neuro-degenerative disease set contains 13 PD subjects, 13 HD subjects and 13 ALS subjects. In our previous work it was seen that none of the four features, namely CV of left foot heel strike, Left foot toe strike, Right foot heel strike, Right foot toe strike interval is capable of classification on the basis of threshold, because of overlapping layer. It is therefore essential to design some multi input classifier. Our proposed ANN has four inputs, namely CV of left foot heel strike, Left foot toe strike, Right foot heel strike, Right foot toe strike interval. We are proposing to have two-class classifier, and therefore the output layer will have only one neuron. The output will be 0 or 1 as per the case. We decided to classify the neuro-degenerative disease subjects and healthy control in three phases.

3.5.1 Artificial Neural Network (ANN)

A neural network consists of hidden neurons arranged in layers. It is an interconnected group of artificial network which convert an input vector into some output. The basis network include nodes, called neurons and processing elements, which are connected together to form neural network. The work function refers to the inter–connections between the neurons in the different layers of system. Each neuron takes an input, applies a function to it and then passes the output to the next layer. [36]

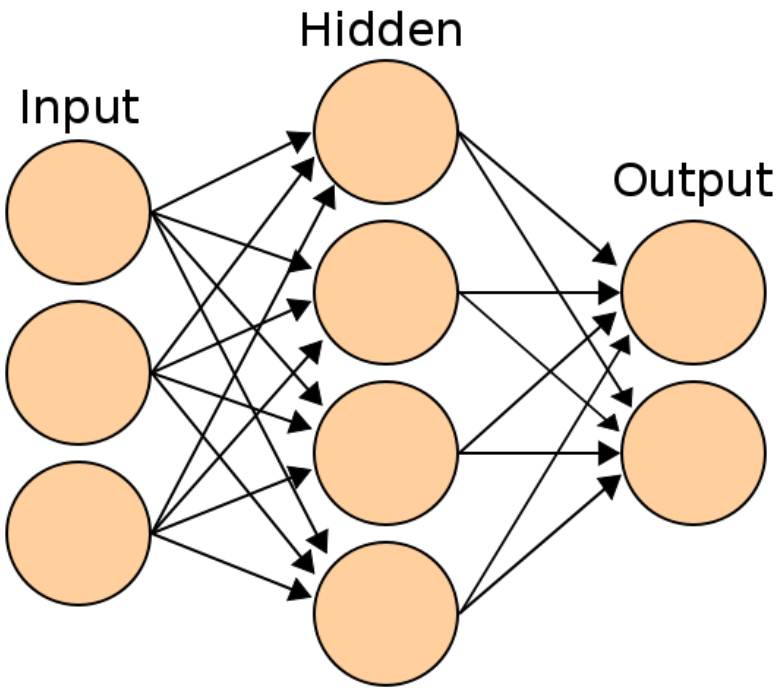

Figure 3.4: Artificial Neural Network Architecture

3.5.2 Feed-forward Network

It is commonly used for prediction, pattern recognition etc. Feed forward Network is the one-way connection network from input layer to output layer. It includes feed-forward back propagation, cascade-backpropagation, and Perceptron networks. As shown in figure, it consists of input layer, hidden layer and output layer.

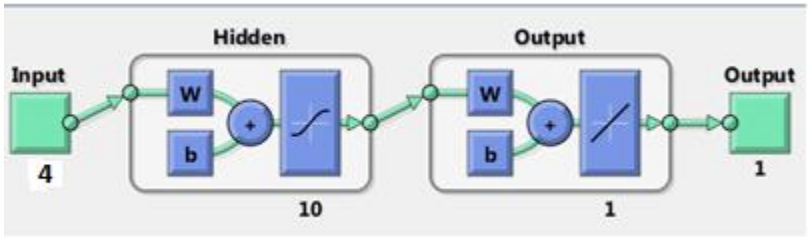

Figure 4: Two layer feed- forward network

4.1Extracted Features

Extracted Features are Heel and Toe strike interval, Mean, Standard Deviation and Coefficient of Variation (CV). Table 4.1 describes each iteration while calculating Coefficient of Variation (CV). The red colored values are the rejected values, which do not lie within mean ± 2*(standard deviation).

Table4 .1: Heel strike interval, toe strike interval, Mean, SD, and CV

ALS 1 Left Foot										
Heel strike	**Heel strike interval**					**Toe strike**	**Toe strike interval**			
13	1886	321	321	410	410	1672	229	229	434	420
1899	321	711	410	414	414	1901	761	288	420	400
2220	711	561	414	403	403	2662	288	434	400	399
2931	561	410	403	397	397	2950	698	420	399	402
3492	410	414	397	401	401	3648	434	400	402	409
3902	414	403	401	412	412	4082	420	399	409	403
4316	403	397	412	413	413	4502	400	402	403	383
4719	397	401	413	383	383	4902	399	409	383	408
5116	401	412	383	398	398	5301	402	403	408	388
5517	412	413	398	394	394	5703	409	383	388	422
5929	413	383	394	426	426	6112	403	408	422	359
6342	383	398	426	366	366	6515	383	388	359	388
6725	398	394	366	397	397	6898	408	422	388	365
7123	394	426	397	368	368	7306	388	359	365	361
7517	426	366	368	358	358	7694	422	388	361	370
7943	366	397	358	359	359	8116	359	365	370	370
8309	397	368	359	384	384	8475	388	361	370	356
8706	368	358	384	345	368	8863	365	370	356	367
9074	358	359	345	368	363	9228	361	370	367	376
9432	359	384	368	363	395	9589	370	356	376	376
9791	384	345	363	395	355	9959	370	367	376	367
10175	345	368	395	355	389	10329	356	376	367	380
10520	368	363	355	389	379	10685	367	376	380	393
10888	363	395	389	379	423	11052	376	367	393	423
11251	395	355	379	423	429	11428	376	380	447	368
11646	355	389	423	429	400	11804	367	393	423	384
12001	389	379	429	400	374	12171	380	447	368	399
12390	379	423	400	374	397	12551	393	423	384	384

12769	423	429	374	397	396	12944	447	368	399	382
13192	429	400	397	396	370	13391	423	384	384	386
13621	400	374	396	370	399	13814	368	399	382	399
14021	374	397	370	399	394	14182	384	384	386	402
14395	397	396	399	394	389	14566	399	382	399	377
14792	396	370	394	389	393	14965	384	386	402	
15188	370	399	389	393	363	15349	382	399	377	
15558	399	394	393	363		15731	386	402		
15957	394	389	363			16117	399	377		
16351	389	393				16516	402			
16740	393	363				16918	377			
17133	363					17295				
17496										
Mean	430.075	400	387.1622	389	390.2571	Mean	400.5897	382.8108	389.9143	386.8485
STDEV	242.9623	62.61469	23.713	21.20916	20.11196	STDEV	85.984	37.60159	22.02054	18.51878
Coefficient of Variation (CV)					0.051535					0.047871

Table 4.2: Heel Strike Interval, Toe Strike interval, Mean, SD and CV of ALS subjects

	ALS 1 RIGHT FOOT		ALS 2 LEFT FOOT		ALS 2 RIGHT FOOT		ALS 3 LEFT FOOT		ALS3 RIGHT FOOT	
	HEEL INTERVAL	TOE STRIKE INTERVAL	HEEL STRIKE INTERVAL	TOE STRIKE INTERVAL	HEEL STRIKE INTERVAL	TOE STRIKE INTERVAL	HEEL STRIKE INTERVAL	TOE STRIKE INTERVAL	HEEL STRIKE INTERVAL	TOE STRIKE INTERVAL
	380	400	343	364	335	340	380	359	324	353
	396	405	344	346	347	350	354	338	358	349
	396	400	350	345	348	343	351	344	353	345
	412	407	356	355	347	353	340	340	328	335
	407	411	341	350	345	351	335	364	351	342
	400	388	346	344	352	336	356	362	363	368
	381	394	357	351	355	352	354	348	353	357
	416	404	367	349	347	344	344	319	354	353
	380	365	333	349	338	334	346	391	342	322
	412	376	339	341	339	338	324	352	337	384
	381	382	335	350	356	350	375	343	368	345
	379	361	338	343	343	340	353	326	353	348
	368	358	350	348	340	340	318	377	350	329
	352	383	346	346	336	357	385	345	334	367
	381	355	341	335	353	330	344	351	376	356
	362	366	341	353	352	354	327	352	354	349
	367	361	373	344	348	334	350	347	335	354

	356	390	357	339	337	351	363	330	351	343
	382	361	348	339	340	348	344	342	331	330
	381	385	332	349	354	347	364	363	337	347
	358	382	320	341	339	331	334	349	366	364
	387	400	372	334	351	347	341	363	341	340
	389	368	351	358	342	351	369	337	362	368
	422	396	345	347	350	341	348	339	357	335
	366	397	342	357	336	340	338	374	327	342
	395	376	347	327	335	341	348	352	335	361
	402	389	350	341	334	348	335	385	364	358
	379	391	337	326	339	330	338	378	352	383
	381	398	372	347	341	346	369	340	345	381
	395	387	322	352		340	371	337	322	347
	400	361	338	332		344	369	339	365	338
	415		308	365		344	377	368	354	339
	353		368	337		335	335	372	368	360
			334	344		346	324	366	364	372
			340	332		334		380	336	372
			349	350		339		333	361	377
				325		335		365	330	330
						341		338	365	370
						339		368	379	328
								362	345	380
								346		358
										342
										337
MEAN	385.7879	383.7742	345.3333	344.7297	342.7647	342.5405	348.9677	353.2683	350.4103	352.5116
SD	19.16174	16.65475	14.28686	9.57035	6.852241	7.076028	17.3054	16.94406	14.81294	16.43222
CV	0.049669	0.043397	0.041371	0.027762	0.019919	0.02065	0.049444	0.048	0.042323	0.046682

Table 4.3: Heel strike interval, toe strike interval, Mean, SD and CV for ALS subjects

	ALS 4 LEFT FOOT		**ALS 4 RIGHTT FOOT**		**ALS 5 LEFT FOOT**		**ALS 5 RIGHT FOOT**		**ALS 6 LEFT FOOT**		**ALS 6 RIGHTT FOOT**	
	HEEL STRIKE INTERVAL	**TOE STRIKE INTERVAL**	**HEEL STRIKE INTERVAL**	**TOE STRIKE INTERVAL**	**HEEL STRIKE INTERVAL**	**TOE STRIKE INTERVAL**	**HEEL STRIKE INTERVAL**	**TOE STRIKE INTERVAL**	**HEEL STRIKE INTERVAL**	**TOE STRIKE INTERVAL**	**HEEL STRIKE INTERVAL**	**TOE STRIKE INTERVAL**
	427	352	391	385	381	406	411	406	539	490	410	494
	462	446	357	398	401	387	381	425	504	488	595	505
	452	390	559	442	394	387	401	387	518	507	438	509

