Movement coordination in Parkinson's disease

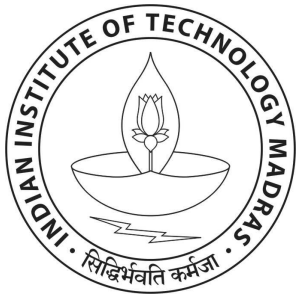
A Project Report

submitted by

R ASHWINI

in partial fulfilment of the requirements
for the award of the degree of

MASTER OF TECHNOLOGY



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THESIS CERTIFICATE

This is to certify that the thesis titled **Movement coordination in Parkinson's disease**, submitted by **R Ashwini**, to the Indian Institute of Technology, Madras, for the award of the degree of **Bachelor of Technology and Master of Technology**, is a bona fide record of the research work done by her under our supervision. The contents of this thesis, in full or in parts, have not been submitted to any other Institute or University for the award of any degree or diploma.

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ABSTRACT

KEYWORDS: Parkinson's disease; tDCS; coordination

We studied the motor coordination in 7 Parkinson's disease (PD) patients and 6 age-matched healthy controls. We created a novel setup to record the eye, head and hand movements of a subject as they completed a natural pointing task. We stimulated subjects with cathodal transcranial direct current stimulation, a non-invasive form of brain stimulation, and studied its effects on the performance of PD subjects.

We found that PD subjects had slightly slower saccades and slower hand movements. They also experienced hypometric saccades more frequently. They were just as accurate and had reaction times comparable to healthy controls for saccades and hand movements. We did not find significant differences in the results of PD subjects with the application of cathodal tDCS for the performance measures we studied.

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ABBREVIATIONS

PD	Parkinson's disease
tDCS	Transcranial direct current stimulation
UPDRS	Unified Parkinson's Disease Rating Scale
SEM	Standard error of mean

CHAPTER 1

INTRODUCTION

1.1 Motivation

Parkinson's disease (PD) is a chronic neurodegenerative disease that is estimated to affect 7 million people worldwide (de Lau and Breteler (2006)). People with PD suffer from a set of characteristic motor disorders. This includes tremors of the hands and legs, impaired balance, postural instability, slow movements and rigidity of limbs. PD patients are also afflicted with a set of non-motor symptoms such as slurred speech, sleep apnea, anxiety and depression (NINDS (2017)).

Parkinson's disease is caused by the depletion of the neurotransmitter dopamine. It occurs due to the death of dopamine-producing cells found in a mid-brain region called Substantia Nigra pars compacta. The cause of this cell death is under investigation and it is currently incurable. (NPF (2017)).

Parkinson's disease is progressive and grows worse as more cells die, so patients have to live with increasing disability.The current treatment options of PD are limited to medication and deep brain stimulation. The medication L-DOPA, a precursor to dopamine, loses its effectiveness with repeated use and has potentially severe side effects. Deep brain stimulation requires implants to be placed with surgery, and its mechanisms are not fully understood (NINDS (2017)). Hence, new techniques that can help us understand PD or provide relief to PD symptoms would prove valuable.

1.2 Overview and Problem Statement

The current diagnosis of Parkinson's disease relies on the presence of symptoms affecting single-limb dynamics such as tremor, rigidity and slowness, and the improvement of these symptoms by using dopaminergic treatment (Savitt *et al.* (2006)). No

tests are available to monitor how PD may exert subtle changes the coordination of multiple movement modalities (Breen *et al.* (2011)). Hence we decided to study visuomotor coordination in PD subjects and created a setup to observe the eye, head and hand movements simultaneously as the subject completed a natural pointing task. This setup was novel compared to other eye-hand coordination studies because the subject was free to move his head, and hence is more representative of the natural environment.

In Parkinson's disease the brain is capable of producing normal motor commands, but requires a significantly larger amount of motivation. A recent study conducted by Salimpour et al. used transcranial direct current stimulation (tDCS), a noninvasive form of brain stimulation, and reported improvements in performance and clinical scores. We decided to record subjects performing the pointing task under two scenarios: they experienced sham stimulation in one and cathodal tDCS in the other.

We recorded data from 7 PD patients and 6 healthy age-matched controls. We focused our analysis on two key questions: (i) How do PD subjects fare compared to age-matched healthy controls in a natural pointing task? (ii) Were any aspects of their performance modified by the application of cathodal tDCS?

CHAPTER 2

BACKGROUND AND RELATED WORK

2.1 Subjective cost of effort in Parkinson's disease

The symptoms of a PD patient seem to spontaneously improve under special circumstances. A study found that when patients were asked to pick up a stationary ball they reached for it slower than normal. However they reached for it at near normal speed if the ball was moving (Ballanger *et al.* (2006)). If there was increased urgency, say if the ball was about to fall on the floor, they reached even faster (Mazzoni *et al.* (2007)). It seems PD patients are capable of producing normal movements, but their brain requires a greater motivation to do so. The slowness and smallness of their movements may be due to an elevated perception of effort.

To study this Salimpour et al. from the Shadmehr lab designed an experiment. They relied on the fact that PD is a lateralized disease, affecting one side first before the other. They hypothesized that the subjective cost of effort would be greater on the affected side (Salimpour *et al.* (2015)). In the experiment subjects were asked to produce forces with both arms, and the sum of the forces was used to move a cursor on the screen. A target force was set, but the subjects could chose the division of force between their arms. They found that PD subjects tended to rely more on their less-affected side, and healthy controls had a more equitable distribution of effort. The distribution of effort was direction dependent.

They then used a technique called transcranial direct current stimulation to stimulate the subject's brain. Direct current stimulation can be categorized into anodal when positive charge is delivered by stimulation and cathodal when negative charge is used. The PD subjects maintained their regular medication schedule when performing the task. Anodal tDCS did not cause any significant changes in performance. However when they applied cathodal tDCS they found that PD subjects became more willing

to apply force with their affected arm. They explained this effect by postulating that cathodal tDCS reduced the signal-dependent noise associated with the arm in the motor cortex.

2.2 Transcranial direct current stimulation

Transcranial direct current stimulation is a form of brain stimulation that uses direct current to stimulate specific regions of the brain. A constant, low intensity current is passed through two electrodes placed on the scalp. It has several advantages - it is cheap, non-invasive and painless. The only common side effect is an itching or tingling sensation on the skin, which is caused by the high skin impedance. Studies suggest that it has potential to treat conditions such as depression, anxiety and Parkinson's disease.

Transcranial direct current stimulation has been found to affect cortical changes, but the precise mechanisms are not fully understood. A set of key principles on DC polarization seem to account for most of the observed effects of tDCS. These are (1) Firing rates are increased by anodal polarization and decreased by cathodal polarization, (2) anodal polarization strengthens newly formed associations, and (3) polarization modulates the memory of new/preferred firing patterns (Xivry and Shadmehr (2014)).

Using tDCS for Parkinson's disease has shown mixed results. PD subjects were stimulated in the primary motor cortex, or M1 region and asked to perform specific motor tasks. Some studies report improvements in performance with anodal tDCS only when the subjects were not taking dopamine medication (Benninger *et al.* (2010)). One study reported that anodal stimulation of M1 improved both the gait and clinical motor symptoms of PD patients on their medication (Valentino *et al.* (2014)). However a recent double blind study that compared PD subjects under the conditions anodal stimulation and sham did not find significant effects of stimulation (Verheyden *et al.* (2013)).

A majority of studies have focused on anodal stimulation with the expectation that it would provide better results than cathodal stimulation. However, a recent study on rats demonstrated that cathodal stimulation of the frontal motor regions produced increases

in striatal dopamine concentrations, whereas anodal stimulation did not produce much change (Tanaka *et al.* (2013)). Based on this, a study of PD patients on their medication was conducted at the Shadmehr lab, and improvements in clinical motor symptoms and in the bimanual force production task were observed with cathodal M1 stimulation (Salimpour *et al.* (2015)). This study served as the basis for my investigation into the effects of tDCS, and I decided to use cathodal M1 stimulation in my experiment.

