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M. S. degree in Biomechanics

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Major professor

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PARAMETRIC STUDY OF PARKINSONIAN GAIT

By

Patricia Soutas-Little

AN ABSTRACT OF A THESIS

Submitted to
Michigan State University
in partial fulfillment of the requirements
for the degree of

MASTER OF SCIENCE

Department of Biomechanics

1990

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ABSTRACT

The purpose of this research was to develop an objective and quantitative examination technique for use with Parkinson's patients. Pilot force and kinematic data were collected in two female Parkinsonian patients, during walking and standing. Posture, stability and balance parameters were examined. A four-camera, three-dimensional motion analysis system was used to record position and trajectory data. The three components of the ground reaction force were examined from both a temporal and spatial perspective. Resolved ground reaction torques provided another parameter for analyzing compensation mechanism in Parkinsonian gait and for characterizing the progression of the disease. The motion analysis allowed a joint-by-joint examination of the upper and lower extremities, flexion extension angles, saggital plane movement, was calculated for the ankle, knee, hip and elbow. A Fourier analysis was done on the motion data at each joint. Stride length, stride width and cadence also were examined. Of the large number of parameters which were examined in this study, the vertical force temporal distributions, the resolved ground reaction forces and moments and the frequency spectrum hold the greatest promise for further examination.

DEDICATION

I Wish to didicate this work to my dear husband, Robert, for his love, understanding, guidance, continued encouragement and incredible faith that I could complete this degree. Robert, without your support I would never have had the courage to attempt this endeavor. My heart felt thank you.

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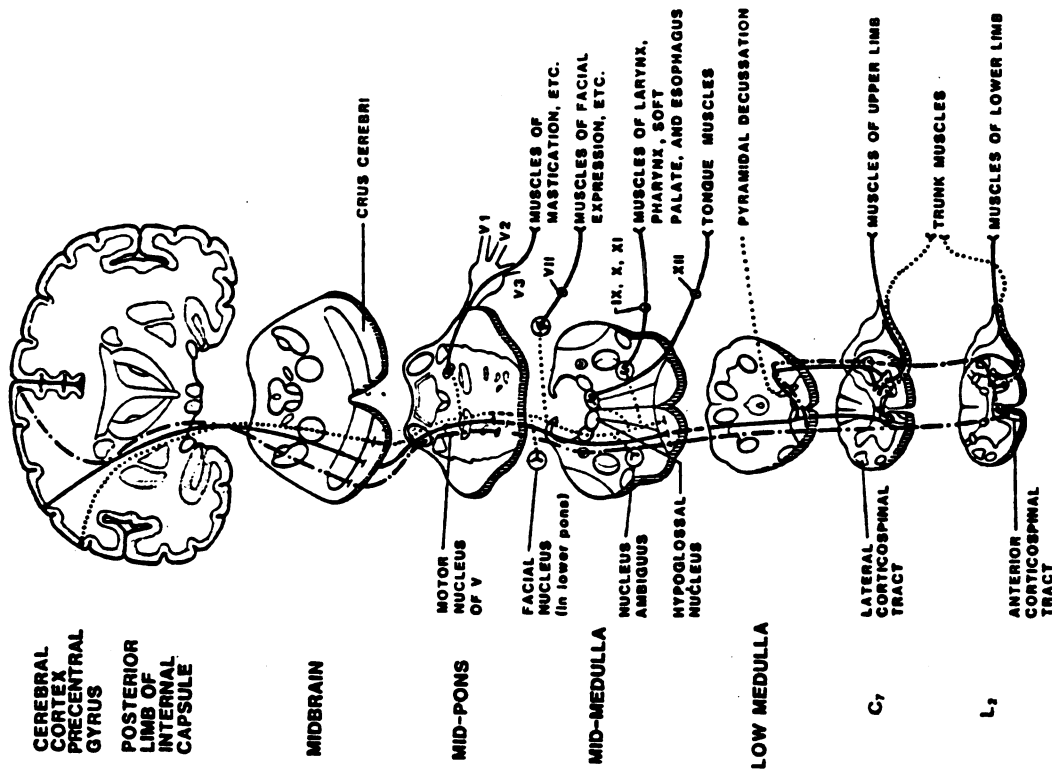
I. INTRODUCTION

Parkinson's disease is one of the growing health problems experienced in many countries today. Parkinson's disease is ranked as the third most common chronic disease of late adulthood, preceded by cerebral vascular disease and arthritis [1]. Over one million people in the United States have Parkinson's disease, and it is growing at the rate of 20 new cases per 100,000 people per year. More people suffer from Parkinson's disease than from multiple sclerosis, or muscular dystrophy [2]. While most victims of this disease are over 40, with almost fifty percent experiencing onset of the disease between the ages of 55 and 69 [3] it also can occur in teenagers. Many health care professionals and the public are unaware of the high incidence of Parkinson's disease due, in part, to the nature of the disease itself. Parkinson's disease is difficult to diagnose in its earliest stages, the onset is very gradual, and milder symptoms in elderly patients can be confused with other diseases of the elderly or with symptoms that characterize the process of aging in general and, therefore, go untreated.

Parkinsonism is a degenerative disease of the central nervous system that develops because of damage to the extrapyramidal tract at the substantia nigra and basal

ganglia of the brain stem (Figure 1). The extrapyramidal nervous system controls movement, walking, balance and posture, and the primary symptoms of this disease manifest themselves in these areas. The primary symptoms associated with Parkinson's disease include tremor, stiffness or rigidity, difficulty in walking or in balance, slowness and poverty of movement. There are a number of secondary symptoms that also can be associated with Parkinson's disease including senility, postural deformity (stooped posture, rounded shoulders, propensity to bend the trunk forward), severe depression, speech impairment, and impairment of some voluntary activities controlled by the autonomic nervous system, resulting in difficulty in breathing or swallowing, forced closure of the eyelids, drooling, dizziness when upright, impotence, constipation and oily skin.

Two classifications of parkinsonism are used [4]. The first classification, idiopathic parkinsonism, refers to Parkinson's disease which is characterized by having at least two primary symptoms present and predominate. There are other neurological disorders which may have both primary and secondary parkinsonian symptoms. These disorders are classified as symptomatic parkinsonism or as Parkinson's Syndrome and can result from brain tumors or repeated head trauma, encephalitis, high dosages or prolonged use of phenothiazines (Thorazine), butyrophenones (Haldol) and reserpine, and toxic exposure to carbon monoxide or



SUBSTANTIA NIGRA AND CORPUS STRIATUM (SHADED)

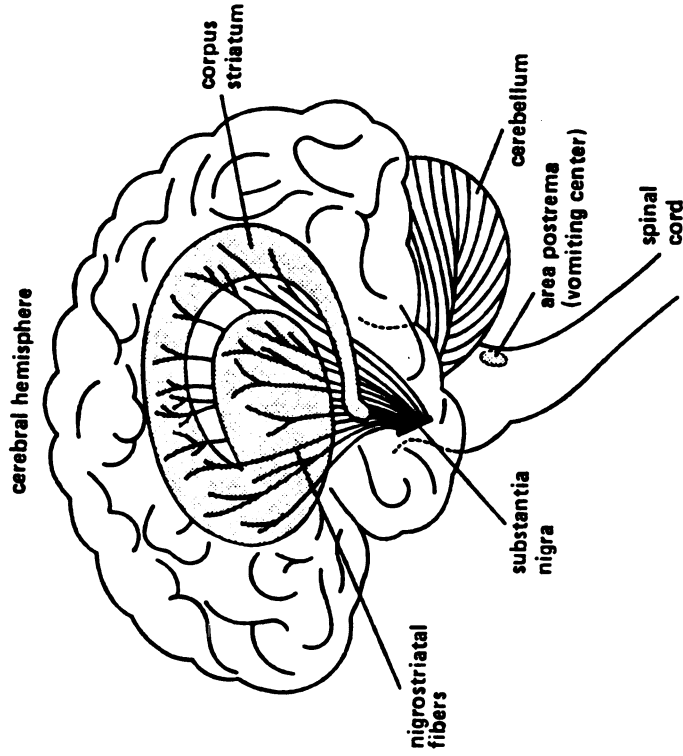


Figure 1: Pyramidal Tract and Lateral View of the Human Brain

manganese. Although this study focused on idiopathic parkinsonism, it is hoped that the results will be useful in the development of clinical, diagnostic tools that would apply to both idiopathic and symptomatic parkinsonism.

From a historical perspective, information concerning parkinsonism--its symptoms, etiology and treatment--has grown slowly over time, and only more rapidly over the last three decades. Most of the significant discoveries were made after 1957. Periods of greatest growth in the understanding of parkinsonism seem to parallel major changes in the philosophy or practice of medicine or technology associated with the medical field. It was not until the end of the 18th century that physicians began to view combinations of symptoms as being associated with a specific disease, and to recognize patterns in the evolution and progression of a disease. Prior to that time, every symptom was considered independently, and was treated as if it represented a disease in and of itself. During the early 19th century, physicians and medical scientists began to describe many of the diseases that are known today. The first attempts were made in studying these diseases postmortem and in correlating the results with symptoms studied in living patients. Early 19th century physicians were handicapped in these efforts by the lack of any sophisticated diagnostic equipment. Basic items such as the stethoscope or reflex hammer, used in the practice of medicine today, were not yet in existence.

Tracing the evolution of information concerning parkinsonism during the 18th and 19th century, starts with references to independent symptoms of the disease. References to a "resting tremor, different from a tremor that occurs with movement," can be found in papers written by the ancient Greek-Roman physician Galen. However, he did not associate this symptom with any other symptom of parkinsonism. Sauvages, an 18th century French physician described an abnormal gait that progressed from walking into running and named it sclerotyrbé festinans. No other symptom of parkinsonism was described. In 1817, James Parkinson was the first to describe Parkinson's disease, referring to it as Paralysis Agitans, in his monograph, "An Essay on the Shaking Palsy." Parkinson described Paralysis Agitans in this paper as "...involuntary tremulous motion, with lessened muscular power, in parts not in action and even when supported with a propensity to bend the trunk forwards, and to pass from a walking to a running pace the senses and intellect being uninjured." Besides being the first to identify a combination of symptoms as belonging to parkinsonism, he also recognized the progression of the disease.