	513	476	352	473	369	408	394	387	499	499	412	494
	520	450	529	637	383	382	369	408	487	474	651	501
	505	514	557	372	379	360	383	382	531	462	365	515
	472	487	370	496	375	378	379	360	466	491	641	481
	436	516	506	554	386	392	375	378	503	506	320	485
	459	512	519	395	378	378	386	392	487	466	477	488
	480	447	388	428	375	391	362	378	478	476	505	485
	472	456	437	549	402	372	378	391	497	506	581	519
	442	446	477	477	380	377	375	353	501	476	388	474
	453	366	476	465	389	388	402	372	552	459	630	478
	473	524	445	457	392	391	407	377	486	465	442	493
	455	522	514	313	394	376	380	388	482	473	385	473
	488	387	520	602	381	382	389	391	536	470	613	499
	494	451	398	336	381	378	392	376	464	473	392	518
	512	392	453	459	401	406	394	382	529	448	457	467
		539	508	501	386	390	381	378	439	470	482	465
		540	601	575	397	392	381	406	499	484	468	491
		501	505	507	382	390	401	302	515	458	438	430
		547			380	400	386	390	491	452	485	485
					377	414	397	400	527	474	539	453
					376	369	382	362	465	450	404	468
							380	394	453	450	450	484
							377	369	446	461	616	471
							376				324	453
											452	449
											608	455
											378	457
												467
MEAN	473.0556	466.4091	469.619	467.6667	384.9583	387.25	385.8889	382.0769	496	474.1538	478	481
STDEV	16.98096	59.67344	72.0628	85.34948	9.257097	13.10907	11.82999	22.85594	219.4485	16.11929	98.1081	21.77475
CV	0.057971	0.127942	0.153325	0.182501	0.024044	0.033852	0.030648	0.05982	0.060014	1.003241	0.205247	0.04527

Table 4.4: Heel Strike Interval, Toe Strike Interval, Mean, SD, and CV for ALS Subjects

	ALS 7 LEFT FOOT		**ALS 7 RIGHTT FOOT**		**ALS 8 LEFT FOOT**		**ALS 8 RIGHT FOOT**		**ALS 9 LEFT FOOT**		**ALS 9RIGHT FOOT**	
	HEEL STRIKE INTERVAL	**TOE STRIKE INTERVAL**	**HEEL STRIKE INTERVAL**	**TOE STRIKE INTERVAL**	**HEEL STRIKE INTERVAL**	**TOE STRIKE INTERVAL**	**HEEL STRIKE INTERVAL**	**TOE STRIKE INTERVAL**	**HEEL STRIKE INTERVAL**	**TOE STRIKE INTERVAL**	**HEEL STRIKE INTERVAL**	**TOE STRIKE INTERVAL**
	586	535	640	566	349	345	351	347	351	363	362	365

	647	563	567	605	346	347	346	348	372	352	351	362
	510	641	569	592	348	358	351	343	350	353	355	352
	588	595	569	582	352	345	347	351	361	362	360	362
	553	505	588	718	345	335	334	345	361	351	352	353
	540	547	531	425	350	346	347	353	355	347	353	339
	479	622	546	476	335	348	347	337	350	354	350	347
	517	500	514	437	340	346	351	341	364	358	361	357
	585	570	616	447	350	349	345	348	350	349	359	360
	539	491	481	679	342	341	338	344	346	351	352	367
	558	466	419	423	340	337	341	340	343	346	347	347
	466	488	573	461	340	347	349	342	347	352	349	342
	571	583	582	582	344	343	343	340	355	362	340	346
	568	582	577	691	335	338	339	337	346	356	359	356
	452	552	478	396	344	344	341	345	337	349	360	341
	542	571	578	617	340	342	341	341	358	353	346	344
	574	510		564	342	337	339	343	366	358	353	353
	611	586		580	339	344	345	335	341	355	349	367
	455	515		555	340	334	337	341	348	358	357	342
	539	575			336	351	343	336	367	360	362	349
		574			342	335	341	344	358	361	359	368
		515			340	335	332	339	357	358	365	354
		523			350	336	337	349	371	344	367	362
					342	334	335	341	361	351	370	356
					341	347	347	343	352	352	345	357
					336	336	337	338	364	348	349	369
					340	355	352	339	373	347	353	365
					346	336	339	346	352	352	345	349
					340	341	340	339	362	359	351	342
					343	337	339	343	338	345	351	359
					341	338	337	342	354	354	359	353
					350	351	361	349	346	344	354	344
					346	339	346	345	358	362	349	347
					344	338	341	346	343	359	339	356
					348	353	340	346	357	352	365	352
						351	352	336	349		358	354
						349	353		345		352	344
						344	344		352			357
						349	344		359			353
						341	351		356			356
							338		334			359
												369

MEAN	544	548.2174	551.75	547.1579	343	343	343	343	354	353.6286	354	354.1905
STDEV	52.11829	45.20655	55.80143	97.05111	4.611276	6.372819	6.172717	4.423961	9.489982	5.557643	7.252006	8.474461
MEAN	0.095806	0.082461	0.10109	0.177373	0.013444	0.01858	0.017996	0.012898	0.026808	0.015716	0.020486	0.023926

Table 4.5: Heel Strike Interval, Toe Strike Interval, Mean, SD and CV of ALS Subjects

	ALS 10 LEFT FOOT		ALS 10 RIGHT FOOT		ALS 11 LEFT FOOT		ALS 11RIGHT FOOT		ALS 12 LEFT FOOT		ALS 12 RIGH T FOOT		ALS 13 LEFT FOOT		ALS 13 RIGH T FOOT	
	HEEL STRIKE INTERVAL	TOE STRIKE INTERVAL	HEEL STRIKE INTERVAL	TOE STRIKE INTERVAL	HEEL STRIKE INTERVAL	TOE STRIKE INTERVAL	HEEL STRIKE INTERVAL	TOE STRIKE INTERVAL	HEEL STRIKE INTERVAL	TOE STRIKE INTERVAL	HEEL STRIKE INTERVAL	TOE STRIKE INTERVAL	HEEL STRIKE INTERVAL	TOE STRIKE INTERVAL	HEEL STRIKE INTERVAL	TOE STRIKE INTERVAL
	334	343	339	353	360	361	356	359	405	410	408	410	420	444	463	451
	336	327	339	344	348	348	361	347	422	417	386	390	459	426	470	433
	345	347	344	343	355	362	356	357	379	396	410	387	434	429	461	447
	345	338	347	333	364	355	347	353	423	404	412	395	423	451	479	458
	335	353	348	345	353	361	365	360	388	411	392	390	445	453	476	452
	340	331	346	344	350	350	341	348	400	418	329	392	437	418	436	424
	335	345	336	352	353	358	349	349	388	388	416	405	448	426	433	447
	337	338	355	340	354	353	347	361	388	394	373	408	431	445	480	433
	333	343	343	340	357	344	357	359	399	389	409	403	429	430	424	429
	328	333	338	345	360	348	357	356	389	401	380	392	438	420	415	439

	332	351	339	339	360	365	362	355	406	410	471	390	427	443	415	431
	333	347	329	336	360	362	350	361	414	406	319	400	431	430	428	425
	332	337	329	335	355	352	355	362	390	388	407	399	439	458	458	437
	346	345	336	329	361	362	367	352	389	395	406	412	410	429	411	421
	344	339	340	356	358	354	355	359	402	396	398	400	427	438	424	404
	344	332	341	332	360	362	356	358	395	412	464	404	442	435	440	457
	348	337	351	349	358	352	354	353	418	401	319	399	436	451	433	434
	333	341	329	355	355	357	368	363	381	395	396	394	427	415	436	442
	337	339	341	328	357	359	358	360	403	384	404	399	450	421	439	432
	342	345	339	328	354	358	342	360	395	397	407	394	427	436	446	440
	340	338	330	344	350	358	366	355	402	397	394	388	437	451	431	414
	342	335	346	340	361	357	348	359	387	394	391	409	430	426	416	426
	337	347	336	333	363	367	363	354	374	389	400	418	449	438	425	451
	342	341	343	346		349	361	352	385	407	394	391	449	436	437	430
	344	350	337	339		362	357	360	404	416	465	398	430	434	462	434
	332	342	340	351		353	367	353	428	399	306	402	435	436	417	433
	334	336	339	328		349	368	363	385	399	467	411		447	443	430
	332	326	352	347		362	339	353	404	412	407	423		432	429	436
	343	347	349	341		353	353	359	403	411	337	385			435	422
	339	335	336	354		365		361	417	401	396	399			416	451

	340	348	332	331		359		355	418	388	477	413			430	430
	335	344	334	345		353		352	381	405	419	405			447	
	342	335	343	320		362		360	400	420	415	412				
	337	328	340	344		355		361	416	400	308	416				
	336	342	331	349		356		365	412	412	470					
	335	336	339	331		352		357	407		329					
	339	342	346	337		366					457					
	340		333	342		357					368					
	336		331	342		361					485					
			337	338												
			343	340												
			339	344												
			336													
MEAN	338	340.0811	340	340.6512	357	356.8974	356	356.9722	399.9167	401.7714	400	400.9706	436	435.6429	439.2188	435.2581
STDEV	4.811985	6.697339	6.453668	8.254533	4.28482	5.637258	8.21359	4.462454	13.9189	9.801218	48.02875	9.740529	10.7963	11.3927	19.91066	12.47656
CV	0.014237	0.019693	0.018981	0.024232	0.012002	0.015795	0.023072	0.012501	0.034804	0.024395	0.120072	0.024292	0.024762	0.026151	0.045355	0.028665

Table 4.6: Heel Strike Interval, Toe Strike Interval, Mean, SD and CV of Huntington's Subjects

	HUNT1_LEFT FOOT		HUNT1_RIGHTT FOOT		HUNT2_LEFT FOOT		HUNT2_RIGHTT FOOT		HUNT3_LEFT FOOT		HUNT3_RIGHTT FOOT	
	HEEL STRIKE INTERVAL	TOE STRIKE INTERVAL	HEEL STRIKE INTERVAL	TOE STRIKE INTERVAL	HEEL STRIKE INTERVAL	TOE STRIKE INTERVAL	HEEL STRIKE INTERVAL	TOE STRIKE INTERVAL	HEEL STRIKE INTERVAL	TOE STRIKE INTERVAL	HEEL STRIKE INTERVAL	TOE STRIKE INTERVAL
	295	294	274	292	423	424	419	453	268	363	377	353
	289	279	297	289	439	458	435	433	370	394	392	288