CHAPTER 3

EXPERIMENTAL SETUP

3.1 Layout of experiment

We studied coordination by recording the movements of the eye, head and hand simultaneously. Subjects with Parkinson's disease and healthy age-matched control subjects were recruited. Data was recorded from each subject on two days. The subject experienced cathodal stimulation on one day and sham stimulation on the other. In sham stimulation the subject is not stimulated but is led to believe that they were being stimulated. It is a precaution taken to ensure that effects seen under stimulation are not due to the placebo effect.

On both days the subject was asked to arrive at the same time. To verify that the PD patients felt the same at the beginning of the experiment on both days, their symptoms were evaluated using the Unified Parkinson's Disease Rating Scale (UPDRS), a standardized clinical score (Goetz *et al.* (2007)), and we ensured that their UPDRS scores were in the same range.

On each day, the subject was seated in front of a screen and instructed to look at a target dot on the screen with their eyes, and reach out to touch it with their finger when requested. They were free to move their head as they felt comfortable. The target was a small white dot on a grey background. One shift in the target position is defined as a trial. A trial was considered complete only when the subject reached the endpoint (within acceptable accuracy bounds). If the subject started to move but failed to reach the target accurately, the trial would be repeated.

The targets were approximately limited to the horizontal axis. The x position of the target was selected randomly from the set $\{-25^\circ, -15^\circ, -5^\circ, 5^\circ, 15^\circ, 25^\circ\}$ and the y position was selected uniformly at random from $[-0.5^\circ, 0.5^\circ]$. The resulting distribution of the target amplitudes are shown in Fig 3.1.

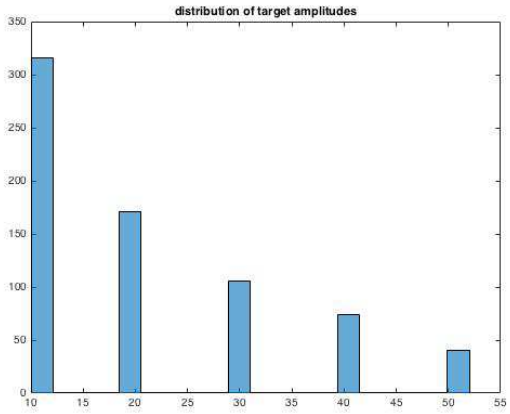


Figure 3.1: Distribution of target amplitudes

The experiment was split up into blocks of 70 trials each, with a total of 8 blocks. Subjects took between 2 to 4 minutes to complete a block. A break of 30s to 60s was provided between the blocks. As the PD subjects often found moving their hands difficult, all subjects were asked to reach with their finger only for 4 out of 8 blocks. Finally, to find a baseline for their eye movements, we recorded 2 blocks with the same targets on a setup where their head would be fixed.

3.2 Eye movement measurement

Eye movements were measured using a non-invasive camera-based system from SR Research called the Eyelink 1000. The Eyelink system uses invisible infrared light to illuminate the eye, and observes the eye using a high-speed camera. The core Eyelink system is depicted in Fig 3.2.

IR light from the source is reflected off the cornea, the outermost layer of the eye, creating a distinctive glint. The displacement between the corneal reflection and the centre of the pupil is used to compute the angular position of the eye. Eyelink achieves an average accuracy of 0.5°. In Fig. 3.3 the pupil is dark blue, the corneal reflection is a small white circle, and the centre of both regions are marked by crosshair. The Eyelink software finds the pupil and corneal reflection in the image using thresholds set by the user. The centre of the pupil is found by fitting an ellipse to the pupil region (SR Research (2009)).

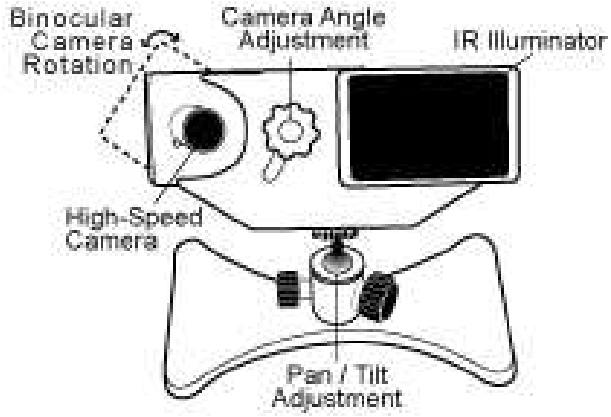


Figure 3.2: Core system of Eyelink 1000

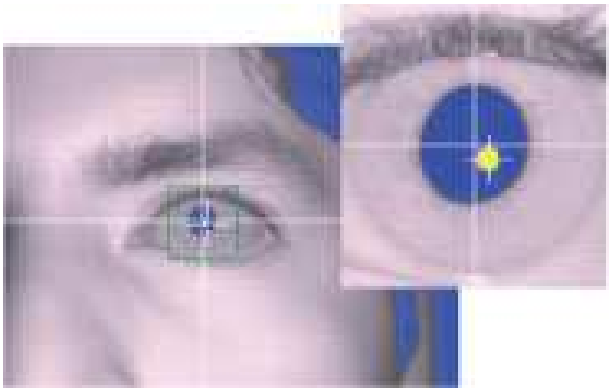


Figure 3.3: Pupil and corneal reflection

In a typical eye tracking experiment, the core system is used along with a head support that keeps the head fixed in one position as shown in Fig 3.4. The subject looks at stimuli through the IR reflective mirror which is transparent to visible light. The mirror is angled to ensure that light from the IR source illuminates the subject's face and is reflected back to the camera. The horizontal and vertical position of eye is sampled at a frequency of 1000 Hz with this setup.

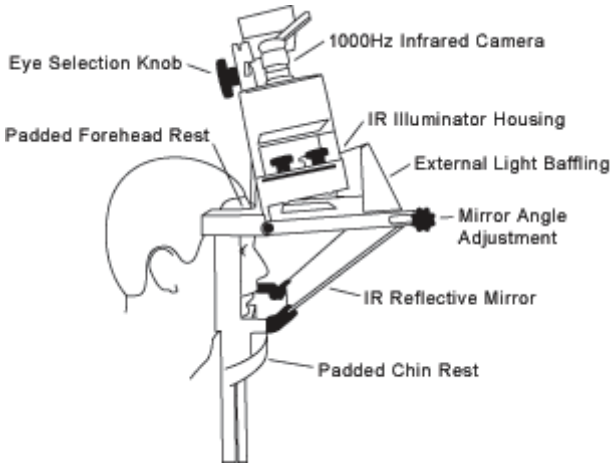


Figure 3.4: Eyelink tower mount setup

By forcing the head to be still the experiment becomes different from visual tasks we perform everyday. In order to have the setup mimic the natural environment better, the traditional setup was modified to allow head movement. A frame was built to support the core system and suspend the IR reflective mirror in front of the subject, using 80/20 - a T-slotted aluminium building system. The modified setup is depicted in Fig 3.5. To identify the eye reliably, the Eyelink system requires the subject to be kept approximately 40cm from the screen. The position of eye is sampled at a frequency of 500 Hz with this setup.

