Gait analysis, a review of a clinical dataset.

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Contents

Introduction:

Gait analysis has become an essential tool in the diagnosing and the monitoring of neurodegenerative disease progression. It is one of the many areas studied when checking for neurodegenerative diseases such as ALS and Parkinson's and Huntington's disease, as it contributes to an understanding of underlying deficits. Gait and mobility defects often prove to be the most devastating to those suffering to degenerative diseases and its analysis is clinically necessary to aid in the development of therapeutic responses. A standard gait analysis studies a full gait cycle, which includes foot progression angle, step length, step width and stride length. The data set selected had been collected by the Journal of Applied physiology in a study on the "Dynamic markers of altered gait rhythm in amyotrophic lateral sclerosis". (Hausdorff, 2000)F

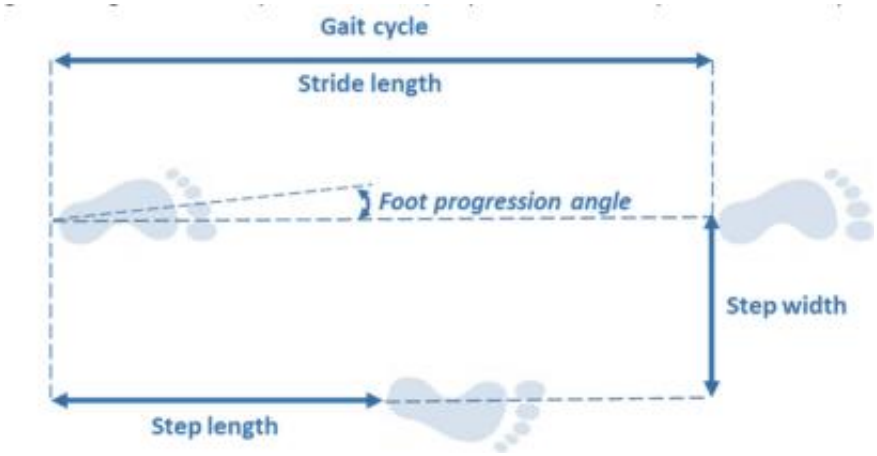

Figure 1: Gait cycle

Abstract

This study focuses on a specific gait dataset which recorded information from control subjects, along with Huntington's, Parkinson's, and ALS patients. This study was chosen due to the data it provided over the course of a gait cycle. This included left and right recordings of force from each foot which was recorded at a frequency of 300 Hz, stride intervals (seconds), swing intervals (seconds), swing intervals as a percentage stride, stance intervals (seconds), stance intervals as a percentage of stride and double support interval over time as well as a percentage of stride. These recording allowed for an assessment on the effect of the disease stat of the subject's gait asymmetry using force asymmetry and time asymmetry, these two metrics provide insight to the onset or progression of neurodegenerative diseases, as well as their prolonged physiological impacts. A study into nonlinear gait dynamics in neurological disease versus healthy control subjects where in which as Poincare plot was used to visualize this data, this highlights imbalances and discontinuities in a subject's recorded data. For this study, a MATLAB file was created to compare the different metrics of those suffering from Parkinson's and Huntington's disease as well as ALS versus control subjects, these results were then analyzed using already established research.

Data selection

This data set was selected due to the results that were provided that could provide a deeper insight into a neurodegenerative diseases progression and diagnosis. There were various Control, Huntington's, Parkinson's and ALS data sets provided and of these 5 were selected for analysis. This was to see how the results varied between different diseases through singular calculations, and by calculating averages. In this analysis it was important to select data that was recorded correctly, and accurately and that is why multiple

measurements were examined. To prevent data which would've impeded the analysis the waveforms were visualized using the data tool provided to check for outliers and inconsistent data.

The dataset as a whole was well balanced, where each subjects gender, weight and age were also known and in this study they were for the most part well balanced for consistency of results. The metric encompassed in the data sets allowed for insightful calculations to be made that give a clinician and patient a deeper insight into their condition, and also which would allow for greater knowledge in the diagnosis and treatment of these diseases. The following datasets were selected to be examined and reviewed.