	279	290	291	283	460	443	437	445	367	336	378	370
	273	286	270	274	449	461	416	462	316	318	333	330
	276	284	295	271	436	430	455	438	322	304	302	311
	282	270	276	287	454	453	436	447	287	314	304	297
	275	282	283	277	437	445	440	440	322	328	327	319
	288	280	274	279	445	439	423	448	298	298	315	316
	278	279	275	280	439	423	431	444	324	294	304	301
	280	279	275	284	430	421	418	409	301	304	293	297
	284	283	298	290	421	449	393	437	294	313	308	308
	287	283	261	288	441	388	423	445	343	322	314	328
	283	289	305	278	396	423	410	383	284	284	318	303
	287	281	272	273	405	404	425	406	268	273	279	319
	281	286	290	259	427	434	375	439	314	313	288	299
	272	278	268	278	408	396	463	397	305	320	316	336
	255	264	265	297	424	434	404	427	329	379	323	370
	287	272	270	272	415	411	352	417	374	342	362	318
	296	283	293	276	387	385	437	376	310	287	339	344
	264	295	303	283	442	429	435	460	315	320	317	335
	287	265	257	276	408	402	359	398	299	288	284	361
	272	283	274	285	375	393	385	362	328	354	292	355
	285	276	301	280	387	358	406	400	363	381	383	350
	283	284	259	271	375	402	379	370	352	358	351	279
	274	288	304	290	403	413	413	410	357	313	374	294
	279	273	258	284	418	412	421	419	328	358	302	291
	291	278	275	269	405	387	357	395	394	365	362	328
	274	289	289	273	384	395	398	397	271	273	366	349
	280	269	275	266	413	382	403	410	300	309	269	354
	266	277	270	263	387	369	389	369	328	340	305	359
	259	271	291	265	401	407	377	374	360	330	347	386
	272	263	247	272	406	367	376	403	285	316	323	365
	259	258	252	276	377	384	401	410	361	376	320	348
	273	266	277	278		401	358	372	359	342	362	381
	283	277	276	279		383	434	410	356	386	357	351
	280	271	272	271		409		393	378	361	385	353
	276	296	294	251					367	352	372	326
	265	263	257	264					351	382	332	335
	268	262	260	275					375	374	390	330
	273	261	266	272					366	352	380	333
	267	274	275	254					337	314	330	345
	254	265	286	259					325	327	332	

	264	265	237	265					342	342	322	
	268	264	268	270					331	352	345	
	264	273	277	258					341	311	343	
	254	258	277	274							320	
	283	271	267	277								
	272	276	280	282								
	288	280	278	292								
	284	283	292	255								
	292	287	266	270								
	258	275	269	252								
	291	296	253	255								
			262	253								
			245	278								
			248									
			254									
MEAN	276.3962	276.8679	274.0877	273.8909	408	411.5	408.0857	413.8333	330.3333	332.4889	333.413	332.0732
STDEV	10.92692	10.09958	16.01147	11.27875	72.00756	26.70313	77.55917	28.5442	32.5716	31.92578	32.72076	27.12507
CV	0.039534	0.036478	0.058417	0.04118	0.05734	0.064892	0.07091	0.068975	0.098702	0.096021	0.098139	0.081684

Table 4.7: Heel Strike Interval, Toe Strike Interval, Mean, SD and CV for Huntington's Subjects

	HUNT 4 LEFT FOOT		HUNT4 RIGHTT FOOT		HUNT5 LEFT FOOT		HUNT5 RIGHT FOOT		HUNT6 LEFT FOOT		HUNT6 RIGHT FOOT	
	HEEL STRIKE INTERVAL	TOE STRIKE INTERVAL	HEEL STRIKE INTERVAL	TOE STRIKE INTERVAL	HEEL STRIKE INTERVAL	TOE STRIKE INTERVAL	HEEL STRIKE INTERVAL	TOE STRIKE INTERVAL	HEEL STRIKE INTERVAL	TOE STRIKE INTERVAL	HEEL STRIKE INTERVAL	TOE STRIKE INTERVAL
	282	306	337	280	363	322	325	331	305	308	282	306
	331	299	278	304	333	343	319	328	309	309	333	309
	269	361	296	325	332	321	349	342	328	321	299	301
	327	316	321	300	343	313	324	313	287	301	324	301
	288	335	336	306	290	328	317	322	319	322	279	317
	299	297	267	302	345	310	323	313	333	299	309	318
	314	306	356	324	316	311	313	321	294	326	340	313
	315	360	325	287	292	327	315	316	310	301	285	313
	337	285	301	318	323	321	327	323	329	312	317	300
	343	345	275	322	347	330	322	330	321	313	307	318
	298	353	278	304	324	316	322	319	323	309	330	332
	315	289	309	319	323	338	329	335	313	312	345	323
	310	352	366	278	312	328	338	324	313	326	295	316

	308	286	263	320	320	334	340	340	323	323	335	300
	354	334	320	274	378	328	330	324	306	307	297	326
	278	365	300	291	315	324	340	332	323	306	327	329
	269	284	324	299	314	318	324	312	328	309	297	307
	288	298	271	301	363	327	321	328	297	312	317	308
	303	290	286	299	315	319	316	327	323	297	328	324
	312	349	296	293	323	341	314	331	299	312	340	307
	280	351	358	291	299	326	319	326	314	314	277	331
	321	264	356	317	362	336	352	327	306	295	325	324
	283	303	245	328	329	328	309	341	310	309	332	318
	343	288	300	291	326	323	335	321	307	308	282	313
	278	315	286	304	338	337	340	335	300	328	341	324
	337	275	295	307	299	337	343	341	315	310	303	316
	256	269	365	310	359	332	316	341	289	299	318	298
	248	296	362	295	346	334	339	329	324	301	282	317
	350	320	347	304	344	332	320	335	330	323	325	321
	308	304	252	309	330	313	302	331	305	302	350	327
	289	323	285	286	333	328	348	321	333	312	323	325
	309	340	325	285	326	311	312	326	315	316	285	323
	306	293	271	309	318	329	319	316	330	315	340	322
	321	288	292	289	318	315	326	316	298	315	317	300
	387	301	309	305	320	329	331	322	310	299	307	309
	306	309	252	324	296	322	314	325	314	329	338	307
	273	298	313		347	321	343	325	320	316	306	316
	313	288	311		323		324	315	319	297	320	323
	316	297	319		336			334	321	310	316	301
	320	325	351		308			313	331	316	286	317
	268	329	282		330				322	324	327	324
	266	328	263		376				290	323	305	304
	300	290	316							318	329	313
			299								322	311
			274								324	323
			310								348	329
			326								315	
			334								344	
			312								339	
			298									
MEAN	305.0698	311.7209	306.26	302.7778	329.381	325.7297	326.3158	326.275	313.9524	311.7209	316.5714	315.3043
STDEV	28.76787	26.90488	31.90151	14.31505	21.28661	8.742135	12.16798	8.587371	12.61426	9.225548	20.63775	9.549566
CV	0.094299	0.086311	0.104165	0.047279	0.064626	0.026839	0.037289	0.026319	0.040179	0.029596	0.065191	0.030287

Table 4.8: Heel Strike Interval, Toe Strike Interval, Mean, SD and CV of Huntington's Subjects

	HUNT7_LEFT FOOT		HUNT7_RIGHTT FOOT		HUNT8_LEFT FOOT		HUNT8_RIGHTT FOOT		HUNT9_LEFT FOOT		HUNT9_RIGHTT FOOT	
	HEEL STRIKE INTERVAL	TOE STRIKE INTERVAL	HEEL STRIKE INTERVAL	TOE STRIKE INTERVAL	HEEL STRIKE INTERVAL	TOE STRIKE INTERVAL	HEEL STRIKE INTERVAL	TOE STRIKE INTERVAL	HEEL STRIKE INTERVAL	TOE STRIKE INTERVAL	HEEL STRIKE INTERVAL	TOE STRIKE INTERVAL
	407	388	382	390	330	317	328	319	337	332	347	340
	315	384	370	348	330	311	319	315	334	329	346	337
	325	385	397	355	313	310	331	316	337	331	333	337
	352	389	384	349	339	320	329	316	325	335	341	334
	372	368	344	399	318	303	317	317	345	332	326	340
	361	393	369	357	309	307	325	314	314	324	339	319
	334	361	398	398	321	317	300	313	336	322	328	331
	382	398	417	376	303	322	336	303	333	336	323	331
	378	376	391	385	364	307	326	316	326	313	335	324
	394	360	377	370	307	319	312	314	331	318	315	336
	422	389	354	383	309	318	306	312	310	304	344	314
	370	382	381	371	320	324	338	312	311	316	313	313
	383	389	385	394	307	308	308	312	312	320	304	309
	362	384	396	349	309	314	299	305	319	311	311	319
	427	390	383	390	332	308	326	311	310	315	320	312
	302	359	389	359	322	316	313	312	317	314	313	315
	445	384	360	360	302	314	305	313	306	317	322	313
	362	362	380	374	319	302	330	319	313	291	312	312
	363	370	361	377	310	304	313	313	298	318	302	301
	369	370	414	381	327	306	312	311	314	313	317	308
	332	390	394	382	296	320	305	308	317	322	295	315
	373	374	366	383	317	313	298	308	319	325	327	314
	389	373	381	399	315	308	331	308	319	309	309	328
	371	396	395	348	302	317	310	318	323	297	316	318
	347	359	356	406	308	316	299	310	298	315	338	304
	360	388	385	380	305	313	294	317	301	309	288	306
	450	397	400	379	312	318	332	317	314	305	312	310
	328	363	359	380	304	312	313	308	312	305	318	312
	384	379	388	373	313	304	315	317	301	308	307	304
	424	374	373	381	315	310	311	305	316	307	299	305
	317	380	339	370	316	320	301	314	301	302	311	307
	440	372	411	353	309	302	317		302	299	309	303
	327	376	372	378	292	315	293		300	307	305	298
	414	384	388		315	312	291		300	298	289	305

	311				305	310	325		302	304	305	300
					322	313	320		301	296	311	304
					301		298		311	295	297	306
					315		311		297		300	300
					305		320				310	290
					313		314				284	
					311		310				287	
					311		302					
					321		316					
					304		305					
MEAN	371.2	379	380.5588	375.0606	314.0455	312.5	313.7273	312.6774	314.7895	313.3514	314.8293	314.7179
STDEV	39.89014	11.65931	18.70536	16.25181	12.34571	5.93055	12.32385	4.245681	12.99929	12.00513	16.57996	13.0383
CV	0.107463	0.030763	0.049152	0.043331	0.039318	0.018978	0.039248	0.013578	0.041295	0.038312	0.052663	0.041429

Table 4.9: Heel Strike Interval, Toe Strike Interval, Mean, SD and CV for Huntington's Subjects

	HUNT10_LEFT FOOT		HUNT10_RIGHTT FOOT		HUNT11_LEFT FOOT		HUNT11_RIGHTT FOOT		HUNT12_LEFT FOOT		HUNT12_RIGHTT FOOT		HUNT13_LEFT FOOT		HUNT13_RIGHTT FOOT	
	HEEL STRIKE INTERVAL	TOE STRIKE INTERVAL	HEEL STRIKE INTERVAL	TOE STRIKE INTERVAL	HEEL STRIKE INTERVAL	TOE STRIKE INTERVAL	HEEL STRIKE INTERVAL	TOE STRIKE INTERVAL	HEEL STRIKE INTERVAL	TOE STRIKE INTERVAL	HEEL STRIKE INTERVAL	TOE STRIKE INTERVAL	HEEL STRIKE INTERVAL	TOE STRIKE INTERVAL	HEEL STRIKE INTERVAL	TOE STRIKE INTERVAL
	351	317	356	361	407	365	361	372	326	219	310	335	298	309	325	317
	359	398	349	349	369	354	368	340	338	379	356	332	308	314	310	264
	351	311	362	357	347	378	357	362	347	372	345	346	320	323	313	325
	381	316	365	365	343	367	182	336	337	291	328	339	327	320	322	370
	370	354	356	365	380	352	196	365	321	400	336	328	310	321	305	316
	352	377	371	363	359	364	363	369	283	286	339	356	324	326	322	280
	376	349	366	371	393	365	365	350	329	363	301	332	312	317	321	368
	357	362	362	365	358	360	345	373	338	291	353	303	299	322	321	277
	367	312	372	366	357	381	375	369	315	347	311	340	306	324	319	292
	351	361	381	351	365	380	367	330	320	268	307	323	306	314	295	330
	359	358	367	370	406	365	206	336	326	380	324	306	331	309	330	349
	364	383	369	355	323	345	184	325	303	258	282	307	291	310	291	272
	366	365	366	376	395	352	360	322	370	352	312	298	319	316	316	356
	367	354	349	374	311	352	183	374	303	278	355	308	306	304	316	271
	355	358	358	366	413	344	168	359	286	294	303	357	301	308	299	348
	344	394	370	340	336	360	350	347	348	362	342	298	316	319	311	258
	341	305	346	365	366	359	367	353	298	314	284	360	320	325	320	364
	372	357	350	351	387	366	356	375	292	300	365	292	323	310	320	278
	366	383	352	341	320	369	394	360	362	334	319	293	300	311	314	361

