Gait Analysis of Multiple Sclerosis Patients

by

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ABSTRACT

Multiple Sclerosis, an autoimmune disease, is one of the most common neurological disorder in which demyelinating of the axon occurs. The main symptoms of MS disease are fatigue, vision problems, stability issue, balance problems. Unfortunately, currently available treatments for this disease do not always guarantee the improvement of the condition of the MS patient and there has not been an accurate mechanism to measure the effectiveness of the treatment due to inter-patient heterogeneity. The factors that count for varying the performance of MS patients include environmental setting, weather, psychological status, dressing style and more. Also, patients may react differently while examined at specially arranged setting and this may not be the same while he/she is at home. Hence, it becomes a major problem for MS patients that how effectively a treatment slows down the progress of the disease and gives a relief for the patient. This thesis is trying to build a reliable system to estimate how good a treatment is for MS patients. Here I study the kinematic variables such as velocity of walking, stride length, variability and so on to find and compare the variations of the patient after a treatment given by the doctor, and trace these parameters for some patients after the treatment effect subdued.

ACKNOWLEDGMENTS

Completing a MS is a challenge especially for an international student, and I would not have been able to complete this without the aid and support of countless people over the past two years. I must first express my gratitude towards my advisor, Professor Jiping He. His leadership, support, attention to detail, and hard work have set an example I hope to match someday.

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Chapter 1

INTRODUCTION

Multiple sclerosis (MS), also known as "disseminated sclerosis", is an inflammatory disease in which the fatty myelin sheaths around the axons of the brain and spinal cord are damaged, leading to demyelination and scarring as well as a broad spectrum of signs and symptoms.[1]

Almost any neurological symptom can appear with the disease, and often progresses to physical and cognitive disability.[2] MS takes several forms, with new symptoms occurring either in discrete attacks (relapsing forms) or slowly accumulating over time (progressive forms).

Symptoms of MS usually appear in episodic acute periods of worsening (called relapses, exacerbations, or attacks), in a gradually progressive deterioration of neurologic function, or in a combination of both.[3] Viral infections such as the common cold, influenza, or gastroenteritis increase the risk of relapse.[1] Stress may also trigger an attack.

Cure for multiple sclerosis has not been discovered yet. Normally, treatments are dedicated to return function after an attack, prevent new attacks, and prevent disability. In the laboratory, objective and quantitative methods are adopted in evaluating the gait pattern changes and this is efficient and cost effective too. Motion analysis is a type of technique used to capture the patient's motion using the various camera kept at different angles. But this is an expensive set-up to be bought by the clinic or for home purposes. The other major barrier in effectively monitoring the progression or relief of the disease using the quantitative methods is that the MS disease is highly variable involving various factors such as environmental setting, weather, psychological status, fatigue. For instance, there

was an overall decline in the performance of patients with MS (PwMS) who have additive cognitive tasks by processing their gait data (Sosnoff JJ, Boes MK, 2011). The patient may react differently while examined at specially arranged setting and this may not be the same while he/she is at home. Even different style of dressing can affect the performance of MS patients: it has been proved that textured insoles can produce improvements in stride length (Dixon J, Gamesby H, 2011).

Numerous previous researches have been done about the conditions and treatments of MS patients. Normally, patients are required to take some clinical tests or do a serial of exercise before recording their data, like the Coefficient of Variation (CoV) and the Approximate Entropy (ApEn) (Kaipust JP, 2012). Here I study the kinematic variables such as velocity of walking, stride length and stability to find the variations of the patient after a treatment given by the doctor. I am taking all the factors mentioned above into consideration and building a cost effective wireless sensor system such the parameters I get from the sensor is easily monitored through a mobile. What's new in this research is that I plan to use fewer sensors to monitor the selected important parameters instead of requesting patients to carry these sensors all over body (e.g. waists, ankles, elbows, etc) (Spain RI, St George RJ, 2012). These can be transmitted through the doctor such that the doctor can monitor the day to day activities of the patient, while the patient is at home.

Chapter 2

LITERATURE REVIEW

Multiple Sclerosis

Since this research is to analysis the quantifiable gait parameters of multiple sclerosis patients, it is extremely important to understand what is multiple sclerosis, what kind of symptoms will MS patients have, what factors will influence the performance of MS patients and so forth.

Whereas I have talked about the possible symptoms that MS patients may have, I will start with the treatment or drugs that may improve the physical functions of MS patients. When it comes to the treatment for PwMS, Joseph R. Berger (2011) has published a comprehensive and prominent review about some weighted drugs to relieve the symptoms of this disease. He mainly classified all these drugs into 3 categories: Disease-modifying treatments (DMTs), Corticosteroids, and Dalfampridine. Moreover, this paper also illustrates whether these drugs could contribute to improve the quality of life (QOL).

The first category, disease-modifying treatments, mainly contains five drugs that are normally applied in clinic.

Interferon-beta (IFNB) is a cytokine primarily secreted by fibroblasts as part of immune response, and it can be reproduced by recombinant DNA technology in therapies. In MS, the IFNB is thought to act by involving modulating immune system through interactions with specific cell-surface receptors. The shortage of this drug includes that its effect could be lessen in some patients who develop neutralizing antibodies over time.

Glatiramer acetate (GA) is a synthetic analog of myelin basic protein, the MS-associated antigen. GA mechanism seems to induce a shift in cytokine production toward secretion of anti-inflammatory cytokines.

Natalizumab is a monoclonal antibody that blocks lymphocyte entry into the central nervous system. What seems more appealing is that adding natalizumab to IFNB-1a further reduced relapse rate and disability progression compared with treating with IFNB-1a alone, which provides an insight about how to improve the efficiency of treatment. Unfortunately, this drug may cause progressive multifocal leukoencephalopathy (PML), which leads to the manufacturer suspended marketing.

Mitoxantrone, an immunosuppressant, reduces lymphocyte proliferation via several mechanisms. Similar to Natalizumab, some serious side effects like decreased systolic function, heart failure prevent the wide use of this drug.

Fingolimod, an immunomodulator originally used in organ transplantation, is marketing as an oral drug. Evidence show that an oral DMT have apparent QOL advantages over injected therapies, especially for newly diagnosed patients who could benefit from early intervention to delay progression. Again, the safety concerns block fingolimod from being the oral therapy that presumably replaces injected agents since the patients may experience fatal infection, atrioventricular block, and elevation of liver enzymes.

Whereas DMTs reduce the rate and severity of relapses, the accumulation of brain and spinal cord lesions detected by magnetic resonance imaging (MRI), and disability progression as measured by Expanded Disability Status Scale (EDSS), relatively few DMT trials documented QOL improvement with QOL

metrics. Hence, even some patients report poor quality of life (QOL), and adverse effects (AEs), clinicians still appreciate the effects of DMTs.