Subject	Dataset	Dataset	Dataset	Dataset	Dataset
Control	3	1	13	16	5
Parkinson's	6	14	9	12	3
Huntington's	20	9	2	15	18
ALS	1	3	8	9	10

Figure 2: Selected subjects from dataset

Method:

The analysis consisted of 2 parts with three different tests. Firstly, gait asymmetry was checked using two methods – these being Force Asymmetry and time asymmetry. Following this nonlinear gait dynamics were checked using Poincare plot geometry, which are described using SD1 - short term variability and SD2 – long term variability. The data was imported into MATLAB using both the readmatrix () function for CSV files, and the fread(fopen()) functions (figure 3). The same method was used to import the time and force files for the 3 other data sets.

```
%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%
% IMPORT DATA

%PARKINSONS
%timestamps
park6data = readmatrix('park6.csv');%reads in time file
park14data = readmatrix('park14.csv');%reads in time file
park9data = readmatrix('park9.csv');%reads in time file
park12data = readmatrix('park12.csv');%reads in time file
park3data = readmatrix('park3.csv');%reads in time file
%force
%LEFT
left_forcepark9 = fread(fopen("park9.let")); % opens force file
left_forcepark3 = fread(fopen("park3.let")); % opens force file
left_forcepark14 = fread(fopen("park14.let")); % opens force file
left_forcepark12= fread(fopen("park12.let")); % opens force file
left_forcepark6 = fread(fopen("park6.let")); % opens force file

%read in
%RIGHT
right_forcepark9 = fread(fopen("park9.rit")); % opens force file
right_forcepark3 = fread(fopen("park3.rit")); % opens force file
right_forcepark14 = fread(fopen("park14.rit")); % opens force file
right_forcepark12= fread(fopen("park12.rit")); % opens force file
right_forcepark6 = fread(fopen("park6.rit")); % opens force file

%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%
```

Figure 3: Parkinson's data being read into MATLAB sheet.

Part one – The effect of disease state on gait asymmetry:

Gait asymmetry, or differences in the bilateral behaviour of the legs during walking, is thought to arise from limb dominance, disease, leg length discrepancies, and strength imbalances (Dain P. LaRoche, 2012). Testing gait asymmetry is one of the best measures to quantify the effects of a disease state on movement. In this review, the two aspects of gait asymmetry were investigated: force asymmetry and time asymmetry.

Force asymmetry:

In this particular experiment force sensors were placed in the patients' shoes. The subjects had to walk along a 77-meter hallway for 5 minutes. The force sensors in the shoes recorded values at a rate of 300 Hz and this allowed for both a calculation of the force applied to the ground with each step, but also the contact time of each stride.

Force asymmetry equation:

$$FA = \left| \frac{lf - rf}{rf} \right| \times 100$$

Where:

FA = Force Asymmetry

lf = left leg force

rf = right leg force

In order to carry out this calculation on MATLAB the average of the mean of the five imported datasets for left and right feet was completed to return the Force Asymmetry value. These equations are detailed in figure 4 and figure 5 respectively. The equation above was expressed as:

```
als_fa = (abs(als_avg_left_force-als_avg_right_force)/als_avg_right_force) *100
```

This example was a calculation of the force values for the ALS group, column 1 was specified when calling in the data to obtain the force values.

```
% FORCE ASYMMETRY
%PARKINSONS
%average force

%average forces left foot
lfp6 = mean(left_forcepark6(:,1));
lfp9 =  mean(left_forcepark9(:,1));
lfp14 =  mean(left_forcepark14(:,1));
lfp12 = mean(left_forcepark12(:,1));
lfp3 =  mean(left_forcepark3(:,1));

park_avg_left_force = mean([lfp3,lfp14,lfp12,lfp6,lfp9])

%average forces right foot
rfp6 = mean(right_forcepark6(:,1));
rfp9 =  mean(right_forcepark9(:,1));
rfp14 =  mean(right_forcepark14(:,1));
rfp12 = mean(right_forcepark12(:,1));
rfp3 =  mean(right_forcepark3(:,1));

park_avg_right_force = mean([rfp3,rfp14,rfp12,rfp6,rfp9])

%Calculate average force asymmetry
park_fa = (abs(park_avg_left_force-park_avg_right_force)/park_avg_right_force)*100;
```