	363	317	370	356	391	355	355	371	286	306	358	346	310	312	310	265
	349	381	386	372	368	366	341	361	287	254	365	303	321	316	332	309
	339	379	387	381	365	349	359	366	339	384	298	348	331	304	298	364
	343	377	372	369	366	376	379	355	336	266	335	332	290	317	304	305
	370	344	363	359	351	360	363	365	316	280	303	332	306	314	312	271
	358	350	350	338	365	361	377	375	344	349	306	332	290	328	316	311
	366	359	361	351	368	342	365	351	289	296	336	307	307	300	331	323
	339	344	356	345	360	371	377	357	340	287	369	318	311	317	305	379
	353	378	369	365	398	349	364	356	354	341	298	340	324	317	308	315
	317	387	345	357	327	346	359	350	300	364	343	332	320	327	307	301
	350	353	382	359	381	335	378	324	302	224	346	327	318	320	326	281
	375	371	348	350	356	328	355	352	366	260	280	325	313	312	318	364
	349	379	384	347	321	373	185	340	312	397	351	313	297	312	325	279
	357	385	380	377	385	349	171	363	343	310	299	326	319	300	318	317
	344	310	372	359	371	348	351	335	318	276	345	319	302	311	304	312
				366	319	345	350	343	305	407	322	326	294	312	317	294
					363	335	364	348	337	243	328	338	309	310	293	359
					344	350	324	325	322	343	343	360	296	312	291	301
					345	363	341	336	334	366	320	310	308	304	310	301
					342	363	348		336	317	335		303	318	299	255
					353		358		349	277			302	320	322	348
					395		187		317	323			319	315	320	257
					322		163			339			321	303	322	309
							346			345			318	303	317	348
							349			378			306	323	297	267
	356.5	356.7059	364.4706	360.0571	361.6905		343			280			298		301	327
	13.16619	26.73952	12.09617	10.89507	26.47731		180						308			361
	0.036932	0.074962	0.033188	0.030259	0.073204		183									298
							347									304
							187									271
							182									333
MEAN						357.4872	309.56	352.3684	323.7561	326.9744	326.9744	325.9737	309.9565	314.2955	312.7333	312.5
STDEV						12.70903	80.95253	15.95504	23.40596	49.26177	24.49864	18.98006	10.89945	7.315417	10.93867	36.10882
CV						0.035551	0.261508	0.045279	0.072295	0.15502	0.074925	0.058226	0.035164	0.023276	0.034978	0.115548

Table 4.10: Heel Strike Interval, Toe Strike Interval, Mean, SD and CV for Parkinson's Subjects

	PARK1 LEFT FOOT		PARK1 RIGHT FOOT		PARK2 LEFT FOOT		PARK2 RIGHT FOOT		PARK3 LEFT FOOT		PARK3 RIGHT FOOT		PARK4 LEFT FOOT		PARK4 RIGHT FOOT	
	HEEL STRIKE INTERVAL	TOE STRIKE INTERVAL	HEEL STRIKE INTERVAL	TOE STRIKE INTERVAL	HEEL STRIKE INTERVAL	TOE STRIKE INTERVAL	HEEL STRIKE INTERVAL	TOE STRIKE INTERVAL	HEEL STRIKE INTERVAL	TOE STRIKE INTERVAL	HEEL STRIKE INTERVAL	TOE STRIKE INTERVAL	HEEL STRIKE INTERVAL	TOE STRIKE INTERVAL	HEEL STRIKE INTERVAL	TOE STRIKE INTERVAL
	326	349	359	329	309	304	308	298	360	369	385	361	405	393	406	417
	340	361	339	349	329	305	303	303	366	369	362	367	396	391	409	432
	360	352	339	339	319	305	305	302	359	348	346	357	414	405	408	425
	347	334	364	346	278	285	265	301	352	360	360	347	439	368	400	425
	338	360	357	339	308	302	309	302	325	329	310	348	395	402	399	401
	356	353	343	330	338	300	306	299	341	336	351	342	404	400	409	408
	348	339	334	341	280	295	300	303	345	343	340	360	395	393	384	397
	352	336	329	350	285	286	301	292	360	349	357	359	397	390	381	392
	331	344	332	331	339	305	296	300	357	367	362	348	403	371	388	408
	354	328	346	354	313	296	299	302	352	354	353	341	433	410	367	409
	335	346	352	336	306	291	301	298	342	343	346	332	385	352	366	415
	328	350	325	330	303	294	300	291	333	335	310	346	467	388	390	417
	344	331	352	334	273	290	293	291	346	345	369	347	423	386	382	432
	333	348	323	357	324	295	291	289	340	337	337	353	388	359	388	425
	338	327	335	348	299	292	292	297	358	343	345	351	384	387	374	425
	334	341	330	351	299	292	292	293	350	365	363	346	381	384	375	401
	359	356	365	349	299	285	294	287	346	351	350	367	376	392	389	408
	339	331	324	342	271	295	287	289	359	348	322	335	369	371	383	397
	353	347	344	339	320	306	288	298	347	360	390	336	399	378	392	392
	363	356	361	347	287	289	292	302	336	338	306	346	366	396	373	408
	343	343	339	349	291	290	310	289	341	333	366	338	372	385	382	409
	350	351	349	343	270	291	289	288	336	337	304	354	401	371	366	415
	345	347	359	330	320	289	288	292	354	348	380	354	432	359	368	385
	346	343	340	336	286	299	292	286	357	357	358	352	379	369	368	385
	361	340	342	348	288	296	286	303	329	344	311	343	383	349	382	380
	355	339	345	329	303	291	302	297	345	334	338	357	384	398	376	377
	359	355	342	339	276	284	299	284	351	349	372	351	368	383	381	367
	341	341	343	341	316	287	289	294	355	361	367	374	357	355		383
	344	329	330	343	283	284	286	297	356	341	339	351	360	388		384
	328	339	352	328	265	289	289	295	368	369	406	357	372	374		377
	347	343	339	351	310	300	280	294	349	359	322	360	362			394
	340	337	335	340	282	290	287	285	358	354	372	349	380			369
	347	339	335		321	295	302	290	356	357	341	359	372			381
	336	341	332		267	285	294	287	349	356	350	355	418			392
		339	349		282	298	289	304	362	352	357	346	397			381

		334	332		285	295	284	301	357	359	361					381
		356	357		276	304	290	306	353	358	357					351
		336	336		308	299	295	305		365	365					353
		340	331		267	288	306	289		351						359
		325	325		303	288	296	287								377
		327			321	293	306	289								367
					285	288	305	289								368
					256	297	287	295								381
					290	295	289	299								372
					335	295	285	296								372
					294	290	291	291								
					316		298									
					302		299									
					289		292									
					255		298									
					297											
					288											
					323											
					288											
					277											
					290											
MEAN	344.7059	342.2683	341.625	341.1875	296.1429	293.7391	294.5	294.9783	350	350.5897	350.7895	351.1143	393.0286	381.5667	384.6667	393.2
STDEV	10.21446	9.473712	11.60612	8.232263	20.7412	6.269626	8.545795	6.173381	10.08023	11.14431	23.73748	9.373842	24.81755	16.27497	13.56182	21.64234
CV	0.029632	0.027679	0.033973	0.024128	0.070038	0.021344	0.029018	0.020928	0.028801	0.031787	0.067669	0.026697	0.063144	0.042653	0.035256	0.055042

Table 4.11: Heel Strike Interval, Toe Strike Interval, Mean, SD and CV of Parkinson's Subjects

	PARK5 LEFT FOOT		**PARK5 RIGHT FOOT**		**PARK6 LEFT FOOT**		**PARK6 RIGHT FOOT**		**PARK7 LEFT FOOT**		**PARK7 RIGHT FOOT**		**PARK8 LEFT FOOT**		**PARK8 RIGHT FOOT**		**PARK9LEFT FOOT**		**PARK9RIGHT FOOT**	
	HEEL STRIKE INTERVAL	**TOE STRIKE INTERVAL**	**HEEL STRIKE INTERVAL**	**TOE STRIKE INTERVAL**	**HEEL STRIKE INTERVAL**	**TOE STRIKE INTERVAL**	**HEEL STRIKE INTERVAL**	**TOE STRIKE INTERVAL**	**HEEL STRIKE INTERVAL**	**TOE STRIKE INTERVAL**	**HEEL STRIKE INTERVAL**	**TOE STRIKE INTERVAL**	**HEEL STRIKE INTERVAL**	**TOE STRIKE INTERVAL**	**HEEL STRIKE INTERVAL**	**TOE STRIKE INTERVAL**	**HEEL STRIKE INTERVAL**	**TOE STRIKE INTERVAL**	**HEEL STRIKE INTERVAL**	**TOE STRIKE INTERVAL**

	339	331	336	328	334	290	339	306	360	373	358	355	452	400	434	442	382	398	388	383
	337	329	330	312	326	234	324	321	355	345	349	354	339	406	487	372	389	384	389	405
	321	330	341	334	126	130	333	306	344	352	353	349	347	354	436	358	391	385	382	391
	346	327	300	320	186	181	320	335	344	347	345	341	367	437	313	345	399	392	396	387
	307	319	330	312	312	323	325	309	337	344	347	336	381	338	324	396	380	399	399	401
	333	314	346	320	329	321	302	332	323	326	328	321	404	434	400	401	396	396	386	394
	320	325	330	312	318	188	336	316	320	317	337	324	265	344	432	387	400	381	383	390
	319	310	299	326	326	317	322	311	327	325	353	327	446	419	459	411	361	381	381	362
	315	319	312	330	316	318	315	320	334	332	344	334	346	387	301	420	376	400	398	392
	308	336	324	321	311	310	316	311	344	341	334	343	387	394	431	396	384	384	390	384
	331	326	301	318	325	187	312	298	353	352	351	349	418	426	399	408	372	377	383	379
	333	315	364	322	306	129	311	310	340	342	332	348	393	384	436	406	380	392	385	372
	319	320	321	310	131	314	339	308	346	351	335	344	382	401	427	380	365	379	390	393
	316	316	295	326	184	339	331	324	323	337	346	327	393	378	342	400	365	369	376	373
	326	315	344	321	132	212	318	307	323	323	325	324	348	395	453	286	378	388	369	397
	303	327	308	316	185	119	320	327	341	323	332	337	373	393	308	393	401	371	379	358
	332	316	300	322	317	180	316	332	340	344	345	343	388	382	351	411	370	376	390	378
	320	322	345	315	367	137	308	315	324	333	349	324	380	395	365	395	391	378	386	361
	316	315	328	332	115	189	334	318	320	333	364	333	387	357	412	379	372	386	376	394
	325	321	290	319	183	333	298	319	334	343	347	358	394	388	368	391	362	391	399	381
	309	334	317	306	134	187	345	307	356	367	362	364	350	410	395	353	373	389	359	396
	329	305	315	327	192	132	336	320	369	362	363	358	423	415	353	414	371	397	370	373
	318	307	358	331	315	186	288	328	371	369	363	368	398	407	434	409	366	379	392	366
	311	306	284	326	328	131	346	319	381	348	350	339	398	420	379	405	384	362	399	367
	303	339	307	312	316	321	326	314	352	359	360	365	431	346	405	423	375	375	373	368
	332	334	309	318	128	208	325	322	349	367	355	350	428	406	455	426	374	369	389	378
	317	306	336	312	191	313	304	321	371	360	352	358	328	400	381	339	366	375	385	369
	317	323	335	318	129	130	327	315	363	349	344	357	405	433	406	395	375	374	376	391
	301	309	302	326	193	306	317	334	352	363	328	351	417	413	323	419	380	377	362	356
	315	309	356	315	339	199	327	314	366	351	348	363	415	441	425	411	356	378	387	382