The second category he introduced is corticosteroids. Corticosteroids have anti-inflammatory effects that reduce severity and duration of acute relapses, but do not affect the disease course. They have been shown to speed relapse recovery in several trials. Corticosteroid treatment commonly begins with intravenous methylprednisolone, followed by tapering oral prednisone; high-dose oral steroids have also been used. QOL scores on MSQOL-54 and MS Functional Composite have improved with methylprednisolone treatment of relapses.

The last drug that proved to be effect in MS treatments is Dalfampridine, which takes effect by blocking the voltage-dependent potassium channels on the surface of demyelinated nerve fibers. Its marketing name, Ampyra, received FDA approval for all forms of MS specifically to improve walking, which was demonstrated by increased walking speed. Dalfampridine does not address disease modification, but can be used with DMTs and other medications. The active ingredient in dalfampridine is 4-aminopyridine (4-AP), which proved to be potent for elevating patient's QOL and satisfaction even before the development of dalfampridine for MS.

Before that, Filippini G. Brusaferri F (2009) had published a review about the efficacy and safety of corticosteroids or adrenocorticotrophic hormone (ACTH) in reducing the short and long term morbidity from MS. In this research, they selected lists of articles, undertook handsearching, and contacted trialists and pharmaceutical companies without any age or severity restrictions for the

patients. The drugs analysed were methylprednisolone (MP) (four trials, 140 participants) and ACTH (two trials, 237 participants).

Overall, the results show that MP or ACTH indeed has a protective effect against the MS disease getting worse within the first five weeks of treatment with some but non-significant greater effect for MP and intravenous administration. Besides, the duration of treatment (5 days vs. 15 days) with MP did not show any significant difference. However, data are insufficient to accurately estimate effect of corticosteroids on prevention of new exacerbations. In terms of long-term progression, no data are available beyond one year of follow-up to indicate whether steroids or ACTH have any lasting benefit or aside effect.

Gait of MS patients

As gait is an extremely important parameter in measuring and monitoring the walking pattern of MS patients, R.I. Spaina, and R.J. St. Georgeb (2011) conducted an experiment to investigate the gait of subjects with any type of MS and normal T25FW (Timed 25 Foot Walk, used in the MS clinic) by body-worn sensors.

In this research, thirty-one subjects need to complete four tasks: Timed 25 Foot Walk (walk 25 feet in a hallway); Timed-Up-and-Go test (stand up from a chair, walk 7 m, turn, then walk back and sit down); Quiet standing task (stand with arms crossed and feet placed by a template block for 30 seconds, three trials with eyes open and three with eyes closed); Self-reported balance and walking measures (subjects complete 3 reports: one is designed to predict falls in the

MS population, one is to reflect the impact of MS on walking , and the last is to rate the neurological function in MS patients).

The results show that during gait, people with MS had increased trunk roll of motion, which means PwMS are harder to control their dynamic balance and easier to cause instability. Meanwhile, PwMS spend significant longer time during turnings suggesting an impaired proprioceptive system. The reason is extra weighting may be placed on the proprioceptive systems when a head turns in preparation for body turn. On the other hand, sway acceleration amplitude increased more in people with MS with eyes closed condition during quiet stance, and they concludes that PwMS have a greater reliance on visual input due to loss of other balance maintenance functions.

In order to comprehend the gait features of PwMS who don't have normal walking speed, Jacob J. Sosnoff and Brian M. Sandroff (2012) compared the gait of PwMS who have mild disability and healthy subjects.

86 participants were selected in this research, half of the sample had mild multiple sclerosis (MS group, had a median EDSS score of 2.0 of a 0-10 scale) and the remaining half were healthy subjects. These participants were told to complete four walking trials along a 26-foot GAITRite™ (a commercially available gait analysis system) mat at a self-selected pace. The parameters recorded includes functional ambulation profile (FAP), cadence (steps/min), velocity (cm/s), step length (CM), step time (s), base of support (cm), and intra-individual variability based on coefficient of variability (CV) of those parameters. The results show that MS patients have a significant lower velocity, shorter step length, larger base of support than controls. Besides, the CV of step length and step

time is much larger in MS patients than in controls, which means MS patients have a relatively unstable velocity and stride length.

Hence, they concluded that patients with even mild MS (not defined as clinical gait impairment by EDSS evaluation) still have detectable differences in gait with utilizing GAITRite technology. Besides, from the CV of these parameters, they assume that these patients with MS (PwMS) had greater step time variability and single support time variability than controls might reflects mobility impairment and/or falls in PwMS.

Moreover, some inconspicuous factors may affect the gait of PwMS. Dixon J and Hatton AL (2011) have found that textured insole is one of these factors that can produce improvement on gait in PwMS. Their previous studies have shown that footwear, including textured insoles, may improve postural stability in healthy young and older adults (Palluel et al., 2008; Hatton et al., 2009; Hatton et al., 2011).

Forty-six people with MS (34 women) were randomized to one of two textured insole groups: texture A, which was used in their previous studies, or texture B, a commercial insole. These participants were then required to walk along the same gait analysis system as Jacob J. Sosnoff and Brian M. Sandroff (2012) used (GaitRite^{TM}). Afterwards, they need to wear the insoles for two weeks and returned for repeat testing.

The results show that stride length increased between baseline and follow-up in both legs in group A and group B. However, both velocity and cadence did not change significantly in either group. They think this implies that textured insoles can at least improve MS patients' stride length.

Chapter 3

METHOD

3.1 Trials of each patient

Here I focus on analyzing the various gait parameters of five MS patients who have been given the treatment of corticosteroids. I collected the data of two patients under before and after treatment conditions, while the other three patients' data is collected under before, after and follow up treatment conditions. Meanwhile, some patients are tested with shoes on only, and others are tested with both shoes on and shoes off. The table below concludes the condition under which the patients are tested.

Table 1: The number of patients under each condition

	Before and after treatment only	Before, after and follow up treatment
Shoes on only	1	1
Shoes on and Shoes off	1	2

The specific aim for this research is to see how the patient is able to walk before the treatment and how is he/she able to respond to the particular treatment given by the doctor, which requires analyzing and comparing the data of patients before treatments and after treatment.