During the mid 19th century, Jean Marie Charcot, a French physician, medical teacher and a founder of modern neurology, added muscular rigidity, and several other symptoms, to the description of parkinsonism begun by James Parkinson. In 1867, Charcot introduced hyoscine, an

alkaloid drug, as appropriate for use in treatment of parkinsonism. Hyoscine continued to be used until the discovery of levodopa a century later. Changing the name Paralysis Agitans (shaking palsy) to Parkinson's disease is attributed to Charcot, who believed it preserved historical accuracy.

Claude Richer, a student of Charcot and an artist, drew sketches of Charcot's patients at the Salpetriere hospital in Paris. Figure 2 is an example of Richer's art. His work captured the parkinsonian posture, and other symptoms of parkinsonism, providing an excellent visual record of the disease. Richer's art is still featured in many medical textbooks.

There are other examples of the use of art as a medium for recording the symptoms of parkinsonism, although not always as obvious. The German poet Goethe, who had some medical training, noted that the innkeeper in Rembrandt's sketch "The Good Samaritan" had hand position and posture typical of parkinsonism.

By the end of the 19th century, Parkinson's disease was an accepted and recognized disorder. Postmortem anatomical exams in the mid to late 19th century failed to determine the cause of Parkinson's disease and engendered considerable frustration and controversy in the medical community. The issue most debated was to which location in the brain to attribute the disease. Some scientists believed the problem centered in the spinal cord, while others were adamant that



Figure 2: 1874 Sketch by Paul Richer

it had to lie in the muscles. During the midst of this controversy, Parkinson's disease was classified as a "neurosis" implying that there was no structural change in the brain to explain the symptoms.

In the late 1890's Professor Brissaud, another student of Dr. Charcot, identified the substantia nigra in the basal ganglia as the area of the brain on which to focus research efforts. Postmortem studies that followed were unsuccessful in confirming this theory due to the inability to factor out other causes in addition to Parkinson's disease, that could be attributed to the changes observed in the substantia nigra. Proof that the substantia nigra was the correct location was not obtained until 1915, when Tretiakoff, a doctoral student in Paris, published his work describing a number of changes in the nerve cells in the substantia nigra. Although today, the changes Tretiakoff documented are accepted as typical for Parkinson's patients, in 1915 his work received great skepticism from the neurologists of his day, primarily because they would not believe so small a group of nerve cells could account for the diverse parkinsonism symptoms. It was not until 1939 that Tretiakoff's observations were supported by a German pathologist, Dr. O. Hassler, who conducted a detailed study of the substantia nigra in Parkinson's disease patients.

Between 1915 and 1939 the debate over the etiology of Parkinson's disease became further clouded due to an epidemic of encephalitis lethargica, sleeping sickness, that

reoccurred from 1916 to 1926, and introduced an entirely new population of patients who exhibited parkinsonian symptoms, along with other unusual symptoms not seen previously in parkinsonian patients [8]. Many of these patients were young, the majority between the ages of 15 and 30. Faced with this new population, clinicians and medical scientists reached the conclusion that there must be two types of parkinsonism. Since there were other diseases whose symptomatology resembled Parkinson's, it was decided that there might be many types of parkinsonisms. The reverse argument, equally popular, was that all parkinsonism was attributable to encephalitis lethargica. Another argument expressed was that Parkinson's disease did not exist; parkinsonism was merely a collection of symptoms that could be associated with any number of different diseases.

Following Dr. Hassler's work, which signaled the end of controversy but received limited attention due to the outbreak of World War II, an English pathologist, Dr. J. G. Greenfield, published his research on the brains of Parkinson's patients corroborating Dr. Hassler's finding that there was involvement of the substantia nigra in Parkinson's disease patients.

Limited knowledge of the functioning of the substantia nigra further hindered the understanding of Parkinson's disease until work done in Sweden by Drs. Ungerstedt, Dahlstrom, Fuxe, and Anden, using a new microscopic technique, revealed that the chemical substance dopamine

could be found in the nerve cells of the substantia nigra. These Swedish scientists discovered a new system of nerve cell pathways, including the system of long, thin fibers that arise from the nerve cells of the substantia nigra and run to all areas of the corpus striatum. Subsequent research performed by biochemists lead to the identification of the substantia nigra and corpus striatum as the primary areas of the brain producing dopamine and provided documentation that the brains of Parkinson's disease patients showed a decrease of dopamine. Results from animal research, conducted during this same period, suggested that a relationship existed between the substantia nigra and corpus striatum. This was based on the finding that when the substantia nigra was injured there was a deficit of dopamine in the corpus striatum on the same side.

In 1957, during the course of his animal research on the tranquilizing effects of reserpine, Professor Avid Carlsson, University of Goteborg, found that levodopa restored dopamine to normal levels. Human experimentation with levodopa as a drug for treatment of Parkinson's disease patients involved administering levodopa in small doses either by injection or orally. Results varied greatly as some physicians reported great success and others, following the same protocol, reported the drug failed to impact any of the symptoms. In 1967, an important discovery regarding the administration of levodopa by Dr. Cotzias, a medical scientist from Brookhaven National Laboratory in New York,

made levodopa a practical form of drug treatment. Dr. Cotzias found that best results were obtained when larger dosages of levodopa were taken orally. He increased the dosage every few days over several weeks, allowing his patients to become tolerant of the side effects (nausea and vomiting) until he was able to give them doses 20 to 30 times larger than the initial dose. By 1968 subsequent studies, performed at various medical centers, had confirmed Dr. Cotzias' discovery and since that time the success of levodopa in the treatment of parkinsonism has resulted in limiting the practice of some other treatment modalities, such as stereotactic surgical procedures, which had been widely used.

New forms of therapy are being studied at the present time that may continue to alter current treatment practices used with Parkinson's disease patients. An example of this is Deprenyl, recently introduced on an experimental basis in the United States, although it has been in use for several years in Europe. Deprenyl retards the destruction of dopamine from the brain, thereby enhancing the effectiveness of a single dose of levodopa. Research into new drugs, termed "partial agonists", that will enhance the production of dopamine by stimulating only those receptors involved in Parkinson's disease hold promise for improving the control of parkinsonism symptoms while decreasing the side effects of many of the current drugs used. Results from recent animal research suggests that skin cells, genetically

altered to produce L-dopa, implanted into the brain of Parkinson's disease patients, may reduce the symptoms of Parkinson's disease. Previous research has focused on the use of fetal cell implants. Although genetically altered skin cells are less effective in controlling parkinsonism symptoms at the present time, it is hoped that they may provide an alternative to the politically and ethically controversial fetal cell implants [8].

Although the cause of Parkinson's Disease is still unknown today, idiopathic parkinsonism is characterized by degenerative changes in the central nervous system, primarily associated with dysfunction in two regions of the brain, the substantia nigra and the corpus striatum. The deeply pigmented cells of the substantia nigra (Latin for "black substance") contain neuromelanin, similar to the melanin pigment found in skin and eyes. The pigmented cells of the substantia nigra produce and store dopamine, a chemical substance used by the nerve cells in synapsing with the corpus striatum or striate body, which controls movement, balance and walking. The striate body is located in the deep gray matter of the cerebral hemispheres. Damage to or degeneration of the pigmented cells in the substantia nigra impacts the cells' ability to generate, store or transmit dopamine. Therefore, a deficiency of dopamine in the substantia nigra means a loss of dopamine in the corpus striatum and, eventually, impairment of movement, balance or walking. There are three dopamine receptors that connect

with the neurons in the substantia nigra. The first two receptors are associated with the striatum, located either on the main body of the cells in the striatum or on elongated cell bodies located in the cortex that send out fibers which pass through the striatum. The third receptors are the processes of the cells of the substantia nigra. The brain attempts to compensate for the loss of neurons in the substantia nigra by increasing sensitivity of the dopamine receptors or by increasing dopamine production by the remaining pigmented cells. When these compensation mechanisms fail, Parkinson's disease symptoms begin to appear. Pharmacological treatment of Parkinson's disease patients can include antiparkinsonian drugs, administered to help control parkinsonism symptoms, which function by stimulating one or more of the dopamine receptors.

Acetylcholine is another chemical neural transmitter, found in the striatum, affected by the degeneration of the substantia nigra. Although levels of acetylcholine remain normal in patients with Parkinson's disease, the functioning of the striatum requires an equal amount of dopamine and acetyl choline to maintain equilibrium. Anticholinergic drugs and levodopa are used to counteract this imbalance by blocking the actions of acetylcholine and increasing dopamine.

Secondary symptoms occurring with Parkinson's disease result primarily from loss of dopamine in other parts of the brain or from loss of norepinephrine, a chemical neural

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transmitter that acts on the involuntary autonomic system [1,2,5,6,7].

Diagnosis and treatment of idiopathic parkinsonism is based on type and severity of symptoms. The most common symptom is tremor. Resting tremor, shaking of nonmoving limbs, affects approximately 75 percent of the idiopathic parkinsonism population. Tremors usually appear first in the hand or feet but can involve other parts of the body. Tremors are characterized as regular and rhythmic with a frequency of 4 to 8 Hz (tremors per second¹); somewhat variable, coming in bursts and then subsiding; sometimes worse on one side of the body; decreasing when hands are stretched out in front of the patient or are in movement; but for some patients increasing when hands are in movement.

Rigidity is an increase in muscle tone and is measured in terms of resistance to passive motion tests performed by the clinician. Rigidity is present when the limbs are still and increases with movement. Increased tone is interpreted by patients as stiffness, soreness or an aching-cramping feeling and can cause considerable discomfort. The characteristic leaning forward posture of most Parkinson's disease patients (flexion of the head, shoulders, hips and knees) aggravates rigidity of the spinal muscles causing low back pain.

Bradykinesia is a complex symptom characterized by a number of traits. It manifests as a delay in starting all

¹The reported frequency varied by author but is in the range given above.

movements, such as in walking where the patient may feel his feet are glued to the floor, even though the command to move has been given to the brain, then suddenly he begins moving forward. Slowness or poverty of all movements is observed, and movements are very deliberate with a reduction in spontaneous motor acts. Ongoing movements can not be stopped, without completion of the activity initiated, i.e. reaching out for an object, then, being unable to grasp it. Bradykinesia can vary with time and circumstance, a task that could not be performed on a given day may be accomplished without incident at another time.