	300	321	302	328	313	330	317	302	349	360	346	326	381		418	389	362	363		379
	343	328	288	321	127	305	290	330	350	344	356	337	413		386	407	362	379		359
	298	325	319	324	175	320	308	296	364	324	356	353	414		403	418	374	374		354
	329	316	373	329	330	317	318	328	323	349	349	329			412	393.4848	367	358		361
	328	321	326	319	319	324	309	303	337	344	345	371				30.26458	376.44122	356		384
	335	324	324	328	330	322	345	321	348	345	352	345				0.076914	12.06847	372		356
	337	324	289	319	317	308	286	317	333	360	335	356					0.032059	370		
		310	350		305	309	350	311	393	346	351	343						364		
		311	297		330	316	282	314	363	353	351	351						379.4211		
		321	329		314	308	321	303	346	345		338						11.44819		
		328	328		339	332	324	298	355	335		353						0.030173		
		330	291		309	303	309		347	355										
		327	325		300	329			348											
		324	319		328	306			334											
			335		302	315														
			327		324	303														
			323		312	311														
					317	290														
					316															
					306															
					310															
					311															
					144															
					170															

																270	106		84	
																295	185		212	
																285	150		82	
																294	137		211	
																47	106		279	
																235	185		283	
																46	106		69	
																5	281		224	
																241	289		51	
																46	179		237	
																243	100		302	
																48	173		68	
																5	102		286	
																241	177		82	
																263	107		280	
																307	180		71	
																44	107		280	
																228	280		82	
																45	281		262	
																5	174		95	
																217	97			
																62				
																5				
																235				
																52				
																251				
																256				
																290				
																45				
																123				
MEAN	321.2973	320.7955	321.4468	320.9459	265.5926	260.6667	320	315.6585	347.3778	346.1429	347.1795	345.0244	387.6061	396.7667	395.6765	174.8966	180.5	383.9	291.5535	378.1667

STDEV	12.6773	8.732669	21.4616	6.9079 1	79.9715 8	74.71345	16.4557 8	10.25819	17.4464	13.74431	10.2312	13.4731	37.5898 4	27.7969	47.3412 6	114.2611	66.2962 2	10.4299	96.7172 5	14.37557
CV	0.039457	0.027222	0.066766	0.021524	0.301106	0.286624	0.05142 4	0.032498	0.005027 8	0.039707	0.002946 9	0.039051	0.009698	0.070059	0.011964 6	0.053307	0.036729 2	0.027168	0.052563 7	0.038014

Table 4.12: Heel Strike Interval, Toe Strike Interval, Mean, SD and CV of Parkinson's subjects

	PARK10 LEFT FOOT		PARK10 RIGHT FOOT		PARK11 LEFT FOOT		PARK11 RIGHT FOOT		PARK12 LEFT FOOT		PARK12 RIGHT FOOT		PARK13 LEFT FOOT		PARK13 RIGHT FOOT	
	HEEL STRIKE INTERVAL	TOE STRIKE INTERVAL	HEEL STRIKE INTERVAL	TOE STRIKE INTERVAL	HEEL STRIKE INTERVAL	TOE STRIKE INTERVAL	HEEL STRIKE INTERVAL	TOE STRIKE INTERVAL	HEEL STRIKE INTERVAL	TOE STRIKE INTERVAL	HEEL STRIKE INTERVAL	TOE STRIKE INTERVAL	HEEL STRIKE INTERVAL	TOE STRIKE INTERVAL	HEEL STRIKE INTERVAL	TOE STRIKE INTERVAL
	281	353	264	294	213	276	301	180	380	339	343	329	336	328	345	330
	301	146	286	301	69	282	314	122	364	319	325	330	326	366	326	333
	268	306	288	280	242	338	286	189	293	342	339	348	322	317	333	320
	301	292	279	292	54	260	316	103	350	346	345	329	341	292	331	334
	314	329	208	273	302	343	315	257	329	326	326	338	334	381	319	334
	303	46	83	298	350	200	289	335	376	339	340	333	328	275	326	318
	282	253	134	294	205	298	301	216	295	332	334	330	339	332	347	331
	311	316	149	284	74	218	342	67	330	326	325	331	333	330	329	330
	293	299	248	279	235	260	292	242	332	332	328	322	341	328	341	319
	288	50	196	296	71	310	227	66	319	325	332	333	324	314	347	337
	297	246	165	285	228	304	361	233	337	332	323	339	324	391	321	328
	278	297	233	301	62	285	238	62	333	333	335	348	330	285	329	329
	317	50	133	291	248	294	381	248	393	350	355	334	335	325	322	330
	288	240	289	294	63	312	200	113	331	346	341	331	344	320	329	320
	281	309	137	286	330	294	285	276	294	319	325	328	343	299	340	316
	286	285	128	274	239	273	296	242	323	333	329	329	339	337	343	335
	304	48	297	297	61	289	291	53	336	325	331	324	343	336	355	337
	287	247	146	279	227	233	289	279	320	324	319	320	321	361	324	337

	294	301	104	292	364	343	291	319	327	325	328	333	343	323	338	342
	292	297	193	293	230	208	221	232	325	344	340	343	319	360	314	319
	281	35	84	282	64	209	346	62	360	343	348	347	343	317	325	345
	274	243	204	291	237	307	237	239	349	356	351	320	331	384	323	313
	302	286	123	287	56	294	228	114	383	335	340	332	342	290	345	312
	297	42	174	288	226	273	294	168	320	324	319	339	336	339	334	341
	301	6	114	289	61	282	290	61	333	328	329	331	326	298	340	335
	296	244	169	282	318	322	290	314	298	338	338	348	323	344	332	335
	260	53	125	285	216	375	289	220	329	338	351	350	324	314	306	340
	287	238	279	286	82	317	296	73	348	356	346	328	324	361	321	319
	302	50	156	285	201	257	376	210	399	344	339	327	326	336	325	322
	294	244	128	288	74	343	337	116	286	329	325	342	339	329	330	324
	287	53	170	289	215	320	223	292	326	331	337	321	334	289	325	325
	290	244	141	286	280	219	328	220	379	331	328	329	331	328	327	326
	288	39	244	299	289	346	210	230	323	326	326	347	335	321	332	322
	262	5	210	276	87	252	286	77	285	333	335	349	332	330	313	338
	302	245	163	292	206	307	293	216	347	336	336	347	329	311	332	311
	263	269	135	277	68	353	214	111	345	336	355	339	331	352	327	330
	281	46	133	283	224	267	285	246	355	344	337	348		351	338	328
	317	251	271	286	299	222	285	292	385	347	347	344		297	339	337
	263	47	299	289	281	253	282	223	357	345	349	338		325	316	333
	286	254	304	280	89	252	291	80	302	336	344	321		348	325	330
	295	290	136	282	209	349	367	218	343	351	340	338		365	329	324
	308	51	148	273	78		379	70	339	316	340	318		319		315
	260	242	134		200		327	208	318	319	325	323		293		340
	293	56	147		68		338	103	334					373		
	296	232	141		219		335	258	331					278		
	284	275	107		319			245	321							
	262	298	181		80			80								
	317	286	134		241			241								

	274	52	295		82			78									
	270	236	248		231			235									
		46	284		64			57									
		5	285		227			295									
		248	183		321			260									
		40	101		75			125									
		237	180		215			225									
		51	150		291			365									
		238	137		306			172									
		270	106		84			74									
		295	185		212			222									
		285	150		82			76									
		294	137		211			279									
		47	106		279			279									
		235	185		283			221									
		46	106		69			65									
		5	281		224			228									
		241	289		51			80									
		46	179		237			308									
		243	100		302			202									
		48	173		68			66									
		5	102		286			288									
		241	177		82			79									
		263	107		280			283									
		307	180		71			136									
		44	107		280			215									
		228	280		82			79									
		45	281		262			265									
		5	174		95			92									
		217	97														

		62														
		5														
		235														
		52														
		251														
		256														
		290														
		45														
		123														
MEAN	289.16	174.896	180.5	287.0952	184.4935	286.3171	294.7111	186.8974	336.5652	335.4348	336	334.3721	332.5278	328.7111	330.3171	328.4651
STDEV	15.49372	114.26116	66.29622	7.433364	96.71725	44.85947	46.22309	87.59004	28.02273	10.15026	9.658453	9.476847	7.469887	28.82283	10.3548	8.899836
CV	0.053582	0.653307	0.367292	0.025893	0.525637	0.156678	0.156842	0.468655	0.083261	0.03026	0.028745	0.028342	0.022464	0.087684	0.031348	0.027095

Table 4.13: Heel strike interval, toe strike interval, Mean, SD and CV of Control subjects

	CONT1 LEFT FOOT		CONT1 RIGHT FOOT		CONT2 LEFT FOOT		CONT2 RIGHT FOOT		CONT3 LEFT FOOT		CONT3 RIGHT FOOT		CONT4 LEFT FOOT		CONT4 RIGHT FOOT	
	HEEL STRIKE INTERVAL	TOE STRIKE INTERVAL	HEEL STRIKE INTERVAL	TOE STRIKE INTERVAL	HEEL STRIKE INTERVAL	TOE STRIKE INTERVAL	HEEL STRIKE INTERVAL	TOE STRIKE INTERVAL	HEEL STRIKE INTERVAL	TOE STRIKE INTERVAL	HEEL STRIKE INTERVAL	TOE STRIKE INTERVAL	HEEL STRIKE INTERVAL	TOE STRIKE INTERVAL	HEEL STRIKE INTERVAL	TOE STRIKE INTERVAL
	327	334	322	378	320	316	312	315	335	341	353	334	306	308	303	319
	319	324	322	355	319	316	311	313	342	344	343	339	301	300	300	315
	319	324	314	347	314	310	315	312	341	339	333	336	303	304	308	303
	318	342	318	352	313	309	314	313	313	343	347	331	304	303	301	302
	311	328	312	357	313	313	314	316	324	334	339	328	305	305	302	304
	325	315	331	358	318	310	308	312	313	326	324	330	316	306	308	306
	314	318	320	345	309	310	310	314	342	334	335	333	303	310	312	310
	310	315	317	349	312	308	311	310	330	338	328	322	319	315	313	313
	307	331	313	354	314	316	314	311	335	333	340	336	321	311	318	315
	314	309	313	351	309	311	315	308	326	331	340	325	306	313	298	315
	316	326	306	351	309	314	307	316	337	324	322	339	322	310	319	309