3.2 Inclusion criteria

Participants included four male and one female MS patients whose age ranged from 21 to 65. These patients have either primary or secondary progressive MS, with gait disorder as primary manifestation. Their Expanded Disability Status Scale (EDSS) score ranged from 4.5 (able to ambulate independently for up to 300 m) to 6.0 (ability to ambulate up to 100 m with unilateral assistance), with change in EDSS of 1 point in the last 12 month based on recorded examinations and report. The planned treatment for them is intravenous methylprednisolone (1000 mg/d x five days). [11]

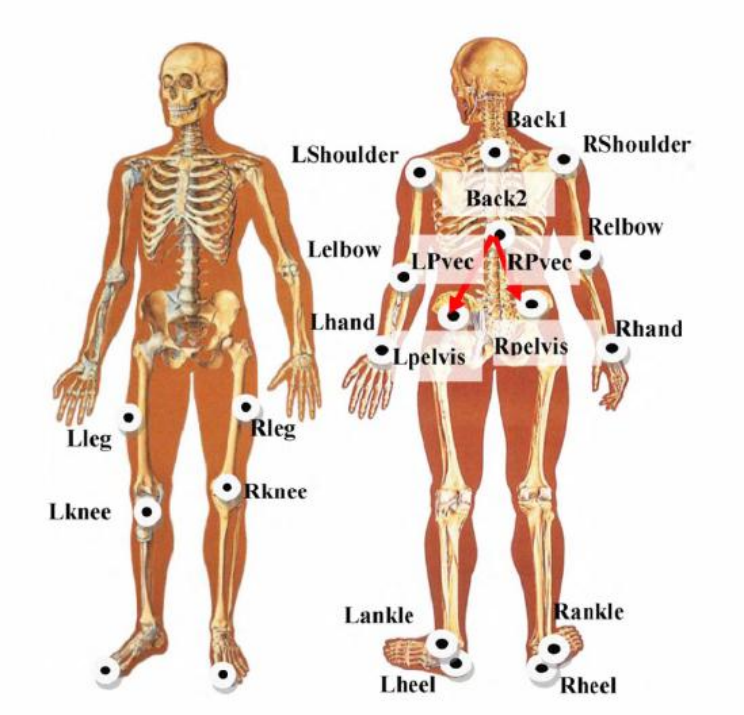
Evaluations:

Clinical: neurological examination, EDSS, ambulation index, timed 25-foot gait, PASAT [Paced Auditory Serial Addition Test; a standard MS clinical outcome], gait phenotype classification (spastic, ataxic, or spastic-ataxic), and assessment of quality of life (SF-36 questionnaire) and fatigue (MSFS; MS-Specific Fatigue Scale). Participants will rate their post-treatment response on a 7 point rating scale from -3 (much worse gait) to +3 (much better), where zero represents no effect. This assessment will be performed three (3) times at Mayo Clinic: up to 14 days pre-treatment; 3-7 days post-treatment onset; and up to 6 months post-treatment. [11]

3.3 Experimental setup

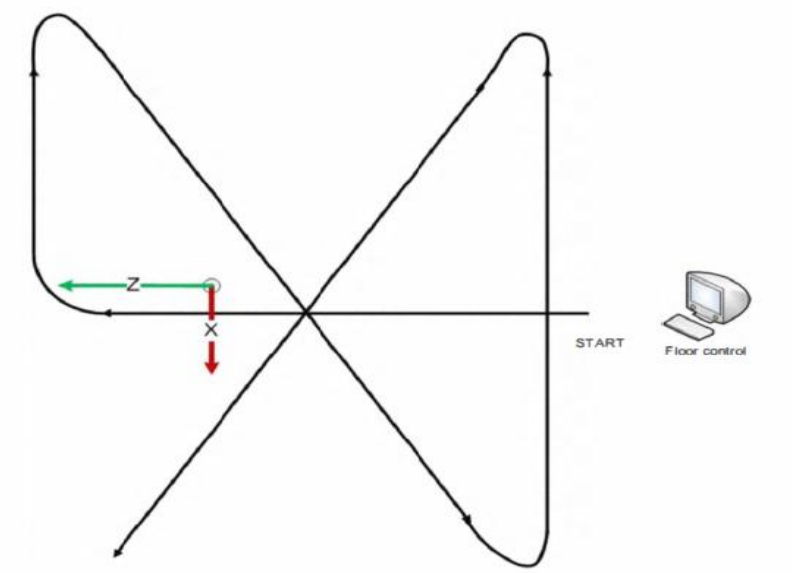
The twenty markers attached on the patients allowed the reconstruction of individual joint angles and trajectories of hands and feet in the three dimensional space.

Figure 1: Placement of 20 markers



Here I used the motion capture system provided by the iStage at Mathews center in Arizona State University. Totally ten infrared cameras were used throughout the analysis covering the patient's walk path, which includes three long straight paths, one short path, one smooth turning and three sharp turnings as shown in the figure 2. Each subject is told to walk along the path for 3-5 trials either with shoe on only or both shoes on and shoes off.

Figure 2: The path that patients work through



The software that was used for this project is Cortex and Evart Motion capture system. Mostly Evart was used. Initial calibration of the motion capture system is done including L-frame, wand calibration and neutral T-Pose with patient wearing all the markers.

There would be analysis in three phases,

- Before the treatment- Before giving corticosteroids treatment and figuring out how the patient is initially walking.
- After the treatment - After the treatment and analyzing how the patient has responded to the treatment since corticosteroids are used in curing the progression of MS disease at least temporarily.
- Follow up treatment - Another analysis is done after the effect of the steroid is completely over in the patient's body to study effectively how the treatment has worked and also to verify the results.

If some markers were misplaced by the motion capture system, then rectification has been done using the software system to correct the marker position. The data I obtained were rectified as accurately as possible, but there are still some markers are missing, especially in the 4th straight path in some trials.

3.4 Body coordinate system

Body coordinate system is used to determine the position of each part of the body with the center, or the origin, is fixed on body. This system is also constructed by 3 dimensional axes: determine x(facing), y(vertical), z(lateral) axis. As long as I have defined 2 axes, the third one can be calculated as the orthogonal vector to the plane formed by those 2 axes. Hence, here I am trying to define and calculate facing direction, which is x axis, and lateral direction, which is z axis.

A. Find Facing Direction

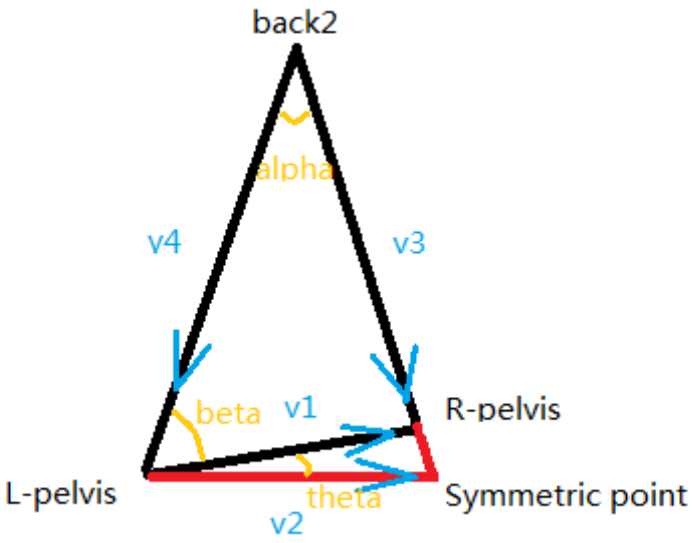
The facing direction is the orthogonal vector to the plane formed by three markers on the lower back. It is computed as the cross product of RPvec and LPvec (see Figure 1), and defined as FDvec.