The ability to maintain equilibrium or balance is impaired as the disease progresses. Also the ability to correct changes in posture to keep from falling becomes difficult, and there is a reduction in the ability to react to abrupt changes in position.

Difficulty in walking also increases as the disease progresses. In the earlier stages, this symptom is difficult to detect but may occur as a decrease in the natural arm swing or a slight drag of one limb. In later stages the patient has difficulty beginning movement, once started, steps are shortened and/or shuffling and speed increases as gait continues with difficulty in stopping, a condition termed festination. Because of the problems experienced in balance, turning can result in falls. Sudden freezing spells also can occur, where the patient is suddenly totally unable to move for a time.

Diagnosis and subjective evaluation of idiopathic parkinsonism is performed by the clinician using one of several evaluation scales currently available. The scale is used to rate the severity of the disease based on symptom evaluation. Some scales may weight values associated with certain symptoms, while others do not. Once a severity level is determined, then the patient also may be rated as to their ability to perform daily tasks of living using one of several functional disability scales that are available. The severity level of Parkinson's disease for patients included in this study was performed by the referring physician using the Hoehn and Yahr Scale of Rating.

This evaluation scale was developed by physicians Hoehn and Yahr, as a product of their research conducted from 1963 to 1964. Their study involved 856 patients, who were seen at the Vanderbilt Clinic of the Columbia-Presbyterian Medical Center from 1949 to 1964 and had been diagnosed as "paralysis agitans, Parkinson's disease or parkinsonism." Following review of each case to establish a definite parkinsonism diagnosis, 54 patients were dropped from the study. An abbreviated patient history was gathered for the remaining 802 patients, all of whom exhibited to varying degrees the characteristic primary symptoms of parkinsonism. An in depth history was taken on 263 patients over the course of the research. Based on their review, 672 patients were classified as "paralysis agitans" or idiopathic parkinsonism. Postencephalitic parkinsonism, which included

82 people, was the largest sub group of the symptomatic parkinsonism patients. Patients who had contracted encephalitis and then immediately began to exhibit parkinsonism symptoms were considered "postencephalitic." Cause was attributed to something other than encephalitis for those individuals who had sleeping sickness but for whom parkinsonism symptoms did not appear until many years latter.

Hoehn and Yahr found that tremor was the most frequent initiating symptom occurring in over 70 percent of idiopathic parkinsonism and 50 percent of the postencephalitis subgroup. Tremor and rigidity were the most frequent physical findings and postural deformities were frequent in the advanced cases. Other frequent physical findings included delay of initiation, slowness of movement, loss of associated and spontaneous movement, speech disturbances, impaired righting reflexes (returning to a balanced position following movement) and various gait disturbances.

Hoehn and Yahr felt that, in addition to considering the type of parkinsonism and its chief manifestations, it also was important to consider extent of disability at the time of treatment and the rate of progression before and after treatment, due to the variability of the onset and progression of Parkinson's disease. The following scale, dividing progression of the disease into stages I through V, based on the level of clinical disability, was used by Hoehn

and Yahr for rating the patients included in their research.

"Stage I. Unilateral involvement only, usually with minimal or no functional impairment.

Stage II. Bilateral or midline involvement without impairment of balance.

Stage III. First sign of impaired righting reflexes. This is evident by unsteadiness as the patient turns or is demonstrated when the patient is pushed from standing equilibrium with the feet together and eyes closed..."

"Stage IV. Fully developed, severely disabling disease; the patient is still able to walk and stand unassisted but is markedly incapacitated.

Stage V. Confinement to bed or wheelchair unless aided."

Currently, there are no objective quantitative parameters available to the clinician to aid in the diagnosis and treatment of parkinsonism. As discussed above, the clinician must rely on one of several scales available to rate the severity of Parkinson's disease based on symptom evaluation. Given the complexity of this disease, the potential for new types of treatment that work best at earlier stages of the disease, the difficulty in early diagnosis, and the continued identification of new disorders and conditions that are classified as Parkinson's Syndrome, a need exists for an objective, quantitative means for diagnosing parkinsonism and assessing the progression of

the disease and/or the effectiveness of a given medical intervention. Studies conducted prior to the mid 1960's described parkinsonian gait in terms of qualitative deviations from a normal walking pattern. More recent studies have provided quantitative information on linear measurements such as stride length, cadence, gait cycle durations, sagittal plane hip, knee and ankle flexion and extension angles, and ground reaction forces. However, these studies have been limited in scope and are very few in number.

Murray [9] and Knutsson [10, 11] were the first to undertake a quantitative examination of parkinsonian gait. Both studies utilized intermittent-light photography to record the data. Strips of reflective tape placed on the sides of the head, arms, legs and sole of the shoes at specific anatomical landmarks were tracked as the subject walked in front of a camera in the illumination of a strobe light flashing 20 times per second. If the speed of the movement being captured was slow, longer flash intervals were used. The camera shutter was opened during these tests so that the serial position of each target at the instant of illumination was recorded on the film. An overhead mirror mounted along the walkway, was used to capture target images in the overhead view as well as medial and lateral aspects of the body on one film.

The main focus of Murray's study was to examine the gait patterns of 60 healthy, normal men between the ages of

20 and 65. He then contrasted the mean displacement patterns for the 60 normal men with the displacement patterns of a 58 year old patient with hip pain, a 38 year old hemiparesis patient, a 55 year old patient with Parkinson's disease and a pre and post (four days) test of a Parkinson's patient who had stereotactic thalamotomy surgery. Parameters examined included stride dimensions and temporal gait components (i.e. stride length, cadence, duration of single limb and double-limb support, walking speed, cycle duration, swing to stance time ratio). The serial displacement patterns were used to examine sagittal plane flexion extension angular patterns at the ankle, knee and hip.

Knutsson examined 21 parkinsonian patients (19 idiopathic and two postencephalitic) ranging in ages from 48 to 76. Twelve of these patients were male and nine female. He also examined phases of the walking cycle and angular displacements of the limbs which he compared to Murray's 50 to 80 age group data and an earlier study conducted by Drillis in 1958. Knutsson found the mean speed and stride length of gait in parkinsonian patients were markedly reduced, as compared to the normal group, while the mean cycle duration was increased. He also found reduced flexion of the hip and knee joint, reduced extension of the knee joint but normal extension for the hip joint. Both Murray and Knutsson attributed deviations in displacement patterns

to poverty of movements associated with Parkinson patients and mechanical restrictions due to hypokinesia.

Given the measurement techniques employed, neither of these studies provide accurate angular data which could be used as a baseline for comparison with other studies on parkinsonism. In addition, as pointed out Stern et al. [12], the Murray data may not be an appropriate norm to use for comparison with pathological gait patterns. Stern felt that, for objective measurements of gait to be used by clinicians in both diagnosing Parkinson's disease and assessing progression of the disease, a less expensive and less complicated means of objective gait assessment needed to be developed. Stern employed a metal walkway, ultraviolet recorder and photocells as the major equipment in his study. Foil contacts were placed on the heel and soles of each subjects shoes and then, using the ultraviolet recorder, the duration of each heel and sole contact was recorded. The photocells were placed at either end of the walkway such that the subject interrupted the beam at the beginning and end of each trial, providing velocity data for that trial. The beam interruptions were stored on the ultraviolet recorder and, together with heel/sole records, provided data for calculating stride length, cadence, ratio of stance to swing phase, single and double support duration and walking speed. The subjects included 24 men and 26 women, aged 31 to 78, rated at stages II, III, and IV on the Hoehn and Yahr scale of disability. All patients were

taking their prescribed medication for Parkinson's disease during the study. In order to compare the results from the "objective tests" with qualitative clinical assessment of the patients' motor abilities, 21 of the patients were videotaped performing a variety of activities including walking, sitting, and rising from a chair. Digital time was then superimposed on the videotape. Stern found that, with the exception of velocity measurements, the objective tests he developed failed to characterize specific parameters of parkinsonian gait. Even though test results showed a decline in overall patient performance with disease progression, correlation of specific gait parameters was impossible because of the extreme variation of test results for subjects within a given disease stage. Stern felt that velocity data obtained using his test protocol could be a useful indicator of locomotor performance. Stern suggested that if increased velocity of walking can be interpreted as clinical improvement, then his technique has application in assessing the progression of Parkinson's disease for a given patient, or determination of the success of therapeutic intervention.

The first published research to utilize high speed motion analysis equipment, force platforms and EMG was a 1984 study by Hans Forssberg, et al. [13] from the University of Goteborg, Sweden. This study involved six Parkinson's disease patients, aged 43 to 70, who had been treated with L-dopa for more than eight years and were rated

stage III on the Hoehn and Yahr disability scale. Kinematic data was collected using a SELSPOT system with active targets (light-emitting diodes) placed at specific bony landmarks on the left hip and leg. Data were collected while the subject walked across a force platform at his/her own speed and while walking on a treadmill at a set speed. Force platform data was sampled for the left leg only. Patients were tested in three conditions: before administration of L-dopa; with a visual guidance (stepping over white sheets of writing paper arranged in a line to provide visual cueing); and after administration of L-dopa.

The purpose of Forssberg et al.'s research was to explore another explanation as to why advanced stages of Parkinson's disease manifested itself in significant alterations of gait including the bent posture, festination, reduced arm swing, etc. These researchers were motivated to check the hypothesis of Knutsson that such changes can be attributed to mechanical restrictions due to hypokinesia rather than to neural control of locomotion. Forssberg et al. hypothesized that there is a close similarity to the gait pattern of Parkinson's patients (pre-medication) and that of a child between the ages of 18 and 24 months who has not developed a plantigrade gait. They postulated that with the progression of Parkinson's disease comes the reappearance of an immature gait, perhaps caused by the loss of dopamine from those structures in the nervous system that

influence the change from a primitive gait to an adult plantigrade gait.