	318	309	315	368	315	309	304	312	329	337	329	328	302	319	308	319
	313	312	318	346	312	308	306	307	340	332	337	337	316	312	317	313
	316	311	311	340	306	309	312	308	332	328	328	331	303	315	312	309
	312	312	307	349	306	308	310	311	326	327	334	336	303	309	298	305
	311	310	320	350	304	311	309	310	327	320	303	331	307	302	318	305
	314	315	318	331	313	310	307	310	334	338	344	330	316	315	326	303
	310	311	311	349	308	307	314	307	330	334	307	326	307	320	312	311
	315	321	314	338	313	315	305	310	356	334	339	330	322	304	300	319
	316	312	304	343	306	310	312	311	333	326	358	334	309	308	312	315
	319	327	318	345	309	305	309	308	316	334	302	324	304	304	309	311
	327	287	319	334	307	309	308	308	321	332	358	329	315	306	300	306
	320	312	321	365	312	306	306	308	319	330	335	331	301	314	316	310
	321	311	323	370	308	311	306	307	332	329	309	324	316	316	315	301
	308	310	321	342	309	314	307	306	327	327	351	325	305	304	300	310
	316	319	311	338	306	308	312	305	331	320	327	330	313	306	316	312
	313	317	309	336	303	306	308	314	332	329	319	338	309	310	301	315
	320	326	319	335	308	315	311	306	320	319	323	329	306	308	315	308
	325	320	308	341	315	314	310	312	320	318	320	329	306	305	304	302
	319	317	308	339	315	308	311	315	322	324		329	308	310	309	311
	314	316	310	327	310	314	314	306	330	334		330	307	312	312	306
	307	309	315	347	317	312	312	320	338	330		338	312	307	309	302
	305	314	324	327	306	308	312	306	326	330		325	306	312	308	319
	318	309	319	328	313	305	307	314	327	323		332	319	302	304	305
		314	317	340	308	306	309	307	339	319		336	298	307	309	314
		301	305	350	308	311	308	308	324	326		337	305	315	310	302
		318	310	335	309	308	307	308	339	323			314	319	306	303
		334	309	345	310	312	310	307	336	339			313	303	306	314
		306	310	352	315	315	308	311	332	329			315	312	309	315
		318	309	344	317	317	313	307	343	325			304	311	312	312
		303		338	319		314	314	346	329			316	308	303	309
		314		335	316			314		342			303	306	307	311
		307						317		323			310	307	307	311
		315								342			309	317	313	304
		308								331			319	319	315	310
										338			318	310	309	321
										345			323	311		314
										346						319
																315
																310.2449
ME	315.79	316	314.77	345.80	311.2619	310.6	310.0488	310.5581	330.8537	331.2292	331.9655	331.1667	309.8936	309.57	308.8913	5.5209

AN	41		5	95										45		1
STDEV	5.580156	9.661545	6.044652	11.35296	4.367617	3.364978	2.999593	3.607547	9.180308	7.444088	15.16218	4.69346	6.699234	5.089395	6.32887	0.017795
CV	0.017667	0.030575	0.019203	0.032812	0.014032	0.010834	0.009675	0.011616	0.027747	0.022474	0.045674	0.014173	0.021618	0.016444	0.020489	

Table 4.14: Heel strike interval, toe strike interval, Mean, SD and CV of Control subjects

	CONT5 LEFT FOOT		CONT5 RIGHT FOOT		CONT6 LEFT FOOT		CONT6 RIGHT FOOT		CONT7 LEFT FOOT		CONT7 RIGHT FOOT		CONT8 LEFT FOOT		CONT8 RIGHT FOOT	
	HEEL STRIKE INTERVAL	TOE STRIKE INTERVAL	HEEL STRIKE INTERVAL	TOE STRIKE INTERVAL	HEEL STRIKE INTERVAL	TOE STRIKE INTERVAL	HEEL STRIKE INTERVAL	TOE STRIKE INTERVAL	HEEL STRIKE INTERVAL	TOE STRIKE INTERVAL	HEEL STRIKE INTERVAL	TOE STRIKE INTERVAL	HEEL STRIKE INTERVAL	TOE STRIKE INTERVAL	HEEL STRIKE INTERVAL	TOE STRIKE INTERVAL
	329	326	326	330	298	300	297	292	290	300	295	298	299	308	327	312
	330	330	330	327	296	309	305	302	301	307	301	299	317	320	294	310
	325	329	331	328	301	300	301	305	290	307	302	289	275	303	332	308
	320	330	327	327	290	290	290	297	299	304	301	303	256	319	299	320
	326	328	328	332	299	295	299	291	294	297	293	302	365	319	324	308
	330	327	329	327	298	296	295	302	294	300	301	306	313	298	315	310
	313	329	326	329	295	298	296	294	305	305	297	301	397	320	300	316
	331	319	323	318	304	293	295	292	291	306	291	295	315	316	329	322
	329	324	326	329	289	298	301	296	294	296	292	302	289	313	299	309
	317	328	326	326	295	297	294	296	295	295	298	292	355	311	321	316
	323	320	333	330	294	294	295	303	299	301	296	295	343	307	310	317
	321	321	317	326	280	300	296	306	299	294	299	294	255	316	316	316
	328	320	322	320	319	296	299	300	294	291	295	301	310	311	321	313
	319	322	321	320	310	303	306	300	294	292	295	297	250	323	310	315
	321	324	324	321	297	299	295	299	298	307	295	291	346	310	320	316
	320	324	322	322	305	309	309	297	298	294	302	297	221	320	303	317
	313	315	325	323	297	305	303	306	296	296	296	295	381	319	326	318
	313	318	311	323	312	308	306	298	298	293	298	298	336	320	326	308
	317	314	318	313	320	292	295	300	292	294	293	300	376	314	321	314
	307	307	317	314	312	302	306	300	295	302	294	295	300	311	325	322
	308	308	302	315	306	304	301	301	302	296	300	294	299	322	296	321
	309	309	307	306	298	289	301	303	305	301	299	295	362	321	326	312
	323	311	305	307	286	300	301	296	295	288	299	302	282	300	309	312
	308	317	308	306	300	305	306	299	305	300	291	310	285	300	326	315
	313	309	314	306	321	302	301	301	295	301	290	305	334	312	324	307

	310	312	315	316	300	300	295	301	288	304	299	299	295	309	295	305
	305	306	311	313	311	290	298	299	297	302	290	304	339	309	288	310
	312	309	311	312	276	299	305	297	292	299	298	297	289	311	300	315
	325	310	305	307	326	298	302	305	297	292	290	290	317	313	320	314
	316	304	312	308	274	304	296	291	302	288	293	288	283	318	309	300
	320	317	306	310	321	308	299	297	294	298	291	297	319	304	301	307
	323	311	306	304	304	289	288	306	296	290	294	296	321	301	309	309
	314	310	316	315	292	299	297	297	302	300	298	292	239	313	320	305
	308	318	310	311	308	290	301	302	291	286	294	292	310	300	309	302
	327	320	311	317	301	298	299	300	297	297	295	292	391	307	317	303
	317	312	317	331	301	303	292	294	298	288	300	293	283	303	294	305
	317	315	322	318	289	289	324	300	288	292	293	291	316	306	319	308
	320	320	311	314	289	294	294	306	290	300	293	303	264	304	293	318
	315	319	314	319	299	307	303		297	298	300	293	248	315	303	304
	314	316	322	317	280	292			308	290	296	297	186	306	309	303
	317	320	321	317	292	296			300	302	299	295	355	295	293	310
	325	313	318	313	316	303			292	296	295	294	302	297	303	
	323	318	317	320	298	301			302	288	295	291	299	304	307	
	322	316	310	316	294	296			294	288		292	277	314	317	
		322	319	317	277	299				304		306			305	
		327	318	322	319					306		303			298	
		323	324	307	274					297		292			289	
			324	322	317					297		304			309	
			325		278					298		290			311	
MEAN	318.7045	318.0213	318.0204	318.1458	299.1429	298.6444	299.641	299.2368	296.4318	293	295.9535	296	306.6818	310.5	310.551	311.5122
STDEV	7.056515	7.106303	7.867363	7.803408	13.35415	5.649439	6.23862	4.245406	4.766149	297.2	3.518343	296.86	45.32147	7.586708	12.03651	5.749443
CV	0.022141	0.022345	0.02474	0.024528	0.044641	0.018917	0.02082	0.014187	0.016078	5.799367	0.011888	5.174545	0.147627	0.024434	0.038703	0.018457

Table 4.15: Heel Strike Interval, Toe Strike Interval, Mean, SD, and CV of Control Subjects

	CONT9 LEFT FOOT		**CONT9 RIGHT FOOT**		**CONT10 LEFT FOOT**		**CONT10 RIGHT FOOT**		**CONT11 LEFT FOOT**		**CONT11 RIGHT FOOT**		**CONT12 LEFT FOOT**		**CONT12 RIGHT FOOT**		**CONT13 LEFT FOOT**		**CONT13 RIGHT FOOT**	
	HEEL STRIKE INTERVA	**TOE STRIKE INTERVAL**	**HEEL STRIKE INTERVA**	**TOE STRIKE INTERVAL**	**HEEL STRIKE INTERVA**	**TOE STRIKE INTERVAL**	**HEEL STRIKE INTERVA**	**TOE STRIKE INTERVAL**	**HEEL STRIKE INTERVA**	**TOE STRIKE INTERVAL**	**HEEL STRIKE INTERVA**	**TOE STRIKE INTERVAL**	**HEEL STRIKE INTERVA**	**TOE STRIKE INTERVAL**	**HEEL STRIKE INTERVA**	**TOE STRIKE INTERVAL**	**HEEL STRIKE INTERVA**	**TOE STRIKE INTERVAL**	**HEEL STRIKE INTERVA**	**TOE STRIKE INTERVAL**