FDvec = RPvec x LPvec

B. Find Lateral Direction

The lateral direction of body is determined by RPvec, LPvec as well as back2 marker. Since the left pelvis marker and the right pelvis marker are presumably not placed symmetrically, I figured out a way to find the point that is symmetric to left pelvis.

Figure 3: Reconstruct body coordinates



v1=R-pelvis – L-pelvis

v2=later axis (z axis)

v3=R-pelvis – back2

v4=L-pelvis – back2

Basically, I built 3 equations to determine v2 (a, b, c), which has 3 variables.

(1) The length of v2 is fixed

$$norm(v2) = (a^2 + b^2 + c^2)^{1/2}$$

Where $\text{norm}(v2) = 2 * norm(v4) * \sin(alpha / 2)$, and

$$alpha = \arccos(v3 \cdot v4 / norm(v3) * norm(v4))$$

(2) The angle between v1 and v2 is theta, which is about 6 degrees (calculated from T-pose)

$$a * v1.x + b * v1.y + c * v1.z = norm(v2) * norm(v1) * \cos(theta)$$

(3) The angle between v2 and v3 is gamma (which is beta plus theta).

$$a * v4.x + b * v4.y + c * v4.z = norm(v4) * norm(v1) * \cos(180 - gamma)$$

Where

$$\text{gamma} = beta + theta$$

$$beta = 180 - \arccos(v1 \cdot v4 / norm(v1) * norm(v4))$$

Or

$$\text{gamma} = (180 - alpha) / 2$$

3.5 Velocity calculation

For each individual straight path, start and end frames are noted from the stick diagram. A new coordinate system is defined with respect to the start frame. Thus the start frame becomes the origin with respect to the other frames for both the x and z axis in the global coordinate system. The position vector (dz and dx)

in the z and x axis respectively is calculated by two point differentiation methods and to give the velocity vector at that instant.

velvector=(b(x+t)-b(x))/ t.

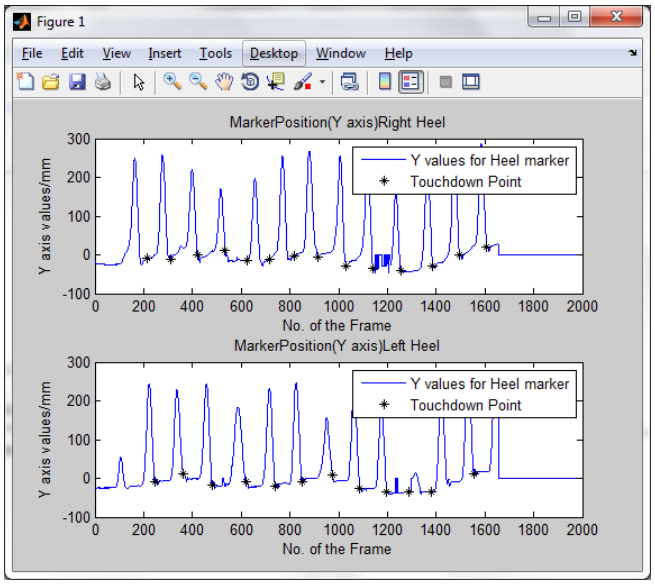
where, b denotes the back2 marker position vector and t is the time difference between them (x+t and x). The velocity magnitude is thus calculated from them. Inasmuch as back2 marker stands around the central point of human body and presents in almost all the frames throughout the walking trials, it would be more accurate to calculate the velocity by using it.

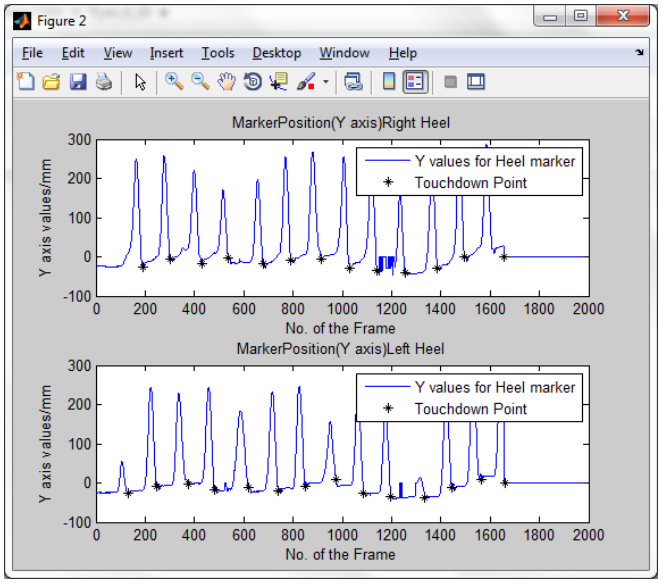
3.6 Gait segment and stride length

With the assumption that patients touch the ground with their heels first, I use the time point as soon as the y-axis value of left/right heel reaches the lowest to segment gait cycles, which means these time points are the ending frames of current gaits as well as the starting frames of next gaits. Since the patterns of gaits are different from patients to patients and also vary between shoes on and shoes off conditions, I manually adjust the parameters to select the right positions of time points.

Figure 4: Adjustments for time points

Before adjustment





After adjustment

After recording the right time points, I calculate the distance between the markers on heels at two consecutive time points in global coordinate system as the stride length. On the other hand, I recorded the starting and the ending frame number of each straight path and each turning so that I can analysis the data separately.

Chapter 4

DATA ANALYSIS AND RESULTS

4.1 Velocity

Table 2: Mean of the patient's velocity

Subject	Before Treatment		Post Treatment		Follow up	
	Shoes Off	Shoes on	Shoes off	Shoes on	Shoes off	Shoes on
A	0.619	0.631	0.545	0.589	0.655	0.696
B	0.639	0.716	0.75	0.773	0.73	0.773
C	NA	0.989	1.16	1.12	NA	NA
D	0.686	0.649	0.717	0.696	NA	NA
E	NA	0.787	NA	0.836	NA	0.797

Table 3: CV of the patient's velocity

Subject	Before Treatment		Post Treatment		Follow up	
	Shoes Off	Shoes on	Shoes off	Shoes on	Shoes off	Shoes on
A	28.17	30.78	28.55	25.67	20.59	21.87
B	19.93	14.22	18.08	16.36	21.75	17.68
C	NA	24.62	18.18	22.17	NA	NA
D	26.33	28.26	27.34	34.44	NA	NA
E	NA	25.81	NA	23.4	NA	22.32

Generally, I compare the mean of each patient's velocity as well as the coefficient of variation of each patient's velocity. The results show that 4 out of 5 patients have a higher average velocity after treatment compared to before treatment for both shoes on and shoes off conditions. However, the change of coefficient of variation depends on individuals and whether the patients are wearing shoes. With shoes on, the data of 3 out of 5 patients (*) indicates their velocity is more stable after treatment (with a decreased CV of velocity). Star

marker in the brackets indicates that patient A is included in this group. Meanwhile, only 1 out of 3 patients with shoes off has a significant decrease in CV of velocity after treatment.