Figure 4: Force Asymmetry calculation for Parkinson's

```
%CONTROL
%LEFT
con_avg_left_force = mean([lfcon5,lfcon13,lfcon1,lfcon16,lfcon3])
%RIGHT
con_avg_right_force = mean([rfcon5,rfcon13,rfcon1,rfcon16,rfcon3])

%Calculate average force asymmetry
con_fa = (abs(con_avg_left_force-con_avg_right_force)/con_avg_right_force)*100;
%Only finite and nonzero points
%con_fa(isinf(con_fa)|isnan(con_fa))=0;
%con_fa_mean = mean(con_fa)
%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%

%HUNTINGTONS
%LEFT
hunt_avg_left_force = mean([lfhunt20,lfhunt9,lfhunt2,lfhunt15,lfhunt18])
%RIGHT
hunt_avg_right_force = mean([rfhunt20,rfhunt9,rfhunt2,rfhunt15,rfhunt18])

%Calculate average force asymmetry
hunt_fa = (abs(hunt_avg_left_force-hunt_avg_right_force)/hunt_avg_right_force)*100;
%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%

%ALS
%LEFT
als_avg_left_force = mean([lfals1,lfals3,lfals8,lfals9,lfals10])
%RIGHT
als_avg_right_force = mean([rfals1,rfals3,rfals8,rfals9,rfals10])

%Calculate average force asymmetry
als_fa = (abs(als_avg_left_force-als_avg_right_force)/als_avg_right_force)*100
%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%
```

Figure 5: Force Asymmetry calculation for the Control, ALS and Huntington's groups

Time asymmetry:

Time asymmetry is defined by spending longer on one leg than another whilst in motion, therefore eh swing time of the opposite leg in step would be of a shorter duration. To estimate time asymmetry, the swing time (SW) can be calculated and averaged across strides for the left and right feet (SWL and SWR). A Positive asymmetry indicates step times or step lengths that are greater from slow-to-fast heel-strikes than fast-to-slow heel-strikes, and vice versa for negative asymmetry (Jan Stenum, 2020). Percentage gait asymmetry (GA) is quantitatively defined by (Yogev, 2007):

Time Asymmetry equation:

$$GA = \left|\ln\left(\frac{swr}{swL}\right)\right| \times 100$$

Where:

GA = Gait asymmetry

SWR = Swing time right

SWL = Swing time left

In MATLAB the time asymmetry was calculated with the equation being expressed as:

```
hunt15timeasym = abs(log (SWRhunt15./SWLhunt15))*100;
```

Were

Hunt15timeasym = Resulting Gait time asymmetry for the Huntington's dataset

SWR = Swing right time for the Huntington's group 15

SWL = Swing time left for the Huntington's 15 group

The snippet below (figure 6) shows the calculations and data used when carrying out the GA for time asymmetry. This specific snippet shows a calculation of control fives data, this process was carried out for each data set to obtain GA values. Columns 4 and five were read in for the left swing interval and right swing interval times respectively.

```
fprintf("control5")
%row 4
left_timecon5 = control5data(:,4);
SWLcon5 =(left_timecon5);
%right
%row 5
right_timecon5 = control5data(:,5);
SWRcon5 = (right_timecon5);
%time assymetry control 13
con5timeasym = abs(log(SWRcon5./SWLcon5))*100;
mean(con5timeasym)
```

Figure 6: GA time asymmetry calculation for control group 5

Part 2 - Nonlinear gait dynamics in neurological disease versus healthy controls:

Due to the nonlinear nature of disease states, it is crucial that when datasets are analyzed to quantify effects of a disease that they are examined in such a way that their linearity is also taken into account. When carrying out this experiment a Poincare plot was used to visualize the correlation between two consecutive data points in a time-series (Reem Satti, 2019). Poincare plots are frequently used to visualize non linear biological data such as heart rate and respiratory patterns (Mikkel Fishman, 2010), however they provide provide useful information regarding identification of gait characteristics due to balance impairments (Ahsan H Khandoker, 2008).

A Poincare plot (figure 7) can be generated by plotting one sample as a function of the previous sample (Goshvarpour, 2012). On a Poincare plot, the y-axis represents a variable time Xn+1, and the x-axis describes Xn. When making a Poincare scatter plot, two calculations must be carried out which make use of the data's standard deviation. First of all, the short-term variability (SD1) is the standard deviation o the Poincare plot perpendicular to the line-of-identity, while SD2 represents the standard deviation of the Poincare plot along the line-of-identity. The values for SD1 and SD2 create an ellipse on the Poincare plot which indicate if the analysed system is exhibiting periodic behaviour. In this experiment the data inputted to be examined was the Double support interval (seconds), this measurement is that of the amount of time at the moment when both feet are in contact with the ground between steps, this occurs twice during each gait cycle (m North American Society for Gait and Human Movement, 1993, 1994).