	L		L		L		L		L		L		L		L		L		L	
	348	333	342	337	320	341	354	344	313	343	350	349	457	452	492	465	324	338	331	325
	339	340	333	345	330	348	364	345	339	334	279	329	425	436	430	451	342	338	323	328
	333	337	339	339	333	342	349	321	334	345	344	345	445	464	502	458	322	332	323	334
	331	326	328	325	329	315	289	323	347	341	349	350	447	464	488	442	340	328	335	329
	326	336	333	327	332	322	336	339	401	344	342	331	442	431	414	456	343	338	326	335
	340	326	325	338	331	334	339	348	333	331	325	333	439	442	488	443	332	327	324	323
	336	334	334	324	327	318	353	322	331	334	338	339	415	449	459	444	323	343	328	334
	346	325	328	323	324	324	342	326	331	341	383	344	441	459	411	453	337	322	330	329
	324	335	328	344	324	334	300	330	363	321	317	351	412	440	449	439	339	334	336	332
	337	338	343	320	332	325	369	332	393	337	388	314	411	441	482	449	322	321	321	330
	339	338	337	350	334	348	293	330	364	338	313	327	428	449	436	452	332	332	335	331
	335	328	324	339	321	330	349	352	337	342	323	340	415	441	451	425	333	328	321	337
	350	334	341	322	321	338	334	346	275	331	343	338	429	418	423	419	326	337	332	323
	337	337	333	334	324	334	303	340	372	333	288	343	414	427	452	417	335	343	328	327
	337	327	328	328	322	328	295	331	347	332	339	329	434	417	453	431	335	327	317	327
	327	334	352	346	327	342	334	319	336	321	336	322	441	433	418	414	339	327	330	322
	338	328	354	346	328	333	358	334	290	340	317	326	426	404	480	426	335	332	313	319
	342	339	333	327	325	328	331	344	325	330	386	317	406	426	425	415	322	327	320	316
	343	341	330	336	324	314	322	326	372	336	308	334	455	439	404	447	335	322	328	325
	345	344	338	340	326	345	341	328	325	331	289	319	423	427	430	434	324	317	320	330
	330	327	345	341	330	318	339	318	272	329	375	337	431	429	452	413	326	324	316	321
	342	339	339	333	325	325	322	343	333	323	278	334	428	421	410	437	321	328	324	317
	344	332	329	337	328	336	320	313	327	340	330	337	419	448	430	438	313	316	320	314
	331	342	339	327		315	317	339	328	329	338	333	409	436	418	430	318	311	327	324
	336	332	331	338		321	346	324	383	340	334	329	420	416	398	415	317	319	317	331
	330	325	345	334		336	329	325	285	340	330	330		416	481	411	324	324	324	318
	335	335	345	343		343	338	313	381	338	327	327		415	421	411	311	327	329	329
	333	344	336	326		337	317	348	329	337	381	345		417	436	418	322	326	322	316
		328	340	334		320	297	344	281	346	284	337		413	398	421	311	326	330	329
		325	33	344		310	32	325	32	341	28	325			46		31	326	33	332

			2				9		9		1				9		4		3	
		332	340	341		327	359	313	397	339	367	325					328	317	317	325
		335	337	341		330	354	318	289	322	331	334					328	332	313	326
		328	346	317		319	304	331	329	324	340	345					325	332	326	319
		337	330	332		320	350	321	373	329	290	339					329	321	330	331
		326	327	344		347	327	328	285	332	341	343					309	327		328
		334	333	338		323	316	324	392	328	340	337					340	314		333
		336	336	330		336	340	333	287	334	325	317					326	343		
			342	340		325	332	341	343		327	329					325	316		
			336	333		319	334	322	383		379	327					324	335		
			333	331		329	319	322	320		332	336					331			
			328	337		323	376	330	330		277	328					315			
			338				377	325	326		330	324					331			
								335	333								329			
									330											
MEAN	337	333.4324	335.9524	334.9024	326.8261	329.3171	333.2619	330.5814	336.2045	334.4865	428.488	333.2857	428.488	433.4483	443.3333	433.5862	326.907	327.6154	324.9706	326.3611
STDEV	6.63843 2	5.64476 4	7.02591 9	8.01500 1	4.07489 2	10.2553 4	22.3509 3	10.5339 2	34.4015 8	6.94670 8	14.4658 2	9.23747 9	14.4658 2	15.9990 8	30.5944 9	16.2667 9	8.88501 7	8.16157 7	6.29326 4	5.98165 2
CV	0.01969 9	0.01692 9	0.02091 3	0.02393 2	0.01246 8	0.03114 1	0.06706 7	0.03186 5	0.10232 3	0.02076 8	0.03376 1	0.02771 6	0.03376 1	0.03691 1	0.06901	0.03751 7	0.02717 9	0.02491 2	0.01936 6	0.01832 8