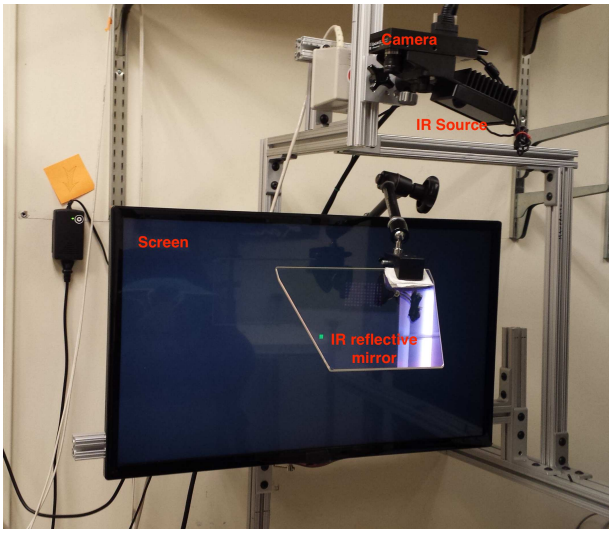


Figure 3.5: Eyelink head-free setup

3.3 Electromagnetic tracking

Head and hand movements were recorded using trakSTAR, an electromagnetic tracking unit from Ascension Technology. The system uses a electromagnetic transmitter to create a field, and the position of a sensor is determined with respect to the transmitter. The trakSTAR unit provides location information along 6 degrees of freedom with a RMS accuracy of 1.4mm for position and 0.5° for orientation data. The data is sampled at a frequency of 240 Hz.

A sensor was attached to the index finger to measure the subject's reaching movement. The subjects with PD were asked to reach with the hand that was affected more by Parkinsonian symptoms, and healthy controls were asked to reach with their dominant hand. Subjects had to hold a bite bar made from dental putty in their mouth, and head movements were tracked by attaching the sensor to this bite bar. A subject demonstrating the task is shown in Fig 3.6.

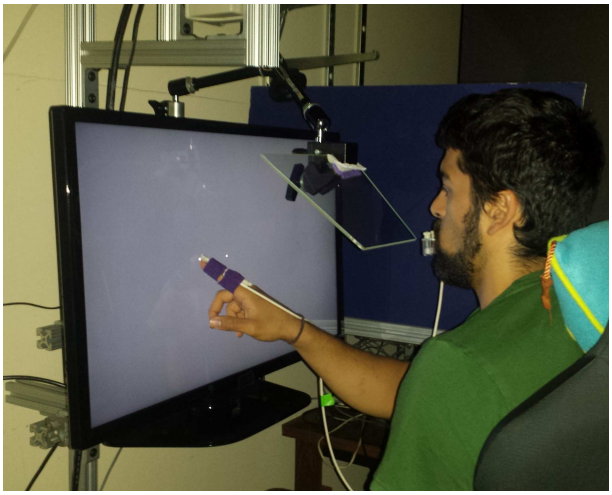


Figure 3.6: Head-free setup demonstration

3.4 Transcranial direct current stimulation setup

The apparatus required for tDCS is quite simple. It consists of a battery powered constant current device and sponge electrodes. The sponges were soaked with saline solution to reduce the contact resistance. Cathodal stimulation was applied to the primary motor cortex, also called M1.The cathode was placed on the hemisphere on the opposite side of the hand used for reaching, or contralaterally. The subjects were stimulated with 2mA current for 25 minutes, in accordance with the current safety regulations.The stimulation was slowly increased in steps of 0.1mA at the start of the experiment, and similarly decreased at the end to reduce any sensation of stimulation felt by the subject. In our paradigm, the PD subjects were asked to follow their regular medication schedule.

CHAPTER 4

ANALYSIS AND RESULTS

We recruited 7 volunteers diagnosed with Parkinson's disease (mean age = 64.14 , 1 female), and 6 healthy volunteers (mean age = 59.6, all male) for the experiment. Participants were divided into two approximately equal groups - one experienced sham stimulation first and the other cathodal stimulation first. All participants were informed of the risks and discomforts of the experiment and gave their written consent. The PD patients were on their normal schedule of medication. The experimental protocol was approved by the Institutional Review board of the Johns Hopkins School of Medicine.

4.1 Analysis within individual movement modalities

Rapid eye movements

In our task there is an abrupt jump of target position, and hence it is designed to elicit a specific type of eye movement called a saccade. A saccade is a rapid eye movement that abruptly changes the point of fixation. Saccades are stereotypical in nature and can be described by a set of parameters. Fig 4.1 shows a standard position and velocity profile of a saccade and the parameters used to describe the saccade.

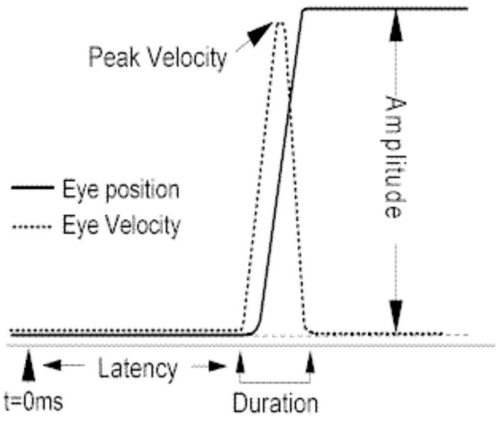


Figure 4.1: Saccade velocity profile

Amplitude is the distance covered by the eye during the saccade, usually measured in degrees. Peak velocity is defined as the maximum velocity reached by the eye during the saccade. Saccades are one of the fastest movements that can be performed by humans and peak velocities can reach up to 900 °/s. Duration is the time taken to complete the saccade and typically lies between 20 - 200 ms. Latency, also called reaction time, is the time taken to initiate a saccade after the target is displayed. It takes 200 ms or more to initiate a voluntary saccade.

The velocity profile of a saccade changes with amplitude, as shown in Fig 4.2. The peak velocity and acceleration increases with amplitude to about 40°. For larger saccades the acceleration phases are similar, and larger amplitudes are reached by a prolonged deceleration phase.

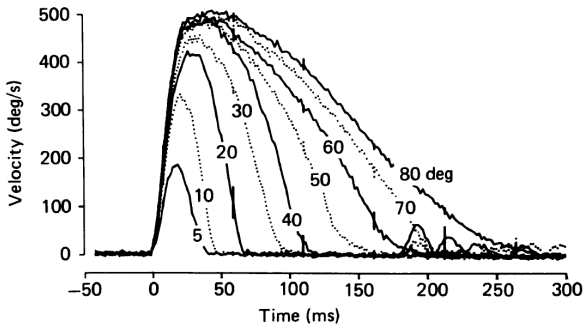


Figure 4.2: Saccade velocity profiles for amplitudes 5 - 80°

This trend can be captured by the peak velocity vs. amplitude relation. The peak velocity of a saccade increases linearly with amplitude for small amplitudes, and asymptotes for larger amplitudes. Analogously, duration increases in a linear manner for small amplitudes and increases non-linearly for large amplitudes. These regularities are also referred to as main sequence (Collewijn *et al.* (1988)). The saccade main sequence of a subject is shown in Fig 4.3 as an example.

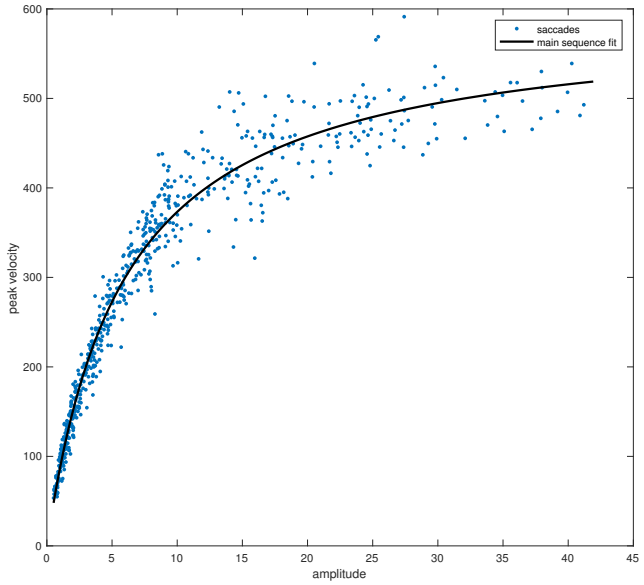


Figure 4.3: Example of saccade main sequence

Data processing for eye movement data

If the subject blinks or if the Eyelink system fails to identify the eye during the task the position information is recorded as NaN. The NaNs were removed from the position data, and it was filtered with a low pass filter to remove noise. A 3rd order Butterworth filter with a cutoff frequency of 60 Hz was used. The position data was differentiated to find the horizontal and vertical velocity of the eye. The absolute velocity given by $v = \sqrt{{v_x}^2 + {v_y}^2}$ was used for further analysis.