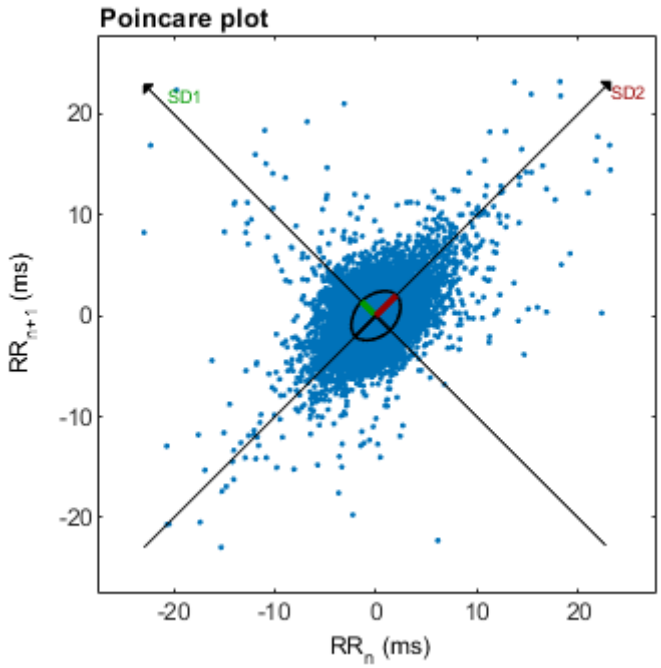

Figure 7: A Poincare plot displaying the roles of SD1 and SD2

The equations for SD1 and SD2 are as follows:

Short term variability SD1:

$$SD1 = \frac{\sqrt{2}}{2} \cdot SD(x_n - x_{n+1})$$

Where:

SD1 = Short term variability

SD = Standard deviation

X_n = X- axis data value

X_{n+1} = Y – axis data value

Long term variability SD2:

$$SD2 = \sqrt{2SD(x_n)^2 - \frac{1}{2}SD(x_n - x_{n+1})^2}^{-}$$

Were

SD2 = Short term variability

SD = Standard deviation

X_n = X- axis data value

X_{n+1} = Y – axis data value

A Poincare plot was generated on MATLAB using the data from the Double support interval, along with the SD1 and SD2 values. The methods as to how this was implemented can be seen in figure 8. The snippet below shows the calculations to find the values for the Parkinsons12 data specifically – reading in column 12 to access the double support interval values.

```
%Parkinsons
%SD1 shows short term variability
%park12scatter= park12data(:,12);

diff_data_park=abs((diff(park12data(:,12))));
diff_data_park;
sd1 = ((sqrt(2))/2)*(std(diff_data_park))
park12scatter= park12data(:,12);
sd2 = sqrt(2*std(park12scatter)^2)-(0.5*(std(diff_data_park)))

x= park12scatter(1:end-1);% takes "odd" values
y =park12scatter(2:end); % takes next "even" value

figure (3);

scatter(x,y,'b');
title('Parkinsons Poincare plot');
xlabel('Xn');
ylabel('Xn+1');
```

Figure 8: Calculations for SD1 and SD2 on MATLAB and creation on Poincare plots for Parkinsons12 data

On MATLAB, the expressions for SD1 and SD2 once the correct data was read in were:

```
sd1 = ((sqrt(2))/2) *(std(diff_data_als))
```

```
sd2 = sqrt(2*std(als9scatter) ^2)-(0.5*(std(diff_data_als)))
```

Results

Effect of disease state on gait asymmetry

The first part of this experiment comprised of the analysis of Gait asymmetry through two different methods – Force asymmetry and time asymmetry.

Force asymmetry:

Using MATLAB, the following Gait Force asymmetry was calculated.

Parkinson's	Left Mean	Right Mean
Dataset 6	125.14	139.18
Dataset 9	143.75	118.3
Dataset 14	129.82	140.45
Dataset 12	105.68	150.29
Dataset 3	136.21	112.91
Average	128.12	132.23

Figure 9: Parkinson's Force analysis

```
park_fa = (abs(park_avg_left_force-park_avg_right_force)/park_avg_right_force) *100;
```

Parkinson Asymmetry = 3.10%

Control	Left Mean	Right Mean
Dataset 5	143.15	131.89
Dataset 13	112.65	134.8
Dataset 1	112.5	112.58
Dataset 16	117.45	110.17
Dataset 3	118.15	113.43
Average	120.8	124.57

Figure 10: Control Force analysis

```
con_fa = (abs(con_avg_left_force-con_avg_right_force)/con_avg_right_force) *100;
```