The results of Forssberg et al.'s work confirmed the finding, reported by Murray and Knutsson, that characteristic Parkinson's gait can be attributed to hypokinesia. However, in addition to showing poverty of movement, they felt the data also supported their theory that "the characteristic coordination of normal plantigrade gait" was lost. Examination of knee and ankle flexion and extension data indicated no initial knee flexion in early stance phase, reversed ankle flexion and extension patterns with foot hitting toe first or flat foot, and a marked reduction of propulsive force (anterior-posterior direction) in the last stage of stance phase. When visual cueing was used, the gait improved. However none of the characteristic plantigrade gait components developed and the gait continued to resemble that of a small child or infant learning to walk. Forssberg et al. concluded that, in addition to changes due to bradykinesia, deficits of neural control of locomotion do occur and also can be attributed to the classic Parkinson gait changes measured. The idea of examining pre-post medication and the effects of visual cueing has significant clinical relevance. However in order to validate a specific hypothesis, Forssberg et al. narrowed the focus of their research. Their evaluation protocol, which was unilateral lower extremity only, also limited

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their results. For these reasons, this study does not provide much useable information on gait function.

The most recent published research examining dynamic parameters of parkinsonian gait was done by Koozekanani et al. in 1987, at Ohio State University [14]. They used a force platform to evaluate the ground reaction force patterns of two Parkinson's patients, comparing their patterns to that of a healthy subject. Both patients were 51 years old. However, their Parkinson's clinical history differed. One patient was rated stage III on the Hoehn and Yahr disability scale and had been diagnosed as Parkinson's for eight years. The other was in the early stages (stage I) with only his left side effected. In addition to the first test, this patient was retested six months later to see if his ground reaction force patterns had altered. Koozekanani et al. collected bilateral kinematic data using a three-camera system and "miniature light bulbs" as targets in a linkage pattern on the shoulders, hips and lower extremity. Sagittal plane flexion/extension angles were calculated at the ankle, knee and hip.

Koozekanani et al. found the vertical component of the ground reaction forces showed reduced magnitude in the acceleration phase of gait. They attributed this reduction in propulsion to the lack of a fully extended knee in parkinsonian patients at toe off. They also found that the stance phase of gait was shorter on the limb most affected by Parkinson's. The angular data showed a loss of knee

flexion symmetry with the knee slightly flexed (as opposed to fully extended) in heel strike and more flexed at toe off. The six-month retest of the one patient showed significant deterioration in the vertical force pattern. The earlier test reflected a slight reduction in the acceleration phase of the vertical force. However at retest, there was a marked reduction in the acceleration force.

Although considerable research has focused on describing the functional walking and running gait patterns of "normal" or "healthy" populations, limited information is available on dynamic parameters of neurological pathological gait. The one exception is research on gait patterns of children who have cerebral palsy.

There are three research studies on parkinsonism, currently in progress, that are known to this researcher.² All three studies are examining gait using motion and force parameters. The Department of Rehabilitation Medicine at the National Institutes of Health and the M.G.H. Institute of Health Professions studies are nearing completion and results should be available before long. The research underway at the Gait Analysis Laboratory of Children's Memorial Hospital is examining three populations: Parkinson disease patients, Alzheimer's patients and the aged. They are collecting electromyographic data on these subjects, in addition to force and kinematic data.

²Personal communication, East Coast Clinical Gait Laboratory Meeting, 11, 1989, West Haverstraw, New York.

From the above literature review it is clear that there is a paucity of research on functional gait of parkinsonism. Very little of the research that has been done can serve as a benchmark for future efforts and no researcher to date has attempted to fully describe, from a dynamic standpoint, all parameters seen in parkinsonian gait. Thus there is a need for a parametric study which examines the full range of characteristics associated with parkinsonism, utilizing state of the art equipment and methodology. Examination of movement in Parkinson's patients is currently the only diagnostic and evaluative technique. The purpose of this research was to develop an objective and quantitative examination technique.

II. EXPERIMENTAL METHODS

Pilot force and kinematic data were collected on three Parkinsonian patients, two females and one male, during walking and standing. All three individuals were patients of Dr. Phillip M. Green, M. D.³, undergoing pharmaceutical treatment for relief of Parkinson's Disease symptoms. Each patient had been clinically rated as to the severity of his/her disease and the level of his/her gait impairment⁴.

Subject 1, was a 72 year old male, 6' 4" tall and weighed 200 pounds. He was rated as a IV on the Hoehn & Yahr Scale. Subject 2, rated IV on the same scale, was a 74 year old female weighing 155 pounds and measuring 5' 3" tall. Subject 3, a 73 year old female, was rated between II and III on the Hoehn & Yahr Scale, and she weighed 96 pounds and measured 5' 3".

Subjects were taking various types and varying levels of medications to lessen the severity of their Parkinson's Disease symptoms. All three patients were taking Sinemet. Patients #1 also took phenobarbital to control grand mal seizures, and patient #2 was taking Parlodel, Quinlan, Zantac and Vitamin C. Patient #3 was taking Symmetrel and Vitamin E and Deprenyl, a drug recently introduced in the

³Adult Neurologist, Kalamazoo Neurology, P.C., Kalamazoo, Michigan.

⁴See discussion in Chapter I on the Hoehn and Yahr Scale of rating.

United States on an experimental basis. Patient #3 reported a marked improvement in her gait since beginning Deprenyl drug therapy.

Prior to testing, the physician was asked to provide a complete medical description of each patient and the patient was asked to complete and return a "patient information" questionnaire requesting anecdotal information about the patient's medical history, onset of the disease, symptoms, medications, special diets, assistive devices, etc. Responses to this questionnaire provided information regarding any special precautions that should be taken or requirements needed by the patient. This information was reviewed with the patients and/or their family just prior to testing.

Subjects were tested at the Biomechanics Evaluation Laboratory (BEL), located in St. Lawrence Hospital, Lansing, Michigan⁵. The BEL is a research and teaching facility that also provides, as an extension of the clinical research program, biomechanical evaluations to the physicians of patients participating in research studies. This information is offered as a service through St. Lawrence Hospital. The BEL's technology includes three major components: measurement of three-dimensional motion; measurement of the ground reaction forces which act on the

⁵The Biomechanics Evaluation Laboratory is a program of Michigan State University and receives support from the University, St. Lawrence Hospital and Healthcare Services and Brooks Shoe, Inc.

body during locomotion; and utilization of telemetered electromyography to measure muscle activity. This study utilized only the ground reaction force and kinematic technologies of BEL.

The test procedure was explained to each subject and accompanying family members and informed-consent forms were obtained where required. All testing was non-invasive in nature and the subjects were told that no beneficial results could be assured.

Subjects were asked to walk across a force platform, both barefoot and in shoes, in order to analyze gait characteristics. To minimize danger of falling, the subject was accompanied by a researcher during testing and a restraining belt was used when necessary. Posture, stability and balance parameters were examined by having the patients stand on the platform with eyes open and eyes closed for a period of 20 seconds. Subject 3 was administered a "nudge" test⁶ during standing, again to examine the effect it had on her balance.

Subjects were targeted bilaterally at specific sites and video data were collected, while subjects performed the activities listed above, in order to examine fluctuations in coordination, joint movement, velocity of gait, duration of

⁶The "Nudge" test is one of a series of tests utilized by physicians to diagnose Parkinson's Disease. It consists of having a patient stand, feet together facing the physician, who then gives them a push or "nudge" on the sternum to see how this effects their balance.

heel/ground contact, stance/swing phase ratio, turning time and stride length.

A four camera, three-dimensional motion analysis system was used to record position and trajectory data for the seventeen targets, tracking discrete bony landmarks on each subject. The "Expert Vision System" by Motion Analysis Inc.⁷, consisted of four 60 Hz pixel-perfect NEC cameras and a VP320 video processor for digitizing data in pixel space. The data were then analyzed on a SUN 4/260C work station to obtain three-dimensional data.. The cameras were positioned so that two cameras' field of view contained a posterior/medial or posterior/lateral view of the targeted subject and the other two cameras had a frontal/lateral or frontal/medial view. Camera heights and distances were set to allow full body, bilateral gait analysis encompassing at least three full strides (Figure 3). A 50 watt flood light was mounted next to each camera as close as possible in order to reduce the observation angle between the light-target-camera. The VP320 measures changes in light intensity relative to ambient light. Apertures of the cameras were closed such that target thresholds were 400-500 times ambient light. The VP320 digitizes by marking pixels at this threshold (Figure 4).

The ground reaction forces exerted on the body during gait and standing were measured using an AMTI force

⁷Motion Analysis, 3650 North Laughlin Rd., Santa Rosa, California



Figure 3: Camera Configuration and Calibration Structures



Figure 4: Video Processor (VP320)

platform⁸ mounted flush with the walking surface. Data were sampled on six channels at a rate of 1000 Hz (millisecond intervals) measuring the three components of ground reaction force in the three principal directions, vertical (F_z), anterior-posterior (F_y) and medial-lateral (F_x) and the three components of the moment about the same axes. Data were collected through an A/D board on the SUN 4/260C work station. The data were received as raw voltages (millivolts) and were converted to equivalent mechanical units with forces expressed in Newtons and moments in Newton-meters. Temporal patterns of the three components of the ground reaction forces were graphed and examined on the SUN work station. Data trials were reviewed by graphing all trials for a given condition (i.e. barefoot walking right foot), at the same time, superimposed one on another, so that the consistency and variability of the data stride-to-stride could be viewed. Data were then transferred, via a Multimodem V32 9600 baud modem, to the A. E. Case Center for Computer Aided Design & Manufacturing, Michigan State University, for analysis using various Department of Biomechanics analysis programs available on the Case Prime mini-computer.

Prior to testing the subjects, four calibration structures, each containing four passive cooperative targets with known locations, were used to calibrate the space

⁸Model OR6-6, Advanced Mechanical Technology, 141 California Street, Newton, MA 02158.

through which the subjects would walk. The three-dimensional coordinates of sixteen predetermined targets provided the data needed for the direct linear transformation routine. A minimum of six calibration targets are required to calibrate the space but sixteen were used and direct linear transformation data were obtained using an EV3D least squares program⁹. The camera location and pixel residual data were examined and the space was recalibrated if residuals exceeded 1.0. Accuracy within the calibration space was two to three millimeters in three-dimensions.

Spherical passive cooperative targets (ping-pong balls covered with retro-reflective tape⁹) were applied to subjects using two-sided hypoallergenic tape. The retro-reflective tape used was 3M Scotchlite Brand High Gain 7610. The retro-reflectance of this tape remains high up to oblique angles of incidence of 50 degrees. When the incident light is placed coincident with the camera lens the luminance factor is 1600 times brighter than a perfect white diffuser¹⁰.