Velocities greater than 1200°/s were removed because they are not possible and were caused by movement artifacts. Saccades were identified from the absolute velocity by using thresholds that were tuned. The onset and end of a saccade were found using a threshold of 30°/s. The other criterion were (i) minimum peak velocity of 50°/s, (ii) minimum amplitude of 0.5° and (iii) a minimum hold period of 10 ms. The minimum hold period defines the period of time that the velocity has to stay below the threshold 30°/s after the end of the saccade.

To remove atypical velocity profiles, the peak velocity vs. amplitude main sequence was fitted with a hyperbolic function given by $peakvelocity = \alpha/(1 + \beta * amplitude)$. The α and β values were found using non-linear least squares estimation and used to compute an estimate of peak velocity for each amplitude. Saccades that had peak velocities more than 2.5 standard deviations away from the estimate were removed.

Data processing for head and hand movement data

The head movements were restricted to the horizontal axis in the task, and the azimuth angle measurement of the sensor was considered to be the proxy for head rotation. The angular position data was filtered using a low-pass 3rd order Butterworth filter with cutoff frequency 12 Hz. Angular velocity was found by differentiation. Head movements were identified using a set of thresholds: (i) minimum peak velocity of 7°/s, (ii) minimum hold period of 50 ms and (iii) onset and offset were identified using a threshold of 4°/s.

The projection of the endpoint of the finger on the screen was found using the hand sensor data and used to represent hand movement. The position data was filtered using a low-pass 3rd order Butterworth filter with cutoff frequency 12 Hz. Horizontal and vertical velocity of the hand was found by differentiation. The absolute velocity given by $v = \sqrt{{v_x}^2 + {v_y}^2}$ was used for further analysis. Head movements were identified using a set of thresholds: (i) minimum peak velocity of 10 cm/s, (ii) minimum hold period of 50 ms and (iii) onset and offset were identified using a threshold of 5 cm/s.

4.1.1 Comparisons of main sequence

For each subject the main sequence for saccades, head and hand movements were found. Since several subjects did not move their head much, the main sequence for head movement was often very sparse, and the standard error of mean (SEM) for the average head movement main sequence was very large. This made head movements unsuitable for this comparison.

To study if PD patients performed worse than healthy controls, I compared the average main sequence under the sham stimulation protocol. The healthy controls made slightly faster saccades than PD subjects, but the result was not significant. This is in contrast with some papers have reported that PD had significantly slower saccades (White *et al.* (1983)). The average saccade main sequences are show in Fig. 4.4. The shaded error bar represents the SEM. The healthy controls almost always made faster hand movements than PD subjects. The average hand movement main sequences for healthy controls and PD subjects are shown in Fig. 4.5.

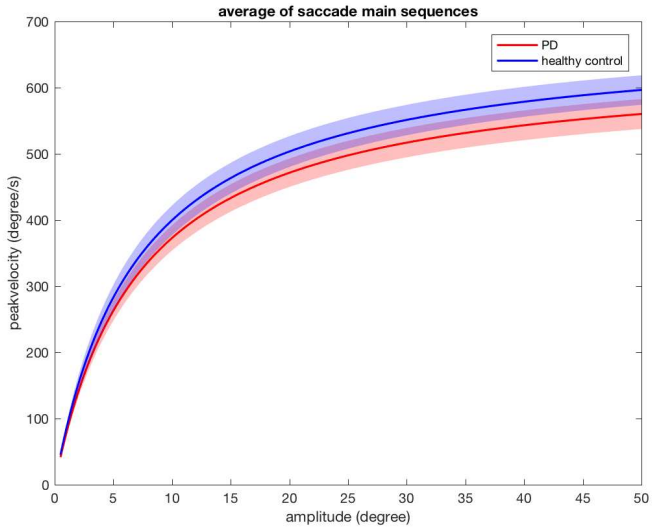


Figure 4.4: Average saccade main sequence: PD and healthy control

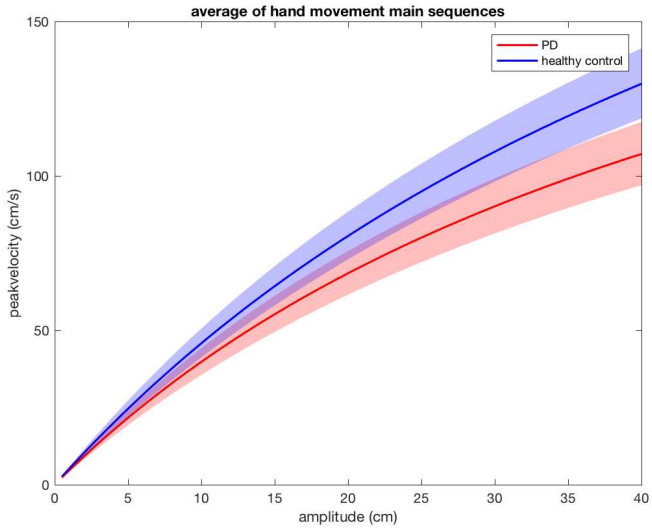


Figure 4.5: Average hand movement main sequence: PD and healthy control

I then compared the main sequences of PD subjects experiencing cathodal stimulation and sham stimulation. When comparing the two scenarios for each individual subject there was no consistent difference in the main sequence. Some subjects made slightly faster movements when experiencing sham stimulation, others when experiencing cathodal stimulation, and most did not show much difference at all. The average saccade main sequences under sham and cathodal stimulation are hardly different, as seen in Fig 4.6. Surprisingly there was no significant effect of tDCS on hand movement main sequences. Fig 4.7 shows the average hand movement main sequence of PD subjects experiencing cathodal and sham stimulation.