Control Asymmetry = 9.36%

Huntington's	Left Mean	Right Mean
Dataset 20	122.85	136.66
Dataset 9	100.74	123.13
Dataset 2	112.47	122.69
Dataset 15	126.68	122.69
Dataset 18	117.11	122.5
Average	115.97	128.29

Figure 11: Huntington's force analysis

```
hunt_fa = (abs(hunt_avg_left_force-hunt_avg_right_force)/hunt_avg_right_force) *100;
```

Huntington force asymmetry = 10.99%

ALS	Left Mean	Right Mean
Dataset 1	140.05	161.92
Dataset 3	134.52	140.99
Dataset 8	156.65	157.74
Dataset 9	115.43	123.3

Dataset 10	152.36	109.68
Average	139.8	138.73

Figure 12: ALS Force analysis

```
als_fa = (abs(als_avg_left_force-als_avg_right_force)/als_avg_right_force) *100
```

ALS force asymmetry = 10.47%

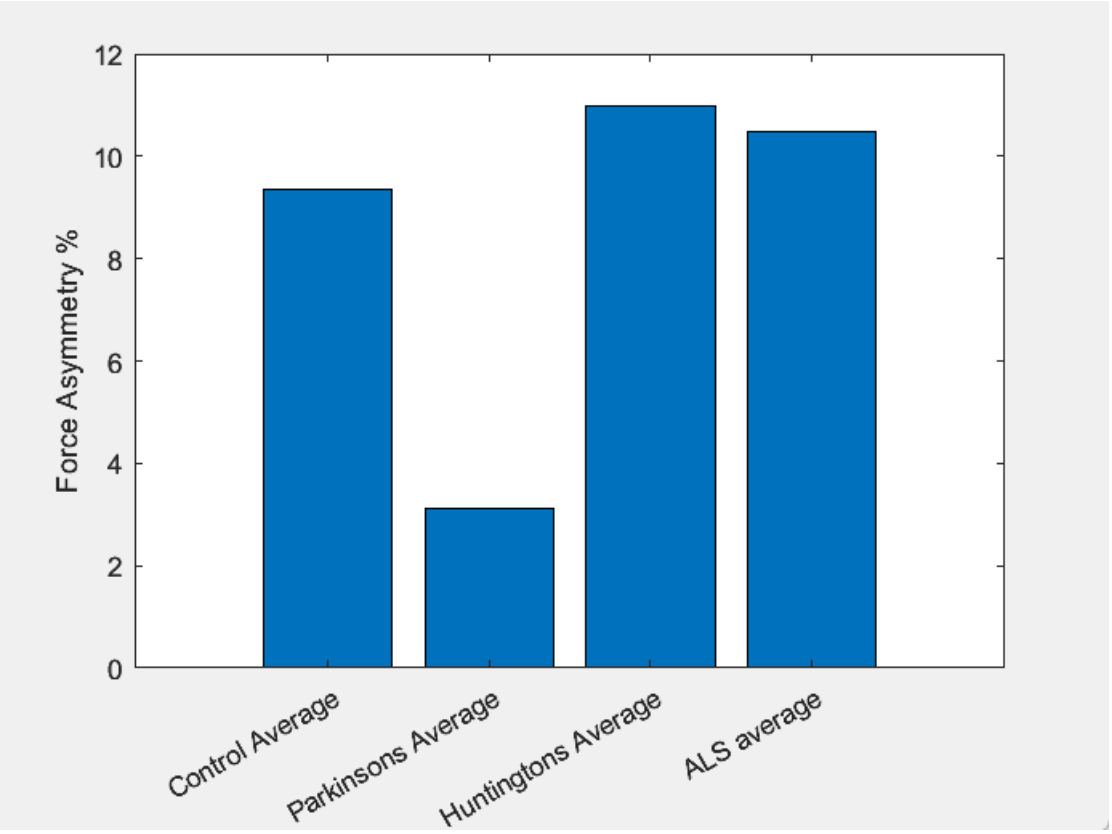

Figure 13: Mean Force analysis of the 4 subject groups

Time asymmetry

Using MATLAB calculations were carried out on the gait asymmetry of the different categories of subjects using time asymmetry. Below the results of the time asymmetry can be visualized.