Each subject was targeted with seventeen targets to evaluate bilateral movement. The targets were placed at the center of the forehead and then bilaterally on the following bony landmarks: distal clavicle or acromion process of the scapula (shoulder), lateral edge of the greater trochanter

⁹Retro-reflective tape is a product of Minnesota Mining & Manufacturing Corporation.

¹⁰3M Product Bulletin "Industrial Optics".

of the femur (hip), lateral condyle of the tibia (knee), lateral malleolus of the fibula (ankle), calcaneus (heel), first metatarsal head of the foot (great toe), lateral epicondyle (elbow), and the styloid process of the ulna (wrist). The targets were used to define theoretical rigid links to approximate the motion of the upper and lower limbs, the torso and the head (Figure 5).

Once targeted, the subjects walked across the force plate several times before data were collected to allow them to relax into a gait pattern that was "normal" for them. In order to reduce visual cueing, the force platform was covered with a piece of carpeting. The outcome of earlier tests, conducted to determine if the carpet had a damping effect on force or moment magnitudes, indicated that no discernible difference could be detected.

Once the subjects had been given an opportunity to relax, video data were collected while each subject was standing on the force plate with feet together in a natural, comfortable posture to provide neutral standing data to be used as the zero reference for all calculations of angular movement. Next, subjects were asked to walk across the force platform barefoot until three successful data trials had been collected with the left foot striking the force plate and three successful trials with the right foot striking the plate. A "successful" trial was defined as one where the foot remained entirely on the force plate during stance phase of gait and no untypical movements were made

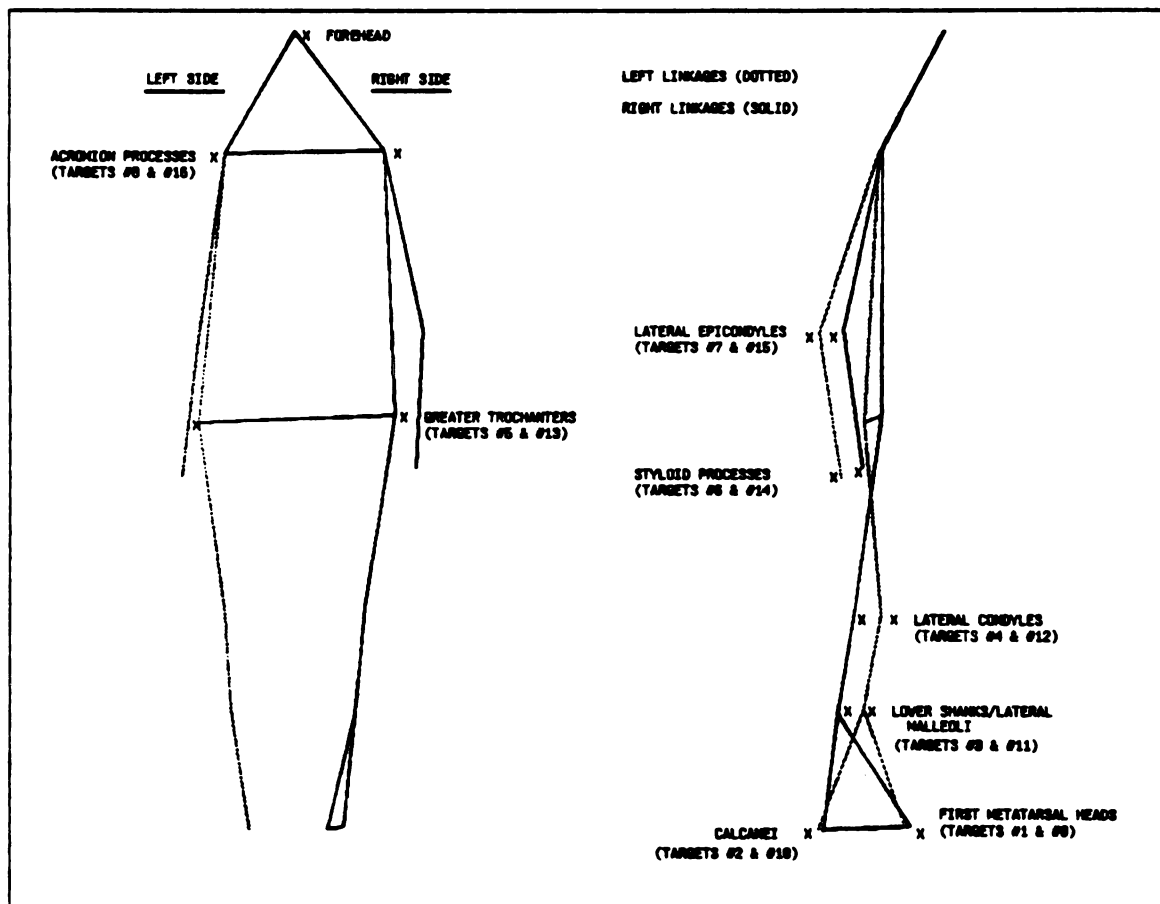


Figure 5: Full Body Linkage Targeting

(i.e. extending or shortening stride length, partial force plate contact, etc). Even though a trial may have been defined as "successful" when observed with the naked eye, it was examined after the data trial had been saved by viewing force data superimposed with other trials of the same condition. (For an example, see Figure 6). At this point the researcher was looking for changes in the temporal patterns of the data. Temporal patterns of ground reaction forces for both "normal" and pathological populations show little variability for a given subject in a given condition (e.g. walking, shoes, right leg). The temporal pattern of the data is highly reproducible trial to trial but will show a difference when the condition is altered for that subject, e.g., an orthotic lift is inserted in the shoe or a different pair of shoes are worn. Trial data were rejected if ground reaction force magnitudes of a given trial were considerably higher or lower than the other trials at any time during the stride or if a major shift occurred when peak magnitudes were observed.

The same protocol was repeated for the shoe trials. Following gait trials, subjects were asked to stand on the force plate, feet together in a comfortable posture, for a series of 20 second balance tests; first with eyes open, then with eyes closed, then starting with eyes open and closing them half-way through the data collection period. No video data were collected during the balance trials.

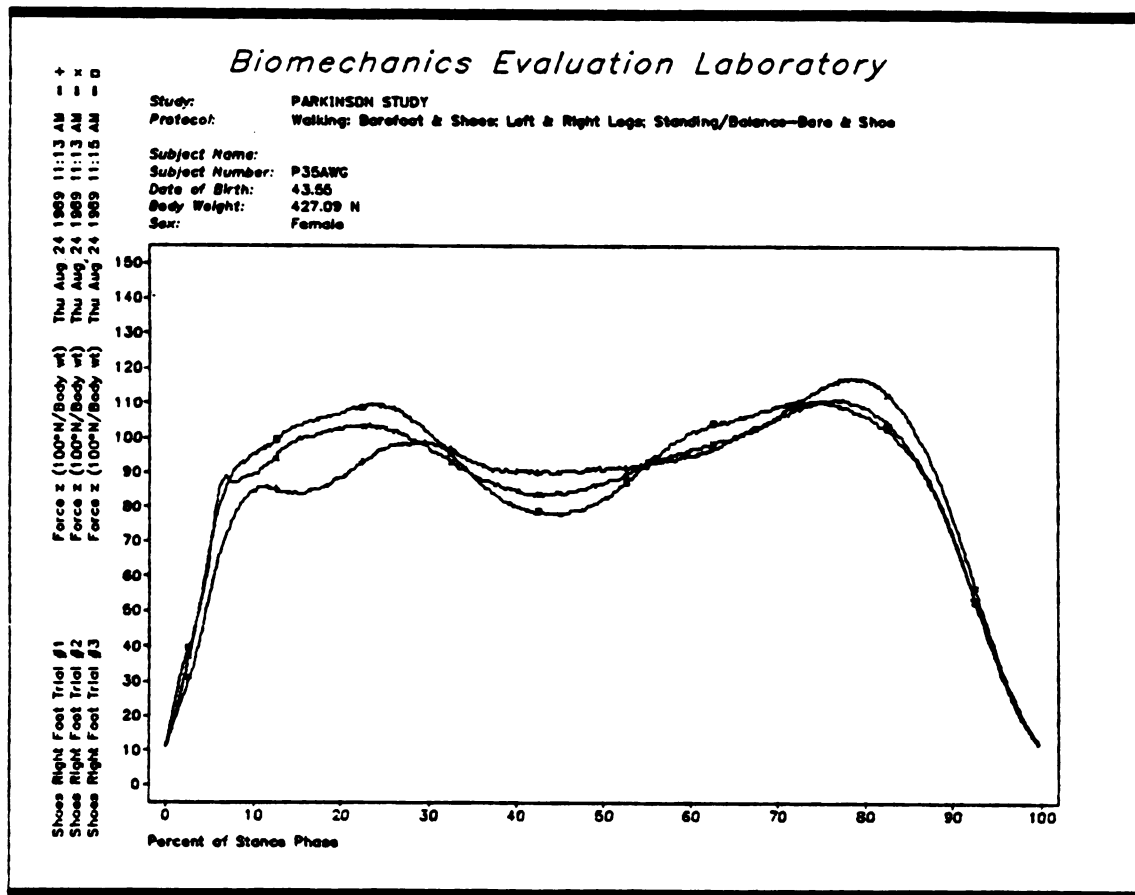


Figure 6: Subject 2, Ground Reaction Forces

III. ANALYTICAL METHODS

The computer programs used for data collection and analysis were developed by students or faculty affiliated with the Department of Biomechanics, with the exception of the Expertvision System three-dimensional software program, EV3D, which is a product of Motion Analysis Inc., and the FTP program. A description of each program used in this research follows below.