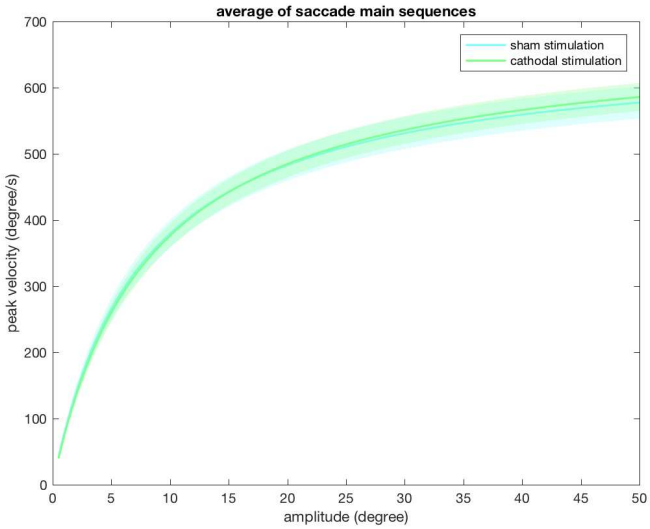


Figure 4.6: Average saccade main sequence of PD: cathodal and sham stimulation

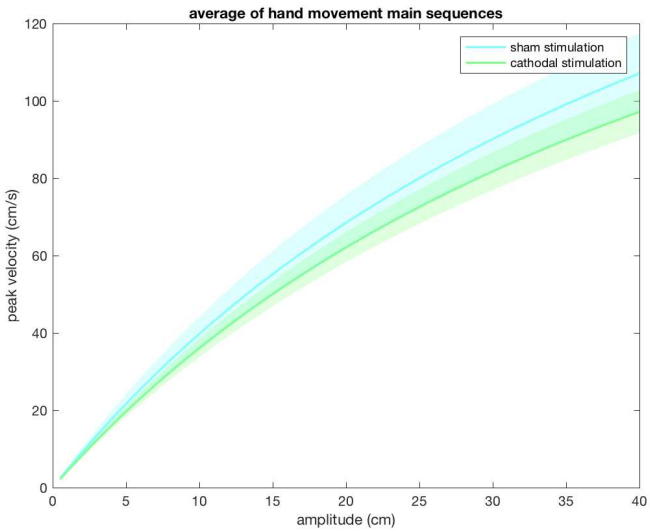
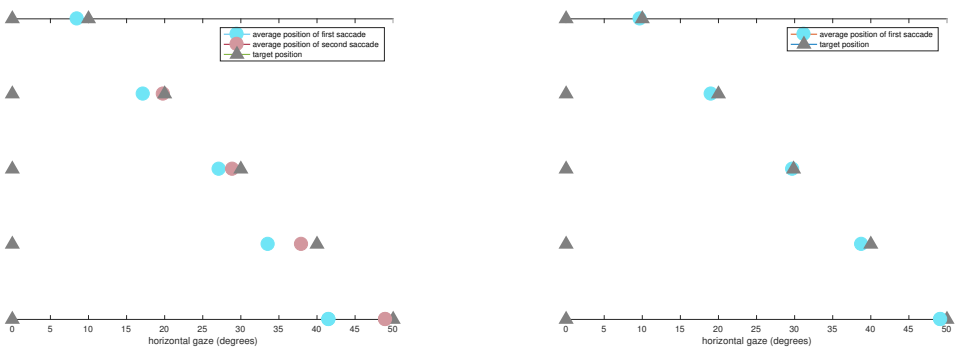


Figure 4.7: Average hand movement main sequence of PD: cathodal and sham stimulation

4.1.2 Accuracy, Hypometricity and Latency

Hypometricity

A saccade is termed hypometric if the eye fails to reach the desired target. In general, the likelihood of hypometric saccades increases with target amplitude. In the example Fig 4.8a, the subject in question makes hypometric saccades for larger amplitudes and needs to make a corrective saccade to reach the target, and hence suffers from saccade hypometria. The other subject shown in the example Fig 4.8b is reasonably accurate with just the first saccade.



(a) example 1

(b) example 2

Figure 4.8: Hypometricity of saccades

We define gain as the ratio of the amplitude of the first saccade to the target amplitude. If the subject reaches the target with one saccade then he has a gain of 1 in that trial. PD subjects tended to be more hypometric than healthy controls. Fig 4.9 compares the average hypometricity of PD subjects and healthy controls. Application of tDCS did not contribute to significant changes in hypometria, as seen in Fig 4.10

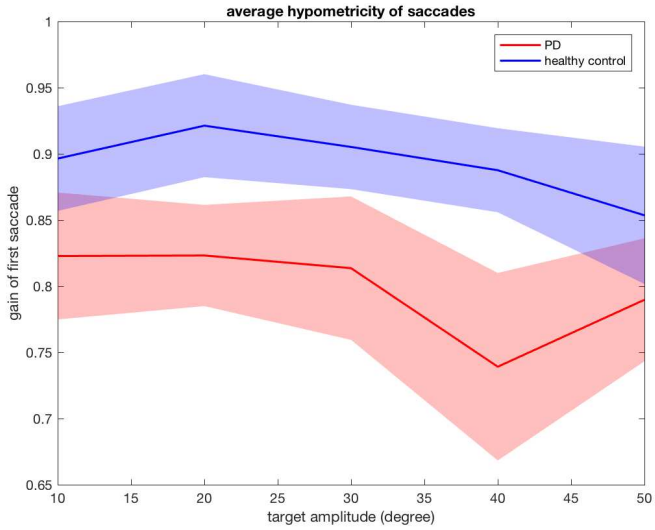


Figure 4.9: Average hypometricity of saccades: PD and healthy controls

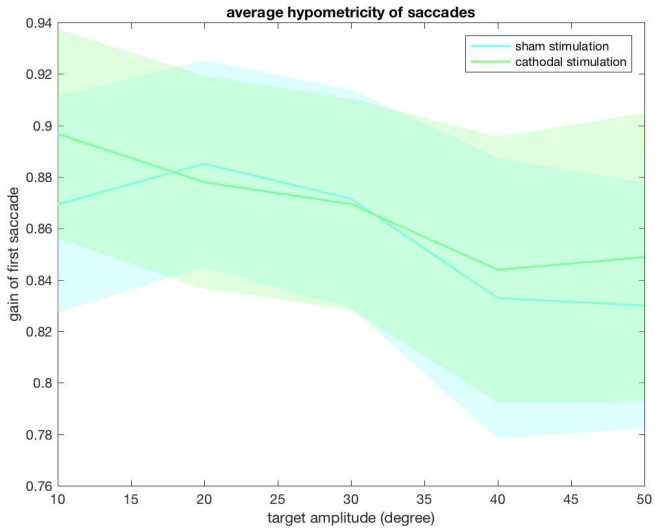


Figure 4.10: Average hypometricity of saccades in PD: sham vs cathodal stimulation

Accuracy

Accuracy was estimated by finding the average absolute end point error. The end point error for a trial is the difference between the target position and the position reached by the subject. PD subjects seem to make less accurate saccades than healthy controls but it is not a significant result as seen in Fig 4.11. Application of tDCS did not result is differences in accuracy of saccades as seen in Fig 4.12.

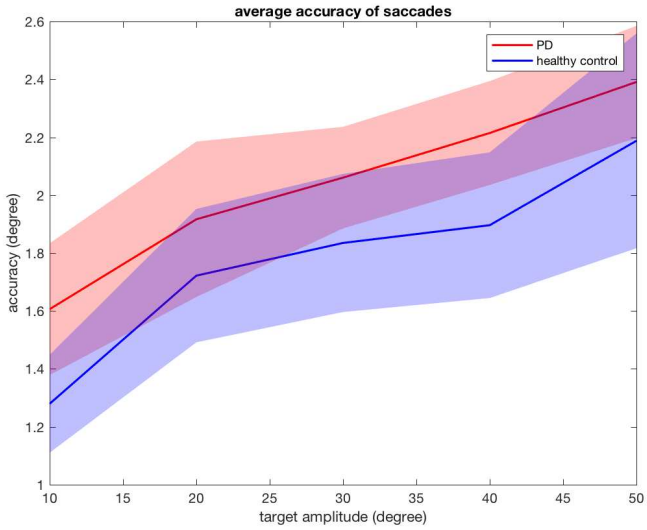


Figure 4.11: Average accuracy of saccades: PD and healthy controls

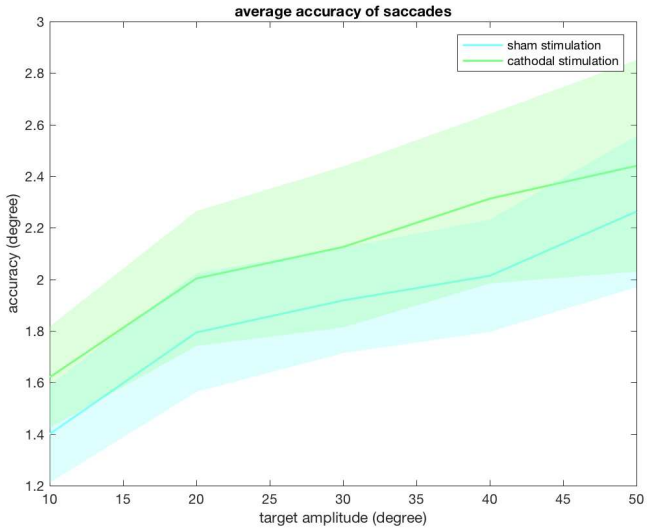


Figure 4.12: Average accuracy of saccades in PD: sham vs cathodal stimulation

Similar results were obtained for comparisons of accuracy of hand movements. Fig 4.13 compares the average accuracy of hand movements for PD subjects and healthy controls. Fig 4.14 shows the average accuracy of hand movements of PD subjects experiencing sham stimulation and cathodal stimulation.