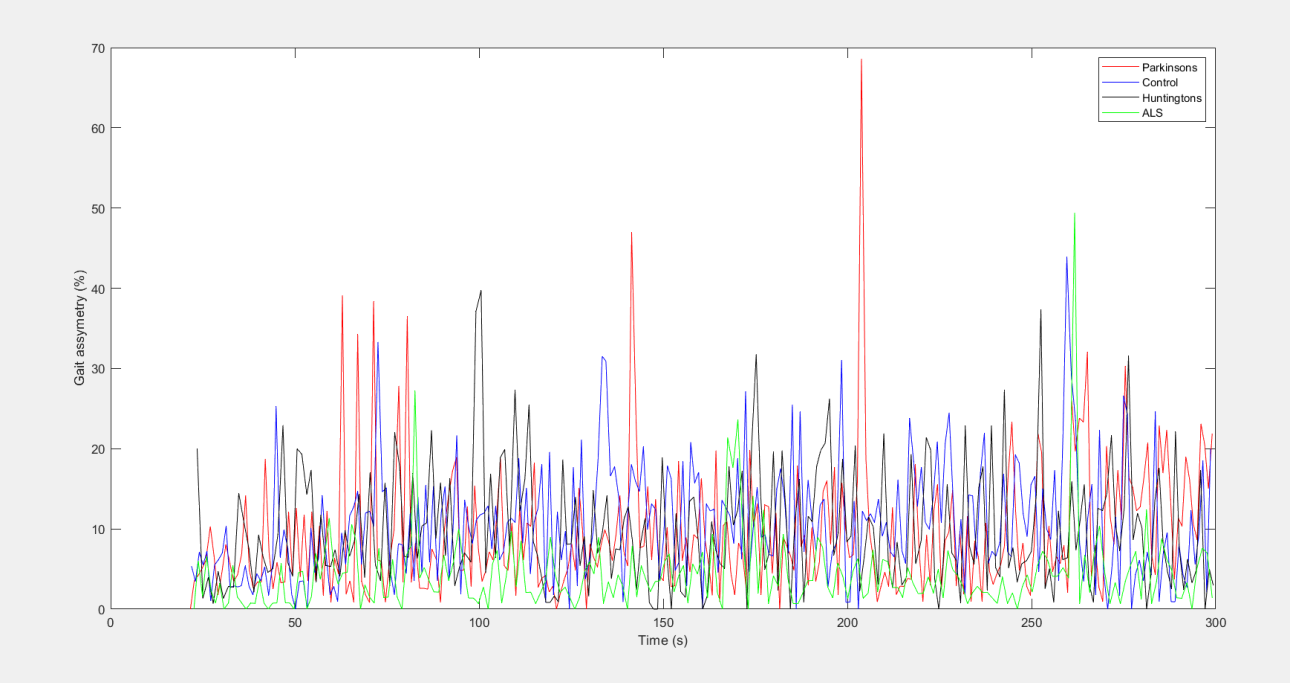

Figure 14: Time asymmetry of the four subject groups

Below is a table of mean values for the time asymmetry of the four different test subjects. These datasets were chosen specifically as they represented a value which the majority of results were in line with.

Control5 Mean	Parkinsons6 Mean	Huntingtons15 Mean	ALS10 Mean
7.83	9.99	36.95	4.45

Figure 15: Mean values of time asymmetry between the four subject groups

Nonlinear gait dynamics in neurological disease versus healthy controls.

The nonlinear analysis of the provided data was represented using a Poincare plot (figure), as well as this the short-term variability (SD1) and long-term variability (SD2) were found.