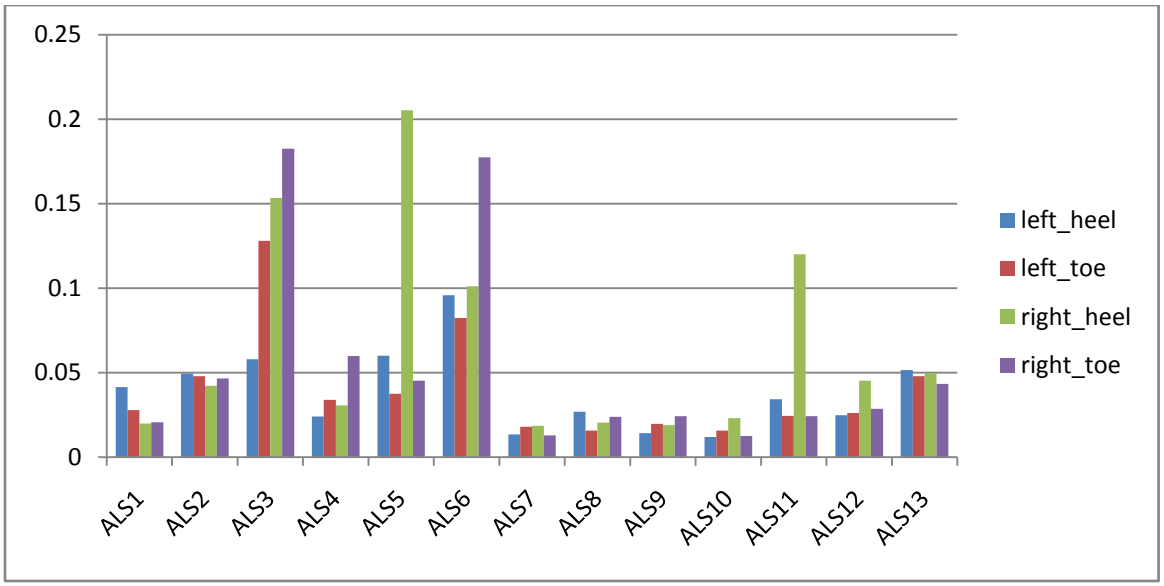

Figure 4.1: CV of ALS Subjects

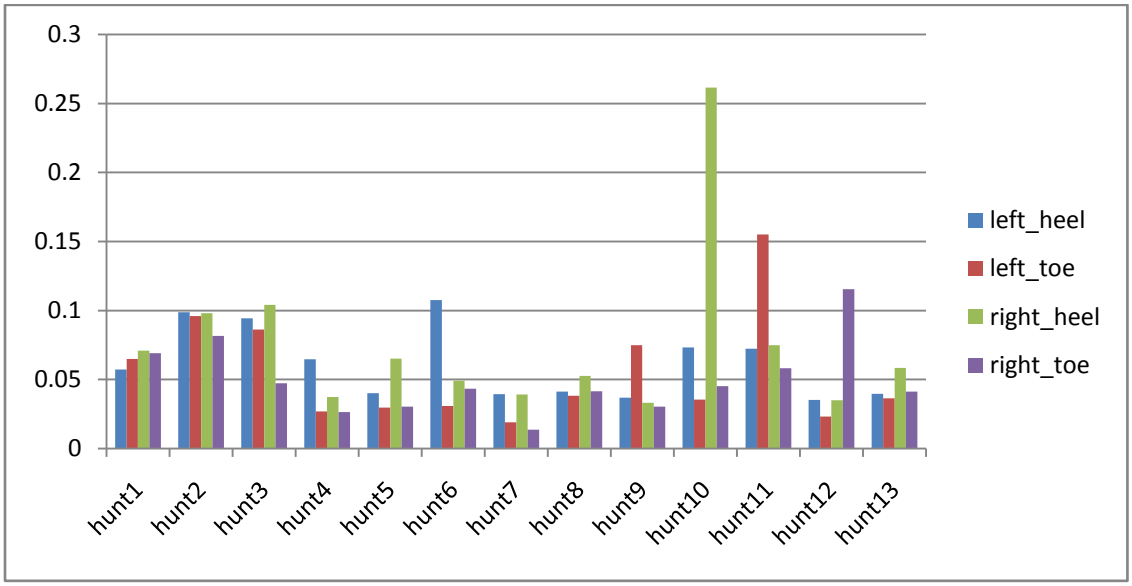

Figure 4.2: CV of Huntington's Subjects

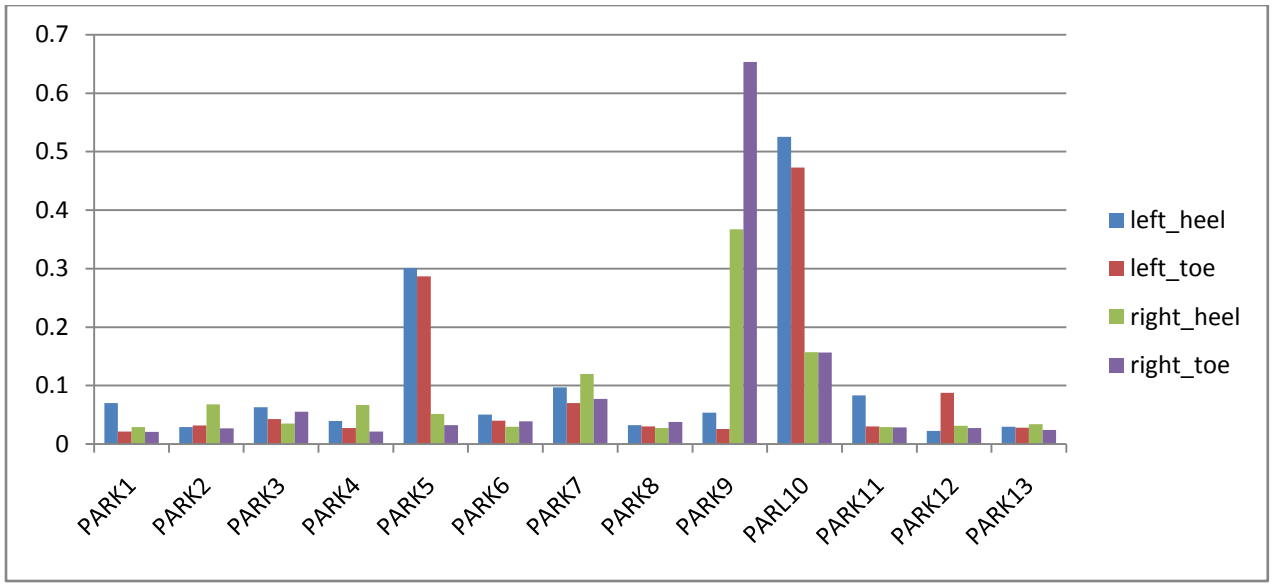

Figure 4.3: CV of Parkinson's Subjects

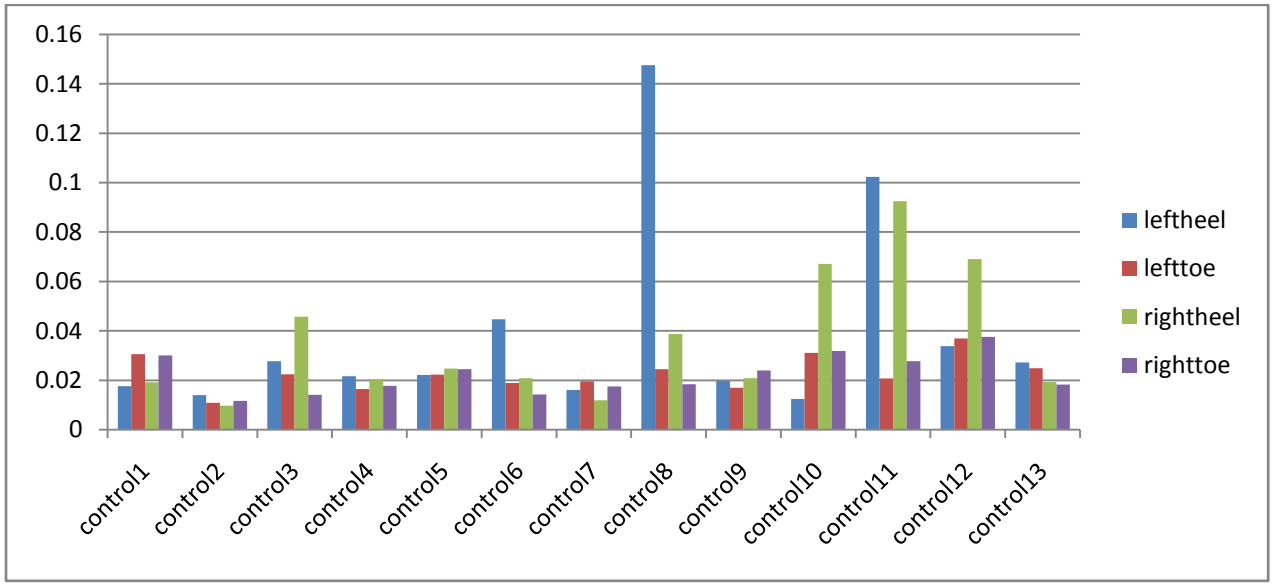

Figure 4.4: CV of Control Subjects

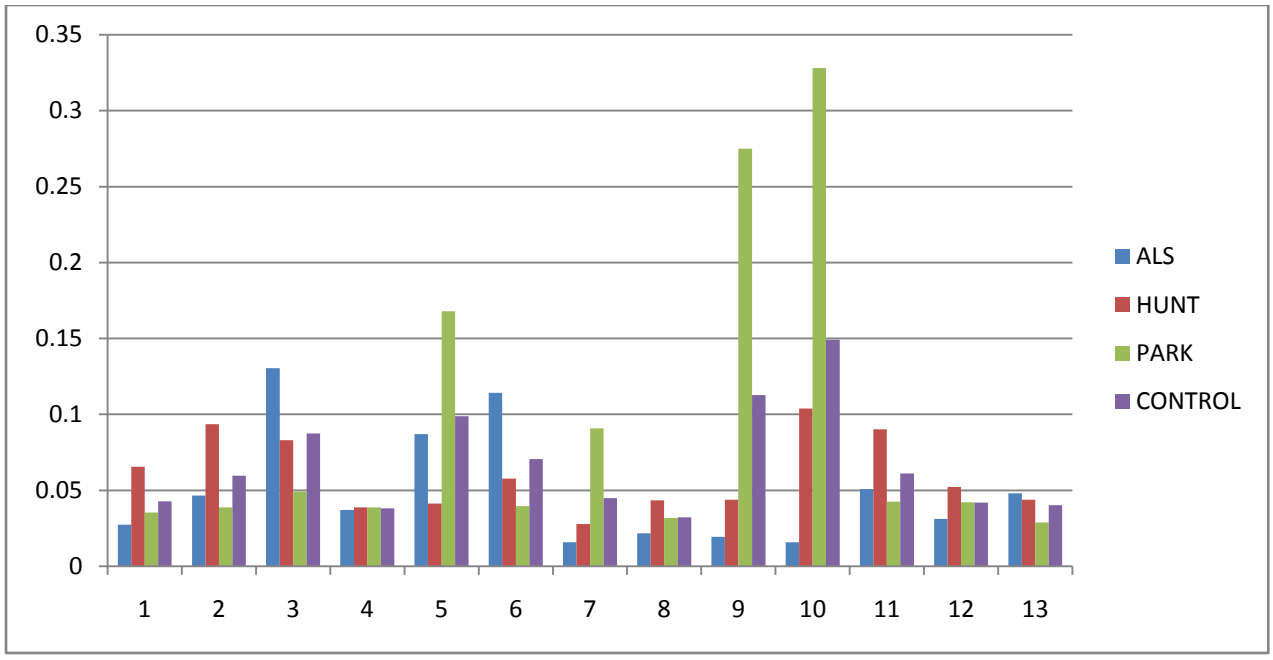

Figure 4.5 Average CV of ALS, Huntington's, Parkinson's and Control Subjects

As we can see from table 1, 2, 3, 4, and bar graph, the CV of patients suffering from neuro-degenerative diseases is higher than control subjects. None of the four features namely CV of left foot heel strike, CV of the left foot toe strike, similarly CV of the right foot heel strike and CV of the right foot toe strike interval can be used in isolation for classification based on threshold method. Classifier was designed to classify with good accuracy.

4.2 Classification Results

Classification of neuro-degenerative disease subjects and healthy control was done in three phases:

4.2.1 Phase 1

In first phase, we classify normal and neuro-degenerative disease. Since we have 13 normal subjects and 39 neuro-degenerative disease subjects, the input training data will have 52 samples. Each sample has 4 features, namely CV of left foot heel strike, CV of the left foot toe strike, similarly CV of the right foot heel strike and CV of the right foot toe strike interval. The target training data is given 0 for normal subjects and 1 for neuro-degenerative diseases.

The ANN gave classification accurately of 94%. If we frame a question “Is the person suffering from neuro-degenerative disease?” The answer may be yes or no. the confusion matrix is given by:

Table 4.16: Confusion Matrix

	Predicted	
Actual	Yes (TP)	No (FN)
	No (FP)	Yes (TN)

We define:

Accuracy = (TP+TN) / (TP+TN+FP+FN)

Sensitivity= (No. of TP) / (No. of TP + No. of FN)

Specificity= (No. of TN) / (No. of TN) + (No. of FP)

TP= True Positive; TN= True Negative; FP= False Positive; FN= False Negative

Table 4.17: Confusion Matrix for phase 1

	Predicted	
Actual	36 (TP)	3 (FN)
	0 (FP)	13 (TN)

Accuracy = 94%; Sensitivity= 92%; Specificity= 100%

5.2.2 Phase 2

In second phase, we further classify neuro-degenerative diseases into Parkinson’s disease and Non-Parkinson’s disease. Since we have 13 normal subjects and 26 neuro-degenerative disease subjects. the input training data will have 39 samples. Each sample has 4 features, namely CV of left foot heel strike, CV of the left foot toe strike, similarly CV of the right foot heel strike and

CV of the right foot toe strike interval. The target training data is given 0 for Parkinson's subjects and 1 for Non-Parkinson's subjects.

The ANN gave classification accurately of 100%. If we frame a question "Is the person suffering from Parkinson's disease?" The answer may be yes or no. the confusion matrix is given by:

Table 4.18: Confusion Matrix for phase 2

	Predicted	
Actual	13 (TP)	0 (FN)
	0 (FP)	26 (TN)

Accuracy = 100%; Specificity= 100%; Sensitivity= 100%

5.2.3 Phase 3

In third phase, finally we classify neuro-degenerative diseases into Huntington's disease and ALS disease. Since we have 13 normal subjects and 13 neuro-degenerative disease subjects, the input training data will have 26 samples. Each sample has 4 features, namely CV of left foot heel strike, CV of the left foot toe strike, similarly CV of the right foot heel strike and CV of the right foot toe strike interval. The target training data is given 0 for Huntington's subjects and 1 for ALS subjects.

The ANN gave classification accurately of 88%. If we frame a question "Is the person suffering from Huntington's disease?" The answer may be yes or no. the confusion matrix is given by:

Table 4.19: Confusion Matrix for phase 3

	Predicted	
Actual	12 (TP)	1 (FN)
	2 (FP)	11(TN)

Accuracy = 88%; Sensitivity= 92%; Specificity= 84%

CHAPTER 5: CONCLUSION AND FUTURE SCOPE

Neuro-degenerative disease includes Parkinson's disease, Huntington's disease and Amyotrophic Lateral Sclerosis. Electroencephalogram (EEG) is commonly used physiological parameter for detection of Epilepsy [37]. In addition to epilepsy, PD and HD can also be detected using EEG [38]. Interestingly analysis of human gait can also be used for detection of PD, HD, and ALS. This is done based on the fact that People suffering from neuro-degenerative diseases face gait problem. Freezing of gait, shuffling gait, taking small steps etc. are the most disabling and distressing symptoms of these diseases. Researchers have done some research related to significance of gait. Foot pressure was measured by placing ultrathin force sensitive switches inside each subject's shoe. All the readings were taken manually and the left and right stride interval calculated from this data. Mean, Standard deviation and Coefficient of Variability (CV) of Parkinson's disease patient, Huntington's disease and Amyotrophic Lateral Sclerosis were compared with healthy control. The process of manually calculating stride interval is very time consuming and error prone task. It is therefore proposed that Automatic detection of heel and toe strikes and calculation of heel and toe strike interval be done using computational technique. After detecting heel and toe strikes for neuro-degenerative disease patients, the strike time shall be compared with healthy control. Additional features like coefficient of variation, mean, standard deviation etc. will also be derived automatically for patients suffering from neuro-degenerative diseases and healthy control. CV of left foot heel strike, CV of the left foot toe strike, similarly CV of the right foot heel strike and CV of the right foot toe strike interval can be used in isolation for classification based on threshold method. An intelligent classifier was designed to:

1. Classify normal and neuro-degenerative disease subjects.
2. Classify neuro-degenerative diseases into Parkinson's disease and Non-Parkinson's disease.
3. Classify neuro-degenerative diseases into Huntington's disease and ALS disease.

Thus we conclude that the four features extracted from the gait, namely CV of left foot heel strike, Left foot toe strike, Right foot heel strike, Right foot toe strike are sufficient for

ANN based Classifier. Classification was done in three phases. First phase includes normal and neuro-degenerative disease, second phase includes Parkinson's disease and non-Parkinson's disease and third phase includes HD and ALS. Multi-class classifier may also be designed to classify into single phase.

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PUBLICATIONS FROM THIS RESEARCH

1. Mandeep Singh, Mooninder Singh, Paramjeet, "Neuro-degenerative disease diagnosis using human gait: a review, *"International Journal of Information Technology and Knowledge management"*, vol. 7, no. 1, December, 2013 [in press]

2. Mandeep Singh, Mooninder Singh, Paramjeet, "Computation of heel and toe strikes using Computer Aided Techniques", *International Journal of Information Technology and Knowledge management",* vol. 7, no.1, December 2013[in press]

3. Mandeep Singh, Mooninder Singh, Paramjeet, "Artificial Neural Network based classification of Neuro-Degenerative diseases using Gait features", *International Journal of Information Technology and Knowledge management",* vol. 7, no.1, December 2013 [in press]