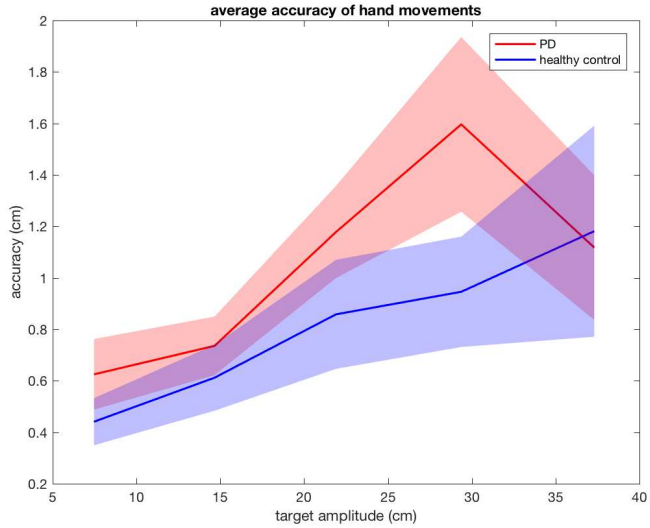


Figure 4.13: Average accuracy of hand movements: PD and healthy controls

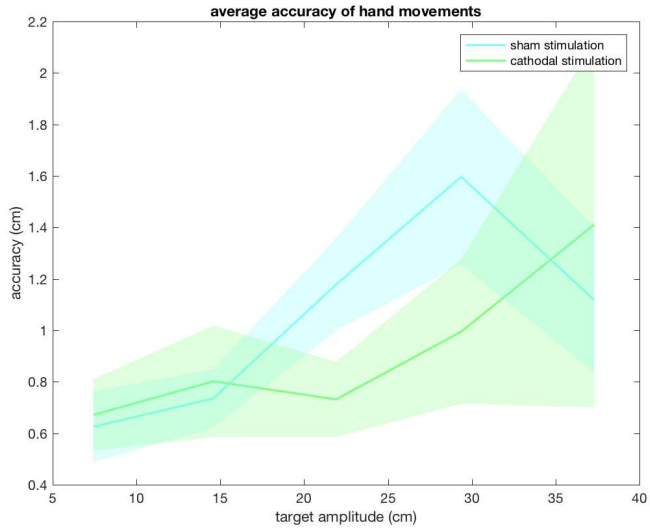


Figure 4.14: Average accuracy of hand movements in PD: sham vs cathodal stimulation

Latency

Latency is defined as the time it takes to initiate a saccade after a target is presented. The papers studying latencies of saccades in PD subjects have shown mixed results.

Some have reported larger latencies (White *et al.* (1983)) while others report shorter latencies (Chan *et al.* (2005)). I did not find any significant results. Fig 4.15 compares the average latency of saccades for PD subjects and healthy controls, and Fig 4.16 compares latency of saccades under sham stimulation and cathodal stimulation.

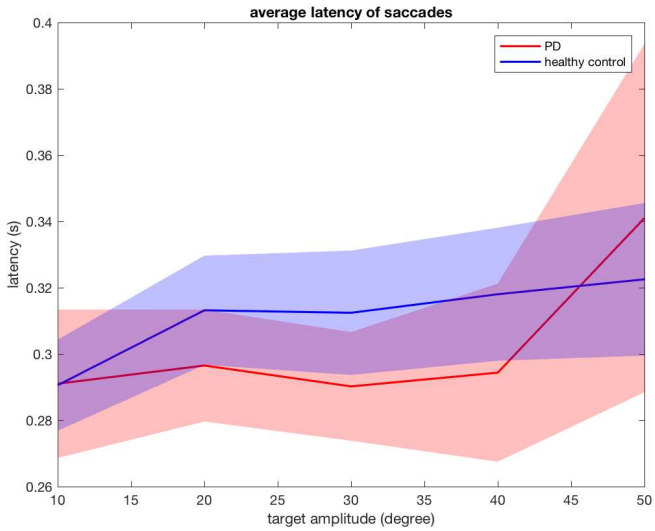


Figure 4.15: Average latency of saccades: PD and healthy controls

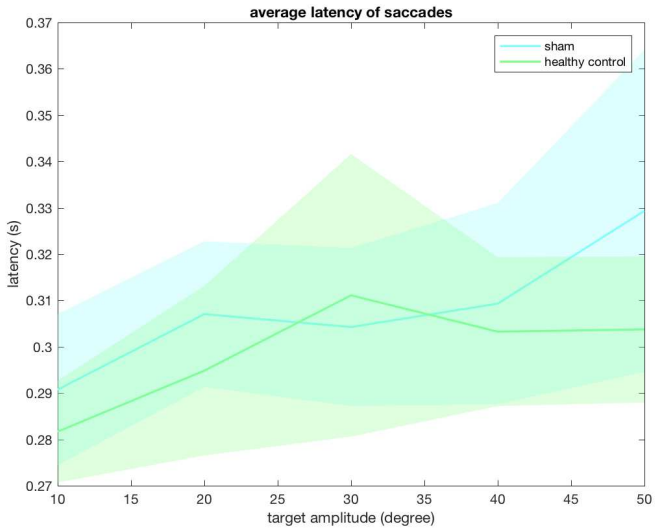


Figure 4.16: Average latency of saccades in PD: sham vs cathodal stimulation

Larger reaction times were expected for PD subjects when considering hand movements, and PD subjects do seem to have slightly larger latencies. Fig 4.17 compares the average latency of hand movements for PD subjects and healthy controls. The tDCS

did not result in changes to latency and Fig 4.18 compares latency of saccades under sham stimulation and cathodal stimulation.

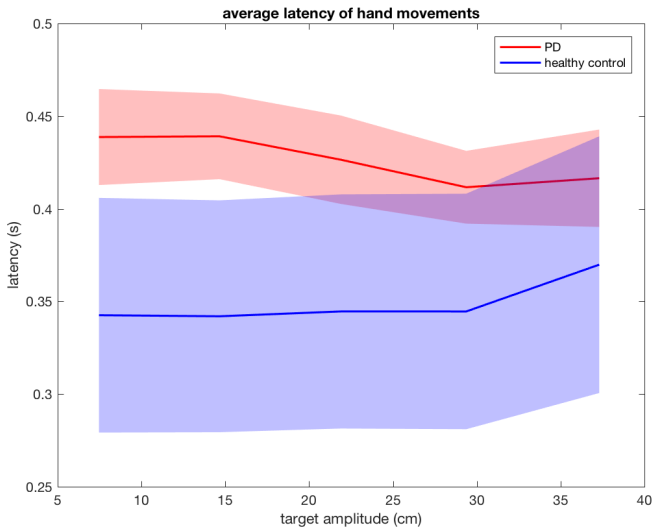


Figure 4.17: Average latency of hand movements: PD and healthy controls

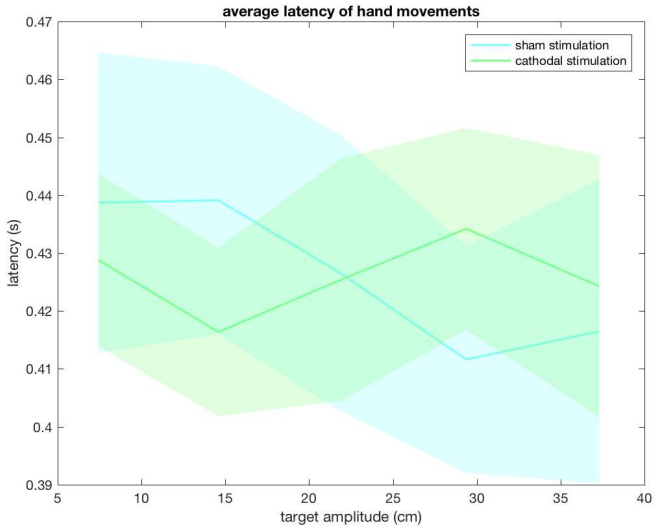


Figure 4.18: Average latency of hand movements in PD: sham vs cathodal stimulation