Poincare plots of the four test subjects

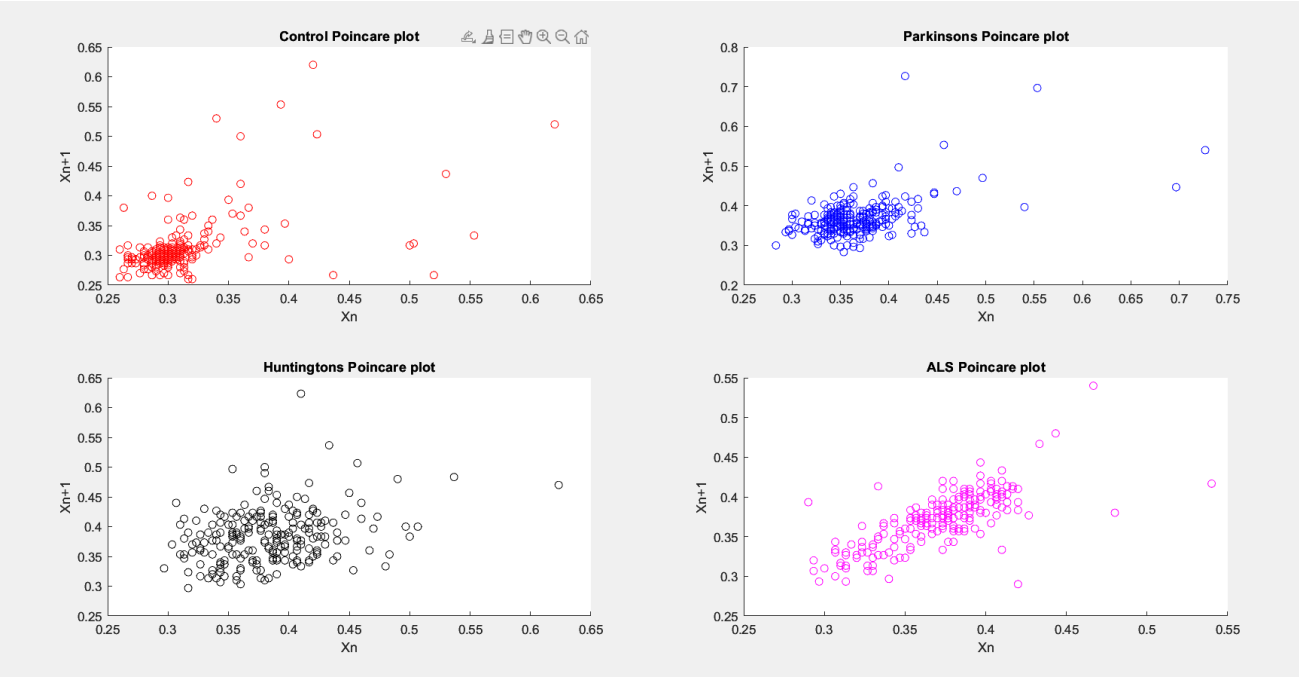

Figure 16: Poincare visualition of the 4 subject groups

Short term variability and long-term variability calculations.

For the sake of consistency, and to aid the examination of the results to draw comparisons the SD1 and SD2 values of the same subject examined for time asymmetry were calculated.

	Control5	Parkinsons6	Huntingtons15	ALS10
SD1	0.0272	0.0245	0.0230	0.0134
SD2	0.0438	0.0506	0.0475	0.0403

Figure 17: SD1 and SD2 values of the four subject groups

Analysis

Gait asymmetry:

The average walking asymmetry for healthy younger adults falls between five and fifteen percent whilst those of the older population generally are closer to fifteen to twenty percent (Dain P. LaRoche, 2012). Based off the fact that the test subjects ages ranged from 20 to 79 it would be expected that the results may be greater than 10%. The time asymmetry gives a directly value on gait asymmetry, in this study based off the amount of data being given time asymmetry could be seen as being more valuable or accurate.

Nonlinear gait dynamics:

Poincare plots are a great way to visually analyse how consistent a dataset is. Short term variability and long-term variability can provide information about the variability of the selected data in a gait cycle, and this can then be further examined based off the subject's condition. Typically, higher levels of gait variability are associated with better balance controls but in the case of those suffering from neurodegenerative diseases it may be a sign of impaired motor control (Sue Lord, 2011).

Control

Gait analysis

The force asymmetry and time asymmetry values for the control subjects were expected to fall within a healthy range. The mean value for the force values across the five datasets was 9.36%. The time asymmetry for the control subjects had a mean of 7.83%. Both of these values meet the criteria for a healthy force asymmetry. Although these values fall within normal limits, there are other factors which must be taken into account when carrying out such reviews such as age, gender, limb dominance (Dain P. LaRoche, 2012) and overall health of an individual – such as previous injuries or imbalances that may affect and individuals mobility.

The values for time asymmetry indicate if a test subject is spending longer on one leg rather than the other, whereas the force values account for how much pressure is put on to the subject's limb. The mean time asymmetry for the control subjects was 7.83 %, this once again falls within the normal categories and represents that the data was recorded correctly.

Parkinson's

An individual who suffers from Parkinson's often suffers from a slowing of gait, reduced arm swing, shorter step length, postural instability, and loss of disassociated arm and trunk movements during gait. Many patients with PD trend to suffer the risk of falls due to occurrence of gait disturbance and freezing of gait (Seung Min Kim, 2018). The mean value for the Parkinson's subjects was 3.1%. Although a this is lower than the normal range, which usually rules a lower asymmetry as being better (Conroy, 2023), Parkinson's is associated with a stiffness, rigidity and bradykinesia and a reduced force asymmetry regularly seen in Parkinson's patients for this reason. This result shows that a person with Parkinson's often spends more time on one leg rather than the other.