The BELDATA¹¹ program was used for sampling, processing and storing the ground reaction force data and for simultaneous collection of the kinematic data. BELDATA initialized by zeroing all channels of the force platform and setting input parameters for force, motion or electromyography (EMG). Ground reaction force and moment data from the force platform were sampled at a rate of 1000 Hz for walking or 100 Hz for balance trials, and stored from the time a vertical load was detected for walking trials or by manual trigger for balance tests. The duration of sampling was set by the user, 1000 milliseconds for walking trials or 20 seconds for balance. Motion data collection was triggered manually and duration was set for one to twelve seconds at a rate of 60 Hz. In walking trials eight seconds of motion data were collected starting when the

¹¹Mr. Robert Wells, Michigan State University, 1989.

subject entered calibration space. When both force platform and motion data were collected, the data were synchronized to within $\pm$ eight milliseconds by placing an event marker on the motion data file when the force platform triggered.

Ground reaction force data binary files were stored on the Sun 4/260C and a duplicate file was stored in ASCII format for ease in transferring the data following subject testing. For each trial, BELDATA created four separate kinematic data files, one for each of the four cameras. The binary files are given a ".raw" extension and later, post data collection, are converted to an EV3D format and are given a ".vid" extension.

During human movement, the only external nongravitational forces acting on the body are the reaction forces occurring between the ground and the foot. Of these, the reaction force in the vertical is greatest in magnitude, reaching 130 to 150 per cent of body weight during walking. Forces acting in the anterior-posterior direction are the true braking and propulsion forces and these peak at 20 to 30 per cent of body weight during walking. The ground reaction forces acting in the medial-lateral direction are much smaller, around two to 10 per cent of body weight. As speed of gait increases the ground reaction force magnitudes increase. For example, maximum reaction forces in the vertical direction for running are two and a half to three times body weight.

In order to analyze reaction forces, hard copies of the three components of the ground reaction force, vertical (F_z), anterior-posterior (F_y), and medial-lateral (F_x) were generated using BELDATA at the conclusion of testing for each subject. Graphed force data were expressed in percent body weight vs time in milliseconds or percent stance phase. Maximum and minimum ground reaction force magnitudes and millisecond data were summarized to allow comparison of temporal patterns in barefoot and shoe conditions for each subject, between subjects, and for comparison with normal populations (Figures 7 and 8). As mentioned earlier, temporal patterns for the three components of ground reaction force are highly reproducible and vary little from trial to trial for a given subject in a given condition. Norm data for ground reaction force magnitudes and temporal patterns are reported in the literature, categorized by phase of gait cycle and stride event.

Human gait is divided into swing and stance phases. Stance phase is defined as occurring from the time at which the heel of one limb contacts the ground through the time at which the toe of the same limb lifts off the ground. During stance phase, the limb in contact with the ground supports the body's weight and permits body advancement over the foot. During swing phase the limb is off the ground moving forward in preparation for the next step. A complete gait cycle or full stride is considered to be heel contact on one limb to heel contact of the same limb. Stance phase

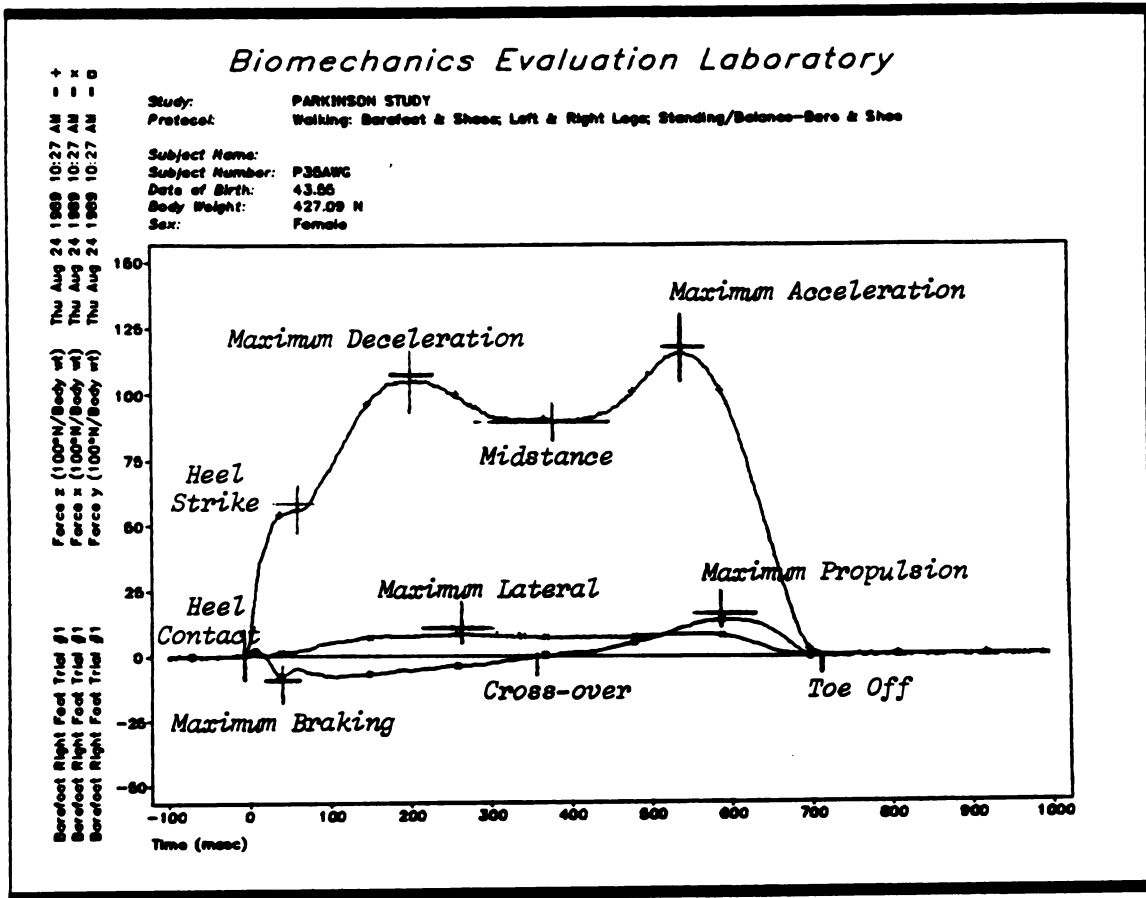


Figure 7: Ground Reaction Forces, Subject 2
 Barefoot Right Trial #1

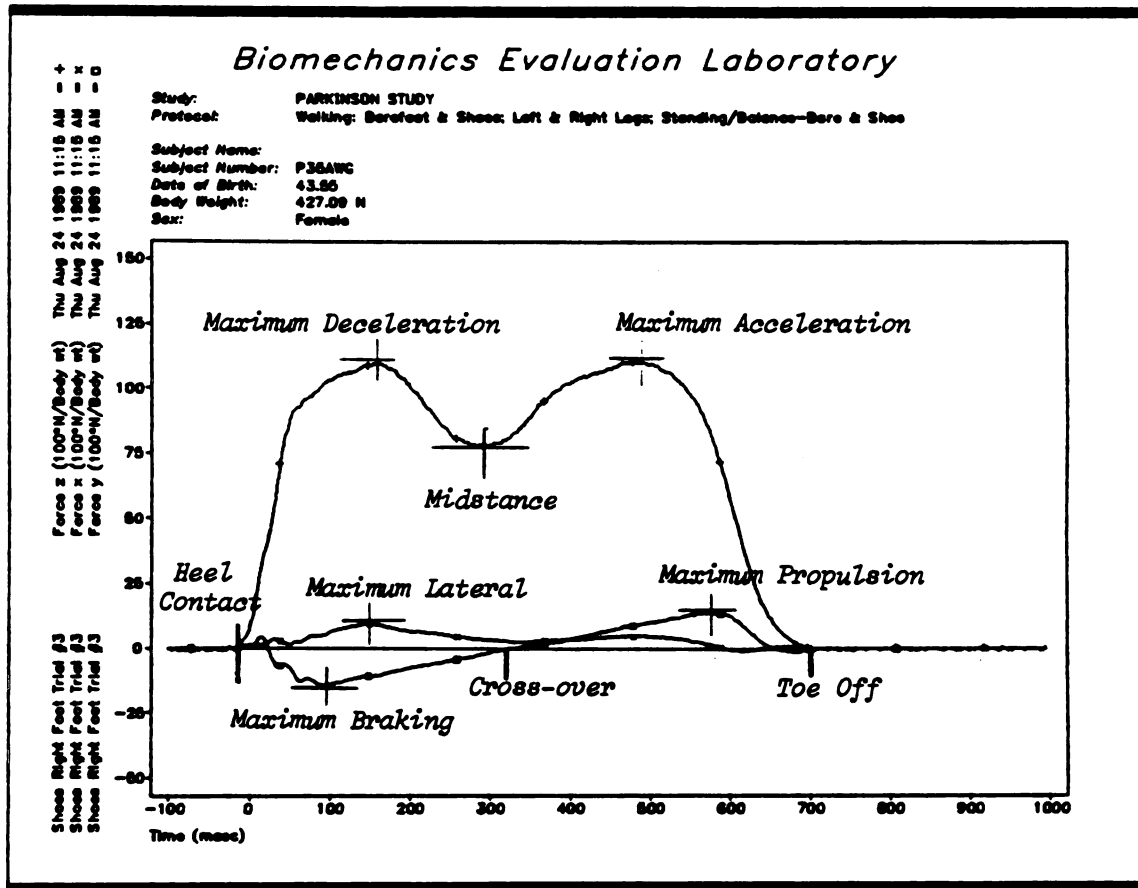


Figure 8: Ground Reaction Forces, Subject 2
 Shoes Right Trial #1

composes 60 to 62% of a full gait cycle and, by definition, the force data presented in this paper will deal with the stance phase of gait.

Stance phase can be thought of as having two components: a braking phase, defined as that portion of gait devoted to decelerating or slowing the body, and a propulsion phase during which time the body is attempting to propel itself forward. For the purpose of analysis, and to compare various stages of stance phase among the subjects and with "normal" populations, stance was divided into six specific events describing the main parameters of human gait. Ground reaction force data for the three coordinate axes were summarized using these event categories.