4.2 Comparisons across different movement modalities

4.2.1 Comparison of vigor

Some people intrinsically move faster than others. Choi et al. found that natural differences between people in saccade peak velocity were consistent and conserved across many days. If moving to a new position carries a reward, then the duration of the movement carries a cost because it delays the acquisition of the reward. They postulated that for people who are naturally faster, reward gets more steeply discounted with time (Choi *et al.* (2014)). They found that the people who made faster saccades were also more impulsive in a decision making task. This implied that there may be a common mechanism for discounting time for both movement tasks and decision making tasks. If speed of movement is a trait due to differences in how individuals evaluate reward, we hypothesized that differences in speed should be present across different movement modalities.

Choi et al. defined vigor, a parameter based on the main sequence, to represent the ratio of speed of a subject with respect to the average speed of all subjects. For amplitude x, they computed the across subject average velocity-amplitude function $g(x)$. They found that velocity-amplitude function for a subject i, given by $v_i(x)$, could be approximated to a scaled version of the average: $v_i(x) = \alpha_i * g(x)$. The scaling factor α_i was defined as vigor and used as a proxy for speed of the person compared to the average speed. In Fig 4.19A, the colored lines represent $v_i(x)$ and the black line represents $g(x)$.Fig 4.19B plots the vigor for each subject.

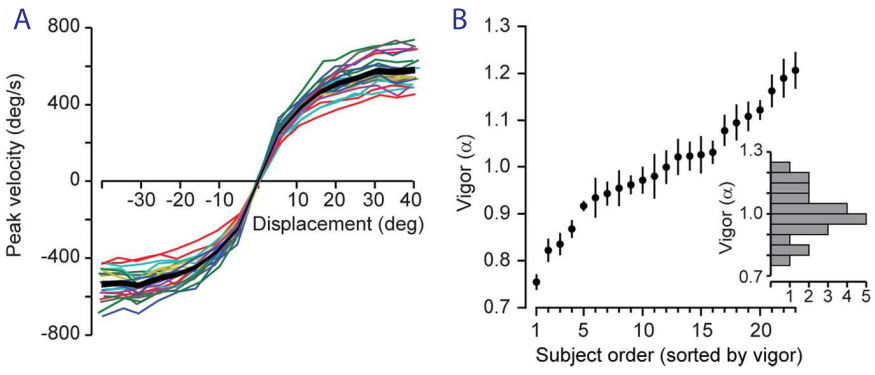


Figure 4.19: Vigor of saccades

I compared the vigor for head-fixed saccades, head-free saccades, head movements and hand movements. Surprisingly, there was hardly an effect of type of stimulation on vigor values. The vigor of saccades in the head-fixed and head-free paradigm were strongly correlated as shown in Fig. 4.20. The vigor of saccades was only weakly related to vigor of head movements and hand movements as seen in Fig. 4.21 and Fig. 4.22.

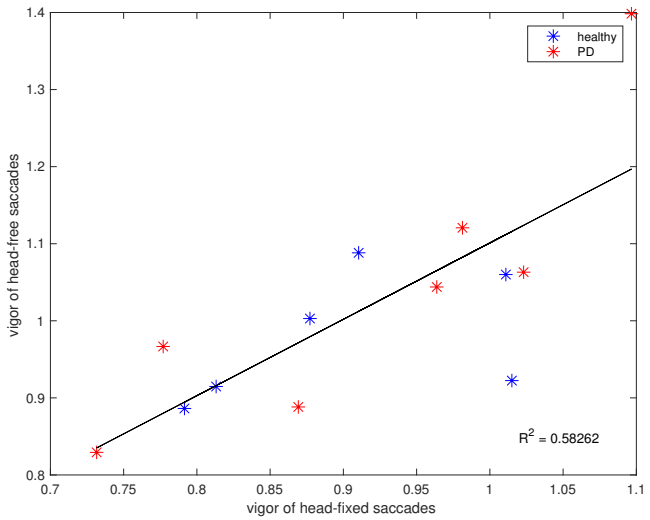


Figure 4.20: Vigor of head free saccades vs. vigor of head fixed saccades

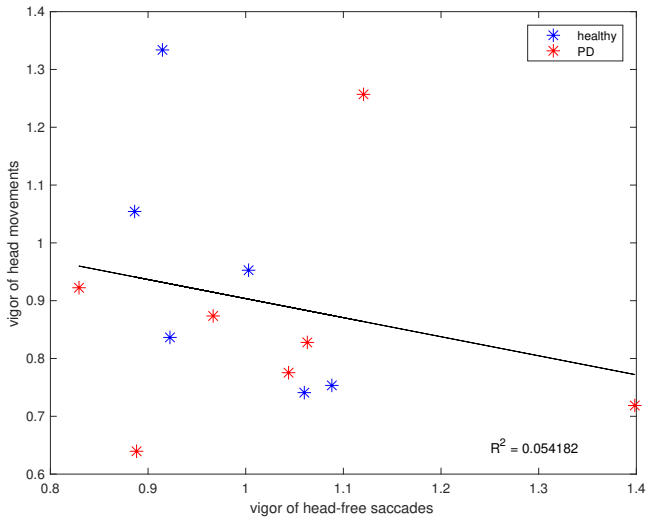


Figure 4.21: Vigor of head movements vs. vigor of saccades

The vigor of head movements and vigor of hand movements only shared a weak positive relationship, as shown in Fig. 4.23. However it is the only vigor plot in which

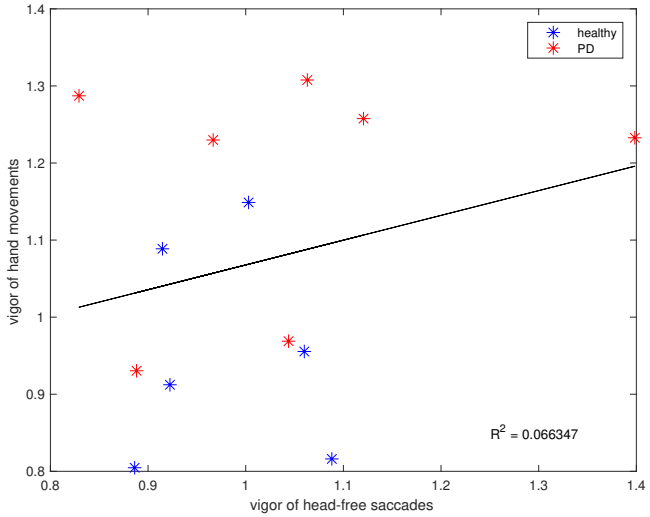


Figure 4.22: Vigor of hand movements vs. vigor of saccades

the PD subjects (denoted in red) and healthy controls appear separable. The PD subjects seem to make head movements with less vigor than healthy controls.