In terms of follow up condition, I have 3 out of those 5 patients come back about 3 months after treatment. Among these 3 patients, 2 patients have lower average velocity and that one who reports he felt worse after treatment actually have a higher velocity compared to after treatment, which means he “recovers” from the treatment. When it comes to CV of velocity, the results are not the same for all the patients. For 3 patients under shoes on condition, 2 of them (*) have a more stable velocity compared to after treatment. While 1 of 2 patients (*) under shoes off condition have a more stable velocity.

From the analysis above, I can see that patients do have a greater velocity after treatment, but it is not sure whether they will have a more stable walking speed after treatment. However, this treatment doesn’t have a significant or unified effect on the variability of velocity for all the patients.

Also, shoes have different effects on patients as the terms of the variability of velocity. Most of the data suggests shoes will impair the variability of velocity, but one of these patients have a more stable velocity with shoes on under all 3 conditions: before treatment, after treatment, and follow up conditions.

4.2 Stride Length

Table 4: Mean of the patient's stride length

Subject	Before Treatment		Post Treatment		Follow up	
	Shoes off	Shoes on	Shoes off	Shoes on	Shoes off	Shoes on
A	807.70	847.70	790.20	869.20	822.50	932.65
B	755.70	863.90	831.10	947.60	859.40	998.80
C	NA	1191.10	1200.30	1186.10	NA	NA
D	844.40	846.50	988.50	968.40	NA	NA
E	NA	868.90	NA	934.90	NA	884.30

Table 5: CoefVar of the patient's stride length

Subject	Before Treatment		Post Treatment		Follow up	
	Shoes off	Shoes on	Shoes off	Shoes on	Shoes off	Shoes on
A	17.57	16.92	16.12	14.56	16.69	9.51
B	18.18	19.92	22.43	19.21	21.17	19.56
C	NA	20.89	27	26.92	NA	NA
D	25.1	20.3	13.96	25.16	NA	NA
E	NA	22.96	NA	20.44	NA	19.71

Similar to the analysis of velocity, I compare the mean of each patient's stride length as well as the coefficient of variation of their stride length. The results also show that 3 out of 5 patients have a larger average stride length after treatment compared to before treatment for both shoes on and shoes off conditions. The only one who has a significant smaller average stride length is patient A, who reported this treatment worsen his condition. The change of coefficient of variation also depends on individuals and whether the patients are wearing shoes. With shoes on, 2 out of 5 patients (*) have a significant improvement as the stability of their stride length after treatment (with a decreased CV of stride

length), and 1 out of the other three patients have a slightly decline as their mean of stride length after treatment. Meanwhile, 2 out of 3 patients (*) with shoes off have a significant decrease in CV of stride length after treatment.

In terms of follow up condition, what attracted me is patient B, who still has a rise as his average stride length compared to after treatment condition. I assume this presumably caused by some other factors like weather, or the treatment itself.

When it comes to CV of stride length in follow up condition, the results are not the same for all the patients. For 3 patients under shoes on condition, 2 of them (*) have a noticeable more stable stride length compared to after treatment, whereas the other one has no substantial change. On the other hand, 1 of 2 patients under shoes off condition gets better as terms of the stability of stride length, while the other one (*) shows no obvious changes.

From the analysis above, it is disinterested to say that patients predispose to have a greater stride length after treatment, while it is not sure whether they will have a more stable stride length after treatment. That is to say, this treatment doesn't have a significant or unified effect on the variability of velocity for all the patients.

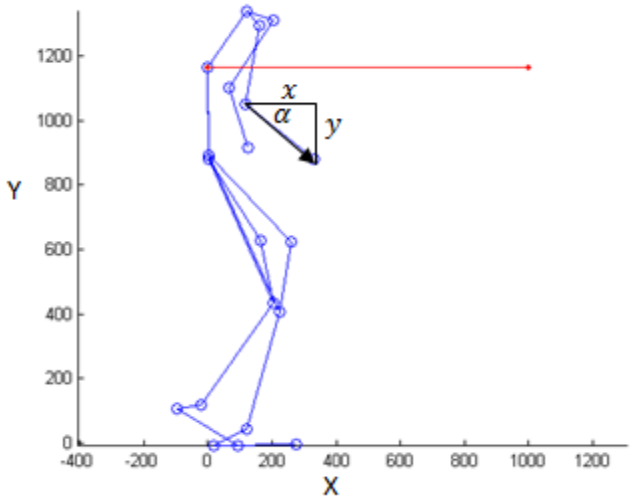
Also, shoes have different effects on patients as the terms of the variability of stride length. Most of the data suggests shoes will impair the stability of velocity, but one of these patients have a more stable velocity with shoes on under all 3 conditions: before treatment, after treatment, and follow up conditions.

4.3 Variability

After converting the global position of all the markers to the body centered position, now it is ready to compute range of motion of ten rigid parts of body. These ten rigid parts include upperArm, lowerArm, upperLeg, lowerLeg, and foot for each side of the body, each rigid body is represented by a vector. The vector is calculated from the marker attached on both ends of the rigid body. Then the range of motion is the angle between this vector and the plane constructed by facing direction and lateral direction of the body.

The range of motion vector is computed from A-P view (Figure 5) as AP angles: In A-P view,$\alpha = Invtan(x, y)$, I define that if α is above horizontal line, it is negative, otherwise positive.

Figure 5: Stick man A-P view



After calculating ten parameters in total for each patient, I found that upper arms and lower arms have the most significant change between before treatment and

after treatment, and these four parameters (right upper arm, left upper arm, right lower arm, left lower arm) could represent all the parameters in variability analysis. This finding can be explained by the free range of motion, which is largest for arms when compared with legs and feet.

Table 6: Standard deviation of the patients' rigid parts performance

Subject	Before Treatment				Post Treatment				Follow up			
	Shoes off		Shoes on		Shoes off		Shoes on		Shoes off		Shoes on	
A	3.83	7.97	3.92	10.64	6.01	11.29	5.54	9.89	5.48	8.25	5.78	7.93
	5.43	8.67	7.03	8.48	5.86	11.22	6.52	12.28	6.44	10.05	5.87	8.63
B	4.65	5.38	4.23	4.96	4.94	7.15	4.63	6.13	4.08	4.58	3.19	4.93
	3.43	4.72	2.98	3.85	4.21	5.23	3.99	4.69	3.91	4.62	3.66	4.51
C	NA		6.51	8.67			8.31	14.45	NA		NA	
			7.62	8.92			5.94	7.8				
D	10.15	12.54			10.77	14.16			NA		NA	
	9.76	11.80			5.43	9.12						
E	NA		5.11	7.76	NA		6.07	8.08	NA		6.22	8.13
			4.49	6.86			4.29	5.91			4.50	6.84

From the table above, it is perspicuous to conclude that the variability issue is different from patients to patients. Even so, there are still some rules that could be observed from comparing with the CV of patients' stride length table. If I compared the mean of standard deviation of upper arm with the mean of standard deviation of lower arm under every single condition, it is easy to obtain that this value is always larger in lower arm than in upper arm, this observation is consistent with the concept that lower arm has a larger free range and significant impact on the balancing system of human. Moreover, the changing between before treatment and after treatment is in the same style for upper arm and lower arm, which means not only are these two parts correlated to each other, but also merely detecting the movement of either one side in the sensor system that will

be built in the future is enough. Whereas the variability pattern of upper arm is similar to that of lower arm, the variability pattern of left arm could be completely different than that of right arm. For example, the last patient's left arm moves more stable after treatment, while the mean of standard deviation of his right arm increases after treatment. However, the treatment has the same effect on the variability of first 2 patients' arms. I assume this is because some patients rely on one side of the body to support their weights, and others don't have a preference of which side of the bodies to put their weight on when they are walking.