Event one, "Heel Contact" (HC), was defined as the time at which the heel first touches the ground. At this point the center of gravity of the body is at its lowest. "Heel Strike" (HS), event two, is the data spike which sometimes occurs 15 to 30 milliseconds into a stride. Event three, deceleration or braking, starts after the heel touches the ground and the limb accepts the body's weight and the body begins to move over the foot, until the entire foot is flat on the ground. Peak magnitudes for this event were termed "Maximum Deceleration" (Max Decel) in the vertical force direction (F_z); and "Maximum Braking" (Max Brake) in the anterior-posterior direction (F_y). Midstance, event four, begins when the full foot is in contact with the ground, the body's full weight is borne by the single, stationary limb

as the body progresses over it, raising the center of gravity of the body to its highest point in the gait cycle. The knee then begins to flex slightly and the body is in a state of falling resulting in vertical force (F_z) magnitudes dropping below body weight. In the vertical force direction (F_z), this event is called "Midstance" (MS) and the vertical ground reaction force is at the minimum. In the anterior-posterior direction (F_y), this event is termed "Cross Over" (CO), and it is that point at which the reaction force in the anterior-posterior direction shifts from braking to propulsion. During event five, acceleration or propulsion, the body begins moving forward in relationship to the limb and the heel comes off the ground as the body propels itself forward. This event was termed "Maximum Acceleration" (Max Accel) in the vertical force direction (F_z); and "Maximum Propulsion" (Max Prop) in the anterior-posterior direction (F_y). The last event is "Toe Off" (TO), and marks the stage of gait where the toe lifts off the ground terminating stance phase. The ground reaction forces occurring in the medial/lateral direction (F_x) during stance phase were summarized as "Maximum Medial" (Max Med), defined as the maximum reaction force generated in the medial direction; and "Maximum Lateral" (Max Lat), the maximum lateral reaction force generated.

The three components of the ground reaction forces and moments can be represented by a unique force and torque concentrated at a point of application on the plantar

surface of the foot. This is referred to as the "resolved ground reaction forces" and provides an analytical method for examining and evaluating the pattern created by the progression of the resolved forces along the plantar surface of the foot. When used with kinematic data to locate the position of toe and heel targets on the force platform, relative to the path of the resolved forces, the image of a foot then can be drawn around the force pattern, providing the researcher with a clear picture of exactly how the resolved forces were acting on the sole of the foot (Figure 9).

Two computer programs were available for use in resolving ground reaction forces and moments, each using a different method of calculating the resolved forces. The Beldata data program was used to graph and hard copy resolved ground reaction force and torque data for comparison among and between subjects (Figure 10). Beldata resolves the ground reaction forces and moments about the force platform center, into an equivalent force system comprised of the resultant force vector and a vertical torque. The intercept of this system in the x and y plane of the surface of the force platform is what is generally termed the center of pressure or C.O.P.

Using the FTP program, ASCII ground reaction force data files were transferred to the Case Center for further analysis with various computer programs. The FTP is a communication software program which allows porting data to

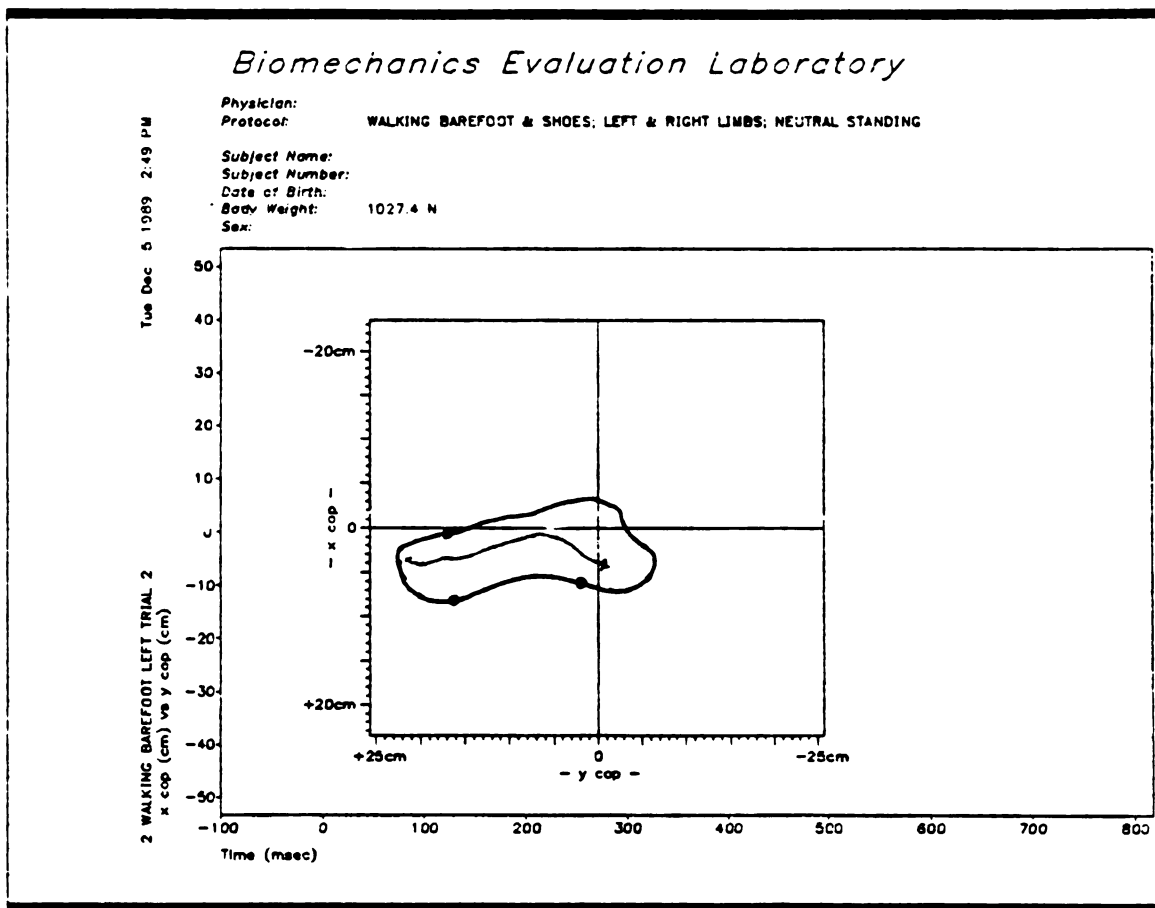


Figure 9: Path of Resolved Forces

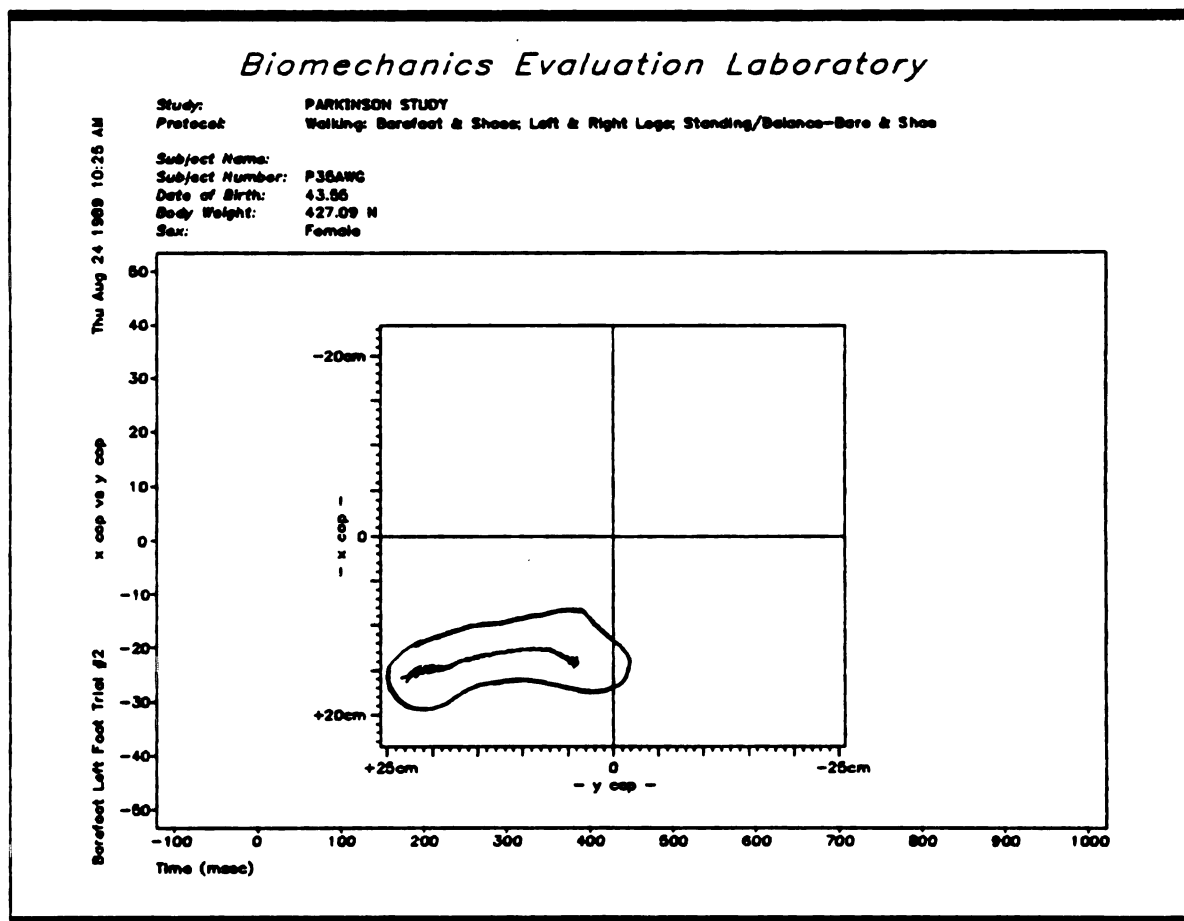


Figure 10: Subject 2, Path of Resolved Ground Reaction Forces

or from other host computers and the SUN 4/260C. Because FTP checks errors on the hardware level, it provides for much faster transmission of data files than many other programs.

Once transferred, data were analyzed using the "Resolved Ground Reaction Forces and Moments" program (RGRFM)¹² loaded on the Prime. The RGRFM program resolves the ground reaction force and moment system about the force platform center into an equivalent force system providing a unique intercept in the x and y plane of the surface of the force platform with the line of action of a wrench (the resultant force and a parallel moment vector).