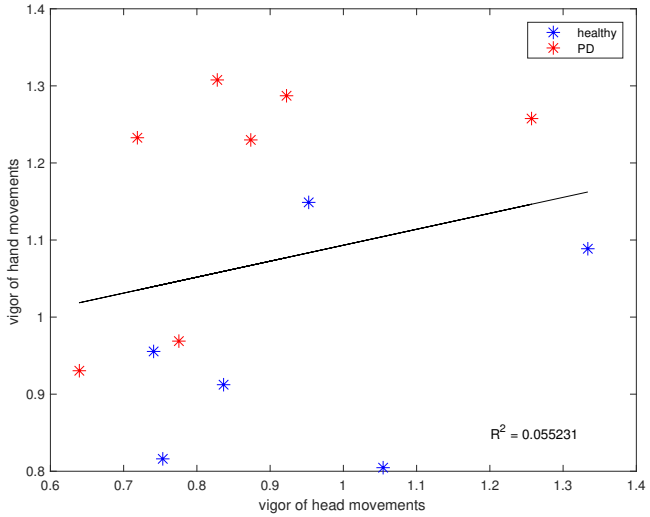


Figure 4.23: Vigor of hand movements vs. vigor of head movements

4.2.2 Comparison of movement traces

Identifying movement using velocity-based thresholds, as in the analysis conducted above, did not work well for head movements. Eye and hand movements are triggered by abrupt target jumps, and a new target is presented only if the subject's eye and finger reach the target. Hence the movements were suitably fast and velocity-based

identification could be used. Since there was no explicit target for the head to reach, the subject's head would drift very slowly to a new position.

In order to study this slow head drift, I decided to plot the average path the eye and head of the subject traced during a trial. I averaged across trials with target amplitude of 40°, because the amplitude is large enough to encourage head movement. For small target amplitudes such as 10° and 20° most subjects might not move their head at all. A movement trace plot example is shown in Fig 4.24.

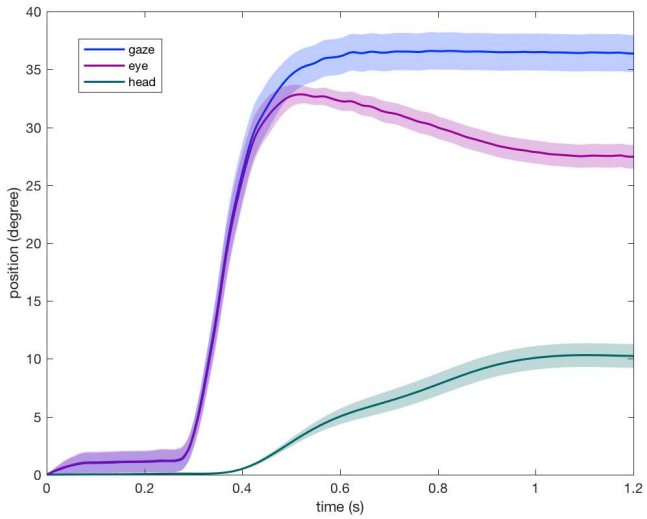


Figure 4.24: Example movement trace plot

To find if Parkinson's disease patients moved their head less, I compared the head traces for PD subjects and healthy controls. There was no uniform trend in the amplitude of head movement. The average head traces are shown in Fig 4.25. I then compared the movement traces for the cases of sham stimulation and cathodal stimulation for each PD subject. There was no significant and uniform difference in the two scenarios. Fig 4.26 shows the average head traces for the two conditions.

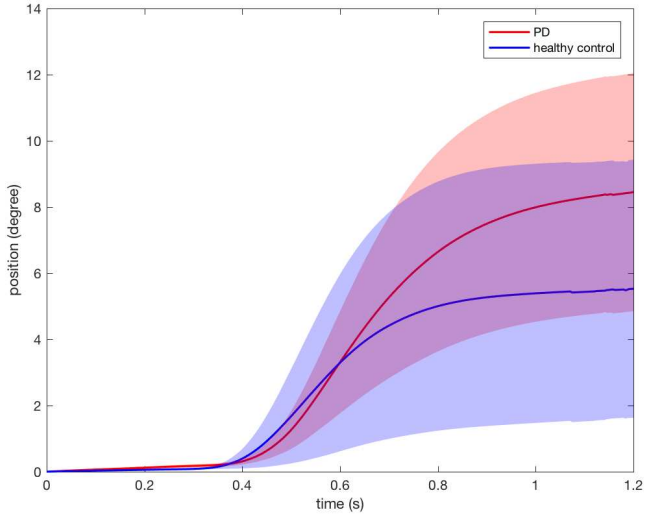


Figure 4.25: Average head trace plot: PD and healthy control

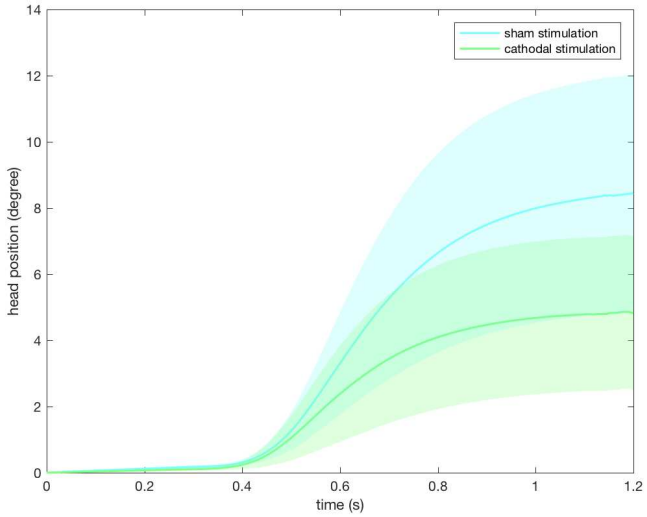


Figure 4.26: Average movement trace plot: cathodal and sham stimulation

CHAPTER 5

CONCLUSIONS

In our natural pointing task, the Parkinson's disease subjects had slower hand movements and marginally slower eye movements. PD subjects also suffer from greater saccade hypometria compared to healthy controls. PD subjects were just as accurate making saccades and had comparable saccade reaction times. However they seemed slightly less accurate and have slightly longer latencies for hand movements. They seemed to have less vigor of head movements compared to the age-matched healthy controls. I believe some of the results did not reach statistical significance due to the small sample size. To conclude, timing and kinematics of eye and hand movements have been altered in patients affected by PD. These results could have significance in providing markers for diagnosis of PD.

We did not find significant differences in the movements of PD subjects with the application of cathodal tDCS for the performance measures we studied. This implies that tDCS does not actually provide significant gains for PD subjects on dopamine medication, in contrast to what has been previously suggested. However, Salimpour et al. propose that tDCS was useful by reducing the signal dependent noise in the motor cortex of the subject. To investigate the effects of tDCS further, I propose to use the current experimental setup to find an explicit measure of signal dependent noise, for example the magnitude of tremor in the hand when the PD subject is asked to hold a fixed position, and find if it is modified by stimulation.

In our experiment, a new target position is shown at random and the subject reaches for the target from the current position. However head movements are influenced by the initial position. Consider a subject who moves his head only if the target amplitude is 30° or greater. When performing this task, if he is presented a 20° to the left of the centre , followed by a 10° to the left again, he would move his head when the 10° is presented. This issue can be solved if a new trial always starts at the centre. The subject would make a movement to the target position and back to the centre again in one trial.

In our task the subjects were asked to move their heads as they felt comfortable in order to mimic a natural environment. We found that data was very sparse and hence difficult to characterize. In an alternate formulation of the task, the subject can be provided feedback about the angle of rotation of their head by attaching a small laser to their forehead such that it points towards the screen. The subjects could then be provided targets on the screen to reach by moving their head, and a head movement main sequence can be found and used for comparison.

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