As terms of treatment effect, I find that the variability of the patients is somehow related to their CV of stride length. For the first patient, his mean of standard deviation for both arms go up, which means this treatment has a negative effect on his variability, and this result is consistent with his condition he reported. As for the second patient, these values also go up as the CV of his stride length indicated. The situation is slightly different for the last three patients. Their right arm has a larger mean of standard deviation after treatment, whereas their left arm acts more stable after treatment.

4.4 Power Analysis

In the following Power Analysis, I consider before treatment data as control groups. Specifically, in this research I choose four parameters: mean of stride length, CV of stride length, mean of velocity, CV of velocity. These four parameters are the most important parameters in this research and in this kind of research. Here I listed two primary reasons of why I choose these four parameters. One reason is that CV of stride length and CV of velocity could aptly

reflect the variability and stability of the walking, whether the patients' stride and velocity went on smoothly. An even more striking reason is that mean of stride length and mean of velocity can reflect the "quality" of the walking. Besides, a plenty of studies show that patients walk slower and use smaller strides than normal people do.

I. Stride Length: before treatment VS after treatment

Hypothesis 1: Patients have 5% greater stride lengths post treatment

Hypothesis 2: The variability is 5% smaller post treatment

Table 7: Power analysis according to patient's stride length

	Size	**Standard deviation**	**Difference**	**Power**	**Actual Power**
Mean of stride length	96	135.9	49.06	0.8	0.801589
Variability of stride length	177	3.804	1.01	0,8	0.801812

II. Velocity

Hypothesis 1: Patients have 5% greater velocity post treatment

Hypothesis 2: The variability is 5% smaller post treatment

Table 8: Power analysis according to patient's velocity

	Size	Standard deviation	Difference	Power	Actual Power
Mean of velocity	235	0.1745	0.04014	0.8	0.800942
Variability of velocity	338	6.46	1.237	0,8	0.800096

Chapter 5

DISCUSSION

From all the results above, it is persuasive to point out that the effect of this treatment depends on patients. Although there are some parameters, such as mean of stride length and mean of velocity, change accordingly for all the patients, most variability-related parameters are not consistent with all the patients. On the other hand, the variability analysis proves that the arms take major responsibility for the balance system of human body. The change of variability also depends on the individual patients and their walking habit, which is the side(s) they put their weights on while walking.

As concluded in the velocity and stride length analysis part, the mean of velocity increases and the mean of stride length becomes larger for four out of five patients (patient B, C, D, E). The reason why patient A has the opposite result of these two parameters is probably because that he reported that he felt perceptible worse after the treatment. The interesting thing is that his CV of stride length and velocity are somehow smaller after treatment, which means he has more stable stride after treatment. However, the variability analysis of his data shows his performance tends to be more variable after treatment as terms of his arms. I guess the explanation underlie this kind of situation is that he walked slower and with smaller strides, as well as trying hard to use his arms to keep balance, so that he can have a relatively stable stride and walking speed.

The conditions of the patients are not only related to their physical status, but also expressed by their mental status. In this thesis, I only take a mathematical computation and statistical analysis to estimate the change of these patients'

physical conditions between before treatment and after treatment, some with an extra follow up condition. The future work could relate the physical improvement with psychological change, e.g. whether the patients feel better, if they have an improvement as quality of life.

I think there are two major aspects that can be improved for this project. Since I only have 5 patients to test in this project, I anticipate reaching more conclusions and testifying some precarious ideas when I have more patients, like 150 of them, to exam statistically. With more data, I can decide whether the occasion described above (patient A) is a rare or common situation, so that I could have a deeper insight about the physical condition of the patient who feels worse after receiving a treatment, or the negative impact of a treatment as terms of physical movement.

Another aspect that can be improved is the motion capture system. I use 10 cameras to capture the motion of patients, which causes markers missing in some frames, especially for turnings. This could lead to varieties of problems such as fail to construct body coordinate system if the back2 marker or left/right pelvis marker is missing, or unable to analyses the variability of some rigid parts of human body if the corresponding markers are not shown in the stick figure. According to my experience and some work form other researchers, 12 cameras would be the optimal number.

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APPENDIX A

STORAGE OF MAKER SET IN ARRAY

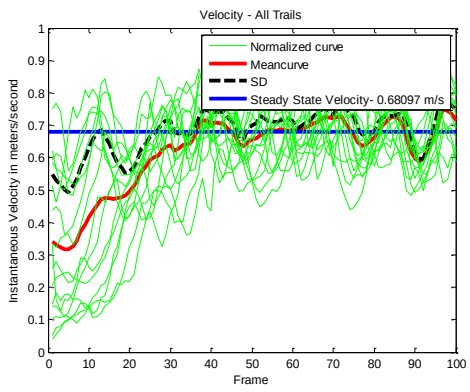
Here is the order of all the 20 markers and their position in array (each take 3 consecutive bytes for x, y, z). “l” stands for left and “r” stands for right.

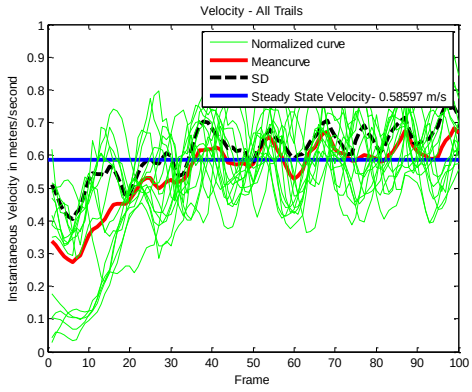
Markers Order	Minimal	Maximum
back1	1	3
back2	4	6
rshoulder	7	9
relbow	10	12
rwrist	13	15
lshoulder	16	18
lelbow	19	21
lwrist	22	24
rwaist	25	27
lwaist	28	30
rleg	31	33
rknee	34	36
rankle	37	39
rheel	40	42
rtoe	43	45
lleg	46	48
lknee	49	51
lankle	52	54
lheel	55	57
ltoe	58	60