The time asymmetry for Parkinson's once again was within the healthier, lower range as 9.99% but as previously explained it is expected for a Parkinson's patients gait asymmetry to be lower due to the stiffness caused by the disease and the slowing of movement. However, from looking at figure 14 it must be observed that there was an outlying spike that may have disrupted the recording of this data. This was likely due to the test subject "freezing" in the middle of the experiment.

Huntington's

The mean force asymmetry value for the Huntington's patients was the highest of the dataset. The mean force asymmetry was 10.99% which although it falls withing the normal range, it shows that of the test

carried out it represents an increased amount of weight being put on one foot over another. Those who suffer from Huntington's disease often display a mild to moderate gait asymmetry in the early stages and those in later stages exhibit a more severe gait asymmetry (Danoudis, 2014), this is due to the fact that Huntington's has quite sever effects on an individual's balance and coordination causing them to have to change their stance to hold balance.

The Huntington's subjects mean gait asymmetry was 36.95 %. This value above the normal age group and signifies the effect Huntington's can have on a patient. It also is a value that would be expected as in this dataset, severely impaired individuals were not tested. It shows the progressive nature of Huntington's and the effect this will have on gait over time.

AlS

ALS is associated with an increased gait asymmetry. This is due to its physiological affects on the motor neurons in the brain and spinal cord which later lead to muscle weakness and atrophy (Anon., n.d.). The mean force asymmetry value for this group was 10.47% which once again falls into what would be considered a healthy range, but it is higher than the controls measured value. ALS can affect people in very different ways, similar to Parkinson's it can cause a muscle stiffness and tightness but also causes balance issues leading people to have a higher asymmetry to catch their step.

The time asymmetry for ALS was surprisingly low measuring at 4.45%. It follows suit with the force asymmetry values being lower within the normal range. Once again this could be due to the face that the mean was taken as when looking at the Poincare Plot on figure 16 some spikes in the signal must be noted. An ALS patient does often however exhibit a low gait asymmetry due the stiffness of their muscle.

Non-linear gait dynamics :

Poincaré plot analysis

A Poincare plot was used to visualize the relation between consecutive datapoints (Satti, 2019). The data that was examined to see the correlation between the datapoints was the double support interval. Poincare plots are useful to see how consistent data is across a given period. As can be seen in figure 16, the control plot is having a high density with outliers, this shows that the double support time of the subjects tested was consistent enough which is a sign of a healthy data set. The Parkinson's set also had a high density displaying a uniform set of data, this means that as well as the data being recorded consistently, the subjects' movements did not vary much, a presumption as to why this occurred is due to bradykinesia, in which the patient's movement is slowed. The Huntington's plot was the most spread out of the data sets examined. For the double support interval, this was expected due to the nature of a lack of balance and motor coordination associated with Huntington's. Finally, the ALS graph had the greatest range of all of the Poincare plots examined. This could be due to the varying nature of ALS as a condition wherein early symptoms of ALS include muscle weakness or stiffness (ALS association , n.d.) and can also progress to cause poor balance or tripping when walking.

Short- term variables and long-term variables SD1 & SD2:

Using the found SD1 and SD2 variables a confidence interval can be calculated for each data set. Short term variability in gait reflects the normal fluctuations that occur in a person's walking pattern over a short period of time. Higher levels of short-term variability in a person's gait are usually associated with decreased stability. The SD2 value checks for a correlation between data points across the entire testing period. These results can be seen in figure 15.

Conclusion

The data collected for the journal article “Dynamic markers of altered gait rhythm in amyotrophic lateral sclerosis” consists of very useful metrics in the measurement of gait analysis. The different calculations used to find time asymmetry, and force asymmetry as well and the Poincare plot to visualize the collected data provides a much deeper insight into the nature of the effect of these diseases on gait and mobility. On drawback on the methods used to carry out this experiment was through taking the means of force values rather than singular value, there is a wide range of forces so this may not have been a suitable way to analyse them. The examination carried out with the values shows that this form of testing is useful in the diagnosis of neurodegenerative diseases as well as monitoring their progression. From what can be drawn from the results in this analysis, the use of force and time asymmetry to analyse a person’s gait could be used for a wide range of purposes, which includes being able to check for physiological impairments following injury or regular bad health practices such as posture.

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