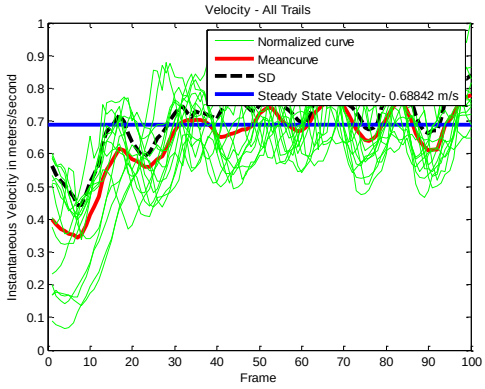
APPENDIX B

VELOCITY FIGURES FOR ALL THE PATIENTS

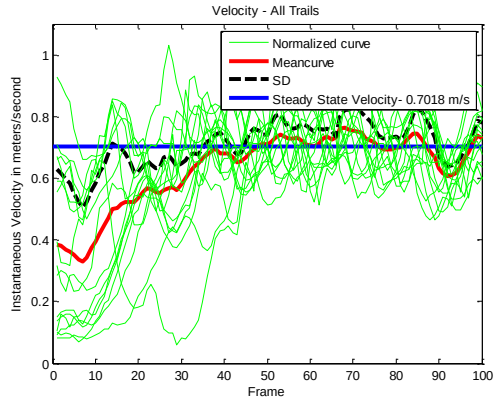
Patient A Before (upper left), After (upper right) and Follow-up (lower) Treatment - Shoes Off

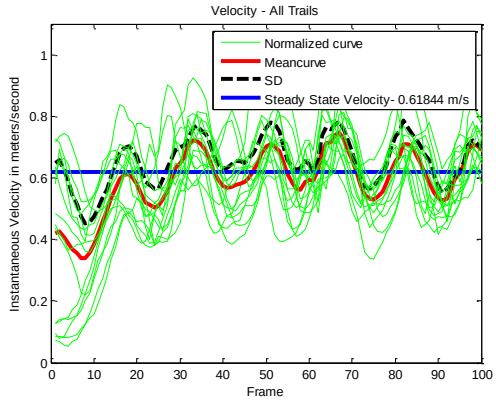


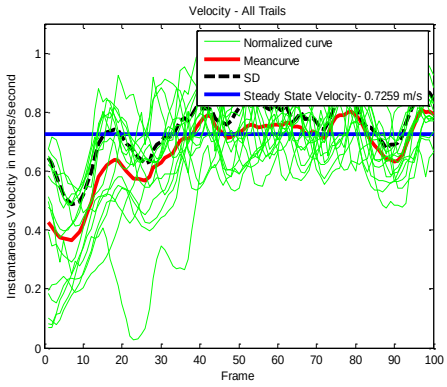




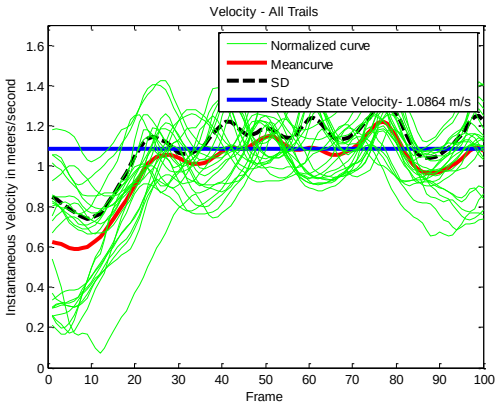
Patient A Before (upper left), After (upper right) and Follow-up (lower) Treatment - Shoes On

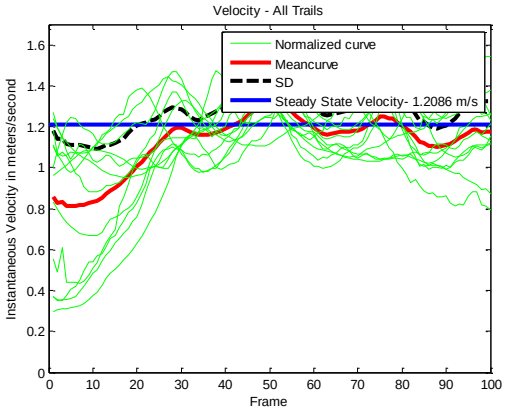




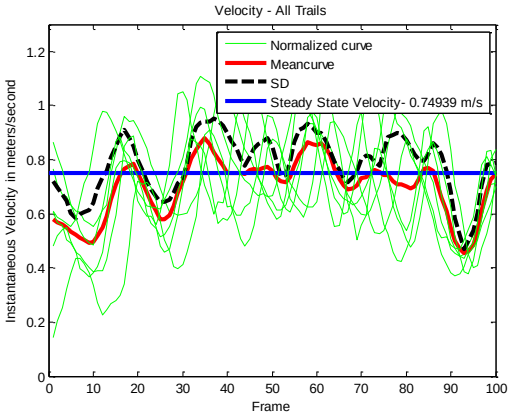


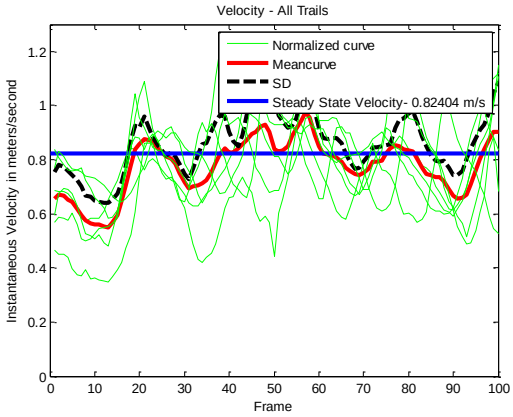
Patient C Before and After Treatment



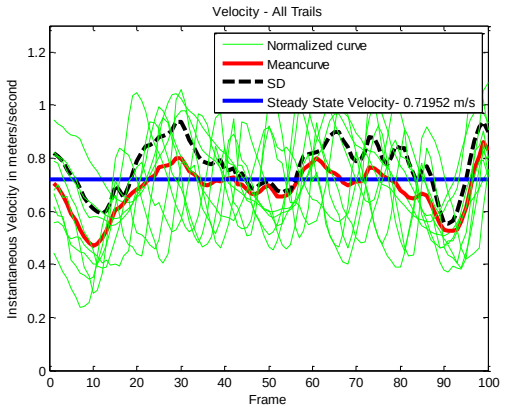


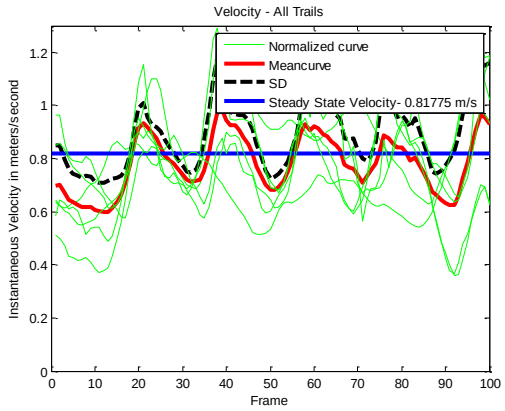
Patient D Before (left) and After (middle) - Shoes Off



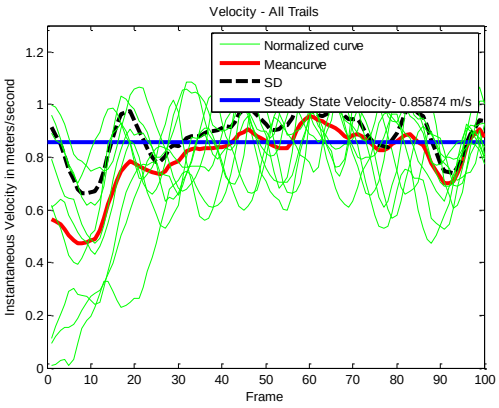


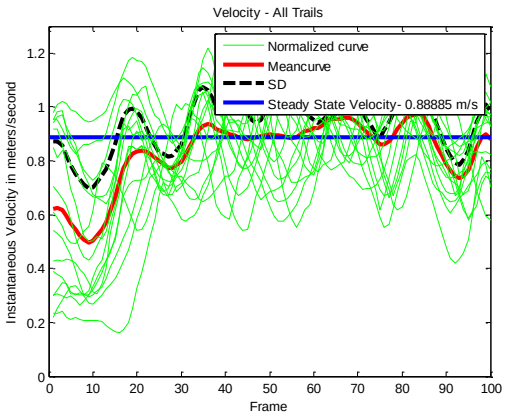
Patient D Before (left) and After (middle) - Shoes On

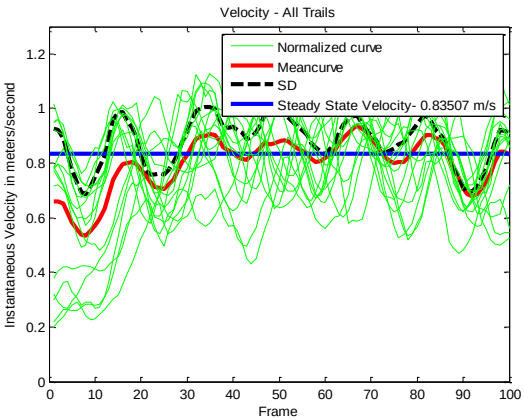




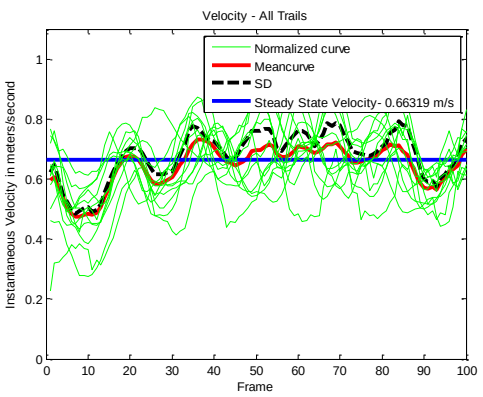
Patient E Before (left), After (middle) and Follow-up (right) Treatment

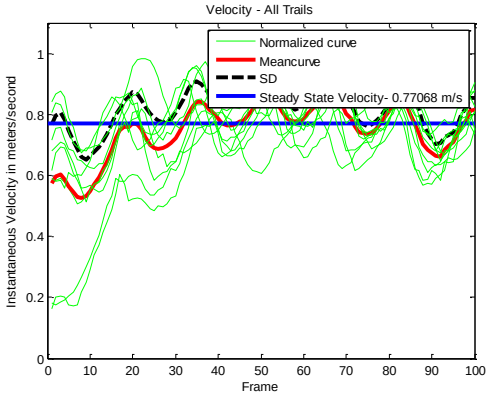


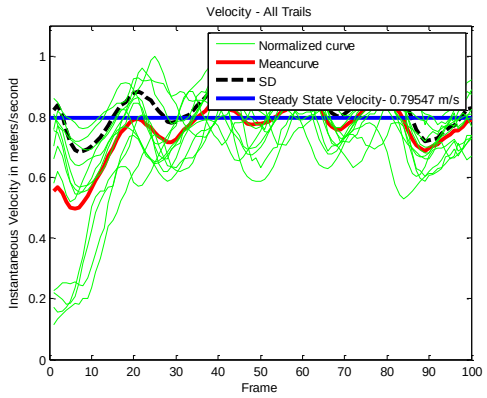




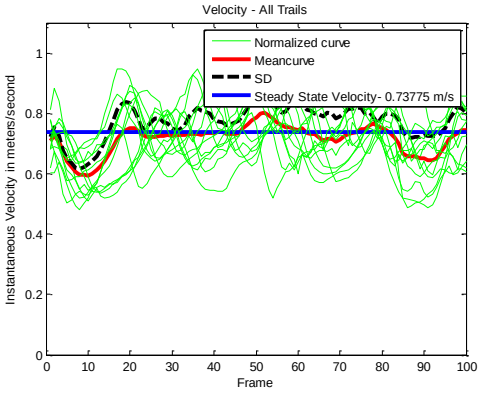
Paitent B Before (left), After (middle) and Follow-up (right) Treatment - Shoes Off

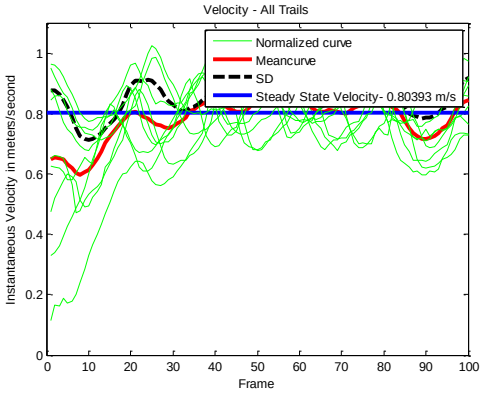


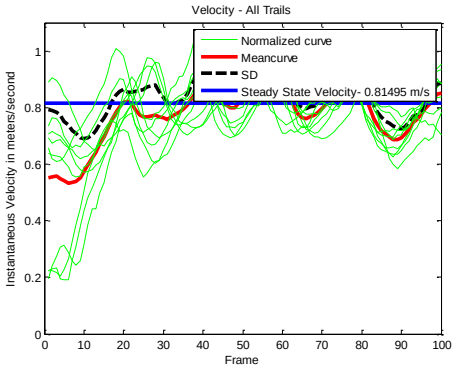




Patient B Before (left), After (middle) and Follow-up (right) Treatment - Shoes On






Velocity - All Trails
Normalized curve
Meancurve
SD
Steady State Velocity- 0.81495 m/s
Instantaneous Velocity in meters/second
Frame
0
0.2
0.4
0.6
0.8
1
0
10
20
30
40
50
60
70
80
90
100