In addition to graphing the resolved force data, The RGRFM program superimposes the resultant ground reaction force, imaged as a vector quantity, over the intercept data so that both temporal patterns and progression of resolved force patterns can be examined together. Resolved data were imaged and hard copied in color using a Tektronix 4105 graphics terminal¹³ and Tektronix 4696C¹⁴ printer. The use of color graphics provided clear separation of the intercept and force patterns, aiding in analysis. The RGRFM program graphs the intercept data in milliseconds, imaging the progression of the intercept as a green dot, while the temporal force pattern is expressed as a red vector (Figure

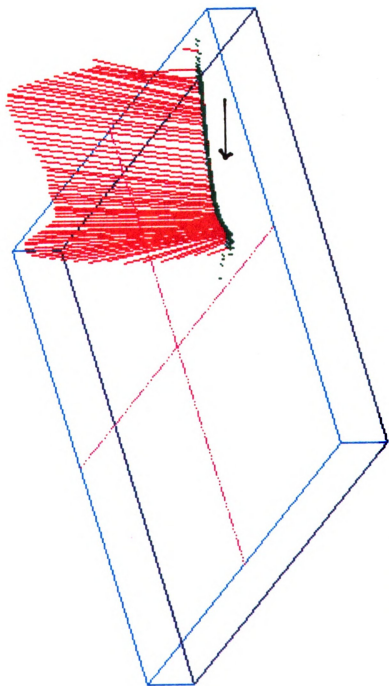
¹²Robert Wm. Soutas-Little, Ph.D. (mathematics); Carol Gremmel, M.S., Martin Oleary, M.S. and Pavan Chavva, M.S. (programming).

¹³Manufactured by Tektronix, Wilsonville, Oregon.

¹⁴Manufactured by Tektronix, Wilsonville, Oregon.

11). The user determines scaling of the force, frequency of imaging force vectors, the total milliseconds to be imaged, and provides the coordinates for viewing the graphed data. As this is a three-dimensional imaging program, the user has the capability of imaging and viewing the graphed data from any angle. All data were graphed using an anterior-lateral viewpoint, using the same scale and vector frequency to allow comparison trial to trial and between subjects. Where progression of intercept patterns deviated sharply, either medially or laterally, or force vector orientations were sharply inclined, other views were selected so that the data could be observed from a different perspective. If unusual patterns were observed in the progression of force (i.e. the force progresses forward, then progresses backwards over itself) the file was graphed in segments so that any portion where the data folded back on itself could be isolated and examined separately (Figure 12).

The RGRFM graphs give six pieces of information for analysis: three force components, two coordinates of the C.O.P., and density of image for time. The RGRFM graphs provide a vectorial representation of the vertical force showing magnitudes and orientation of forces throughout the stride, and the intercept of the unique line of action of the resolved ground reaction forces in the x-y plane of the force plate, over time. It is this unique line of action that is most sensitive to perturbations in an individual's gait. It can be effected by change of footwear, use of an



P35: WALKING BAREFOOT RIGHT TRIAL #1

Figure 11: Subject 2, Resolved Ground Reaction Forces

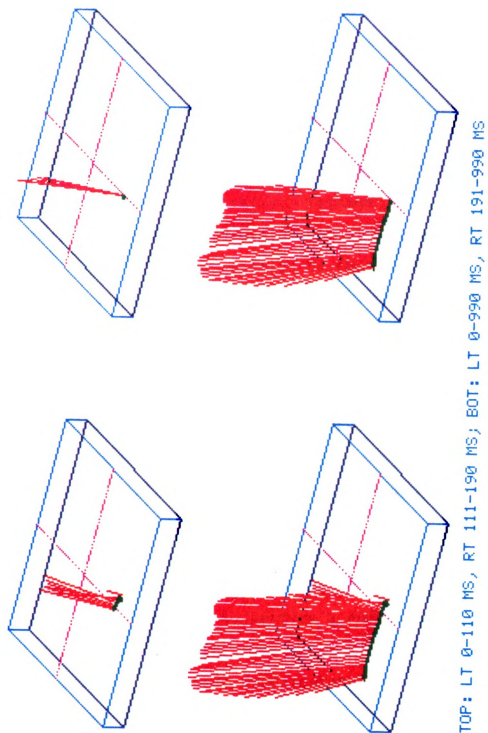


Figure 12: Subject 1, Resolved Ground Reaction Forces, Right Barefoot Trial #1

orthotic, or, in the case of pathology, a sore joint or muscle causing the individual to shift their center of gravity to alter their weight bearing pattern.

In walking gait, there is a torque associated with the twisting or turning of the tibia, relative to the ground, that occurs during stance phase of the gait cycle. During the braking component of stance phase the tibia twists inward medially, and during the propulsion phase of stance the tibia twist outward laterally. Torques (2 to 12 Newton-meters in magnitude) are associated with this twisting action, related to the rotation of the pelvis in order to advance the body forward. The RGRFM program was used to graph this torque, which is the parallel moment vector component of the equivalent force system. These data were graphed on a Tektronix 4105 graphics terminal and the color images were hard-copied using the Tektronix 4696C. A standard view, scale and frequency of imaging torque vectors was used for all data trials to allow comparison of the data.

The torque data also were, in the more conventional manner, expressed in Newton-meters versus time in milliseconds, in order to perform a numerical analysis of the data. The Torqcalc¹⁵ and Dataplot¹⁶ programs on the Prime computer were used to calculate and graph the torque data. Graphed data were hard copied for analysis. Temporal

¹⁵Robert Wm. Soutas-Little, Ph.D. (mathematics), Martin Oleary, M.S. (programming) 1988.

¹⁶Martin Oleary, M.S., 1988.

patterns of torque data were analyzed for each patient and were compared to torque patterns for walking gait of "normal" populations.

The change in momentum or impulse of the actual braking-propulsion force, i.e. the reaction force in the anterior-posterior direction (F_y) were examined using the Numint¹⁷ program. The Numint program, loaded on the Prime computer, calculates the area under the curve of the F_y , force versus time. Whereas ground reaction force data in the anterior-posterior direction (F_y) provided information on maximum magnitude and the time at which peak braking and propulsion was achieved by a subject, impulse data allows comparison and analysis of the overall braking versus propulsion. Normative patterns of gait show braking for approximately fifty percent of the stance phase and propulsion for the remaining portion of the stance phase. Alterations in gait due to compensation for pain, instability, or other problems result in altered braking/propulsion patterns, i.e changes in the amount of braking versus the amount of propulsion an individual does on a given limb.

Kinematic data were digitized by the Motion Analysis Video Processor (VP320) and were tracked using the EV3D software. The VP320 accepted, synchronized and digitized the video input received simultaneously from the four cameras and stored this information on the SUN 4/260C work

¹⁷Written by an undergraduate engineering student.

station. As the data were accepted, the VP320 time-synchronized and time-matched the data, in preparation for later tracking of named targets through time and space. Both nondigitized video and digitized images received from the cameras were displayed, one camera at a time, on a 60 Hz. monitor, which aided in pretest set-up and monitoring of test trials.

The tracking algorithm used by the EV3D system consisted of two procedures: the initialization step and the tracking step. The initialization step associated video images with target names and solved the correspondence problem. The tracking step maintained target identities through space and time.

The tracking algorithm uses the object coordinate data created through calibration (see Chapter 2 for a description of the calibration procedures). The calibration process established calibration coefficients for each camera view. The calibration coefficients and the image-coordinates of a given target were then used to define the path of an optical ray through the object-space. When image coordinates and calibration coefficients were available for two or more views, the three-dimensional path of an optical ray was defined for each view. A more detailed discussion of this process follows.

The EV3D program was used to display, on the SUN monitor, the video data for all four camera views of a given trial, digitized and synchronized by the VP320. Tracking

parameters were established by the researcher which described the object space, maximum norm of residuals for that space, number of pixels that a given target can contain, speed a target can travel and number of frames that a target can disappear before it is considered to be "lost".

To initialize the data, the researcher selected a camera view and a frame of data within that camera view, and then identified a specific video image as belonging to a specifically named target. This process was repeated until all images for that camera view had been identified. The software then paired each image, as it was identified, with every image viewed by the other cameras. For each pair of images, the software used the calibration coefficients and the direct linear transformation (DLT) to project a pair of rays into three-dimensional space. The image which, when paired with the images identified by the researcher, produced a pair of rays that came the closest to intersecting was considered to belong to the target. Using a least squares calculation, a point of intersection in three-dimensional space was obtained from the projections of the paired images. This three-dimensional point then was tested to see if it represented a valid target location. To be valid, the point must be located within the space established in the tracking parameter arguments and the norm of residuals resulting from the least square calculation must be less than or equal to the value of the "maximum norm of residuals" parameter set by the researcher. If the

location was determined to be valid, the target was assumed to be viewed by at least two cameras and the resulting three-dimensional location was stored in the time-space array. If the location was determined to be an invalid location, that meant the target was not viewed by at least two cameras and therefore another frame of data had to be selected and the initialization process repeated.

Once the initialization was completed, then the three-dimensional target locations were defined for one frame of data. Using the DLT, these locations were projected into the two-dimensional image space of each camera's next frame of data and were used to identify two-dimensional images in that frame. Once targets were identified in two or more frames, predicted three-dimensional locations were projected into the next frame and were used to identify two-dimensional images in that frame. The predicted three-dimensional locations were determined by a linear extrapolation of the three-dimensional target locations found in the previous two frames.

Projected three-dimensional locations for each target were subjected to the same two criteria used in the initialization step validity test. A third criterion used was that the distance between the previous three-dimensional location of the target and its new three-dimensional location must be less than or equal to the "maximum instantaneous speed" argument established by the researcher in the tracking parameters. If the pair of images met the

validity test, they were considered to belong to the target. If the validity test criterion was not satisfied, then it meant the target had not been viewed by at least two cameras in the current frame and was considered to be "lost" or dropped from view.

Tracked data were edited and smoothed, using a digital filter on the track editor (TRED) program. The TRED program displays the trajectory paths for the three-dimensional data for each target tracked. The TRED program was used to eliminate all trajectories not associated with a named target, interpolate over gaps in each path using cubic splines, and smooth the data points of the trajectories for each target.

Tracking was performed using the "track/st" option, which allowed the researcher to define theoretical rigid links between specific targets (Figure 5, Chapter 2). Joint angular movements were calculated using the EV3D angle program, which calculates the angle between two line segments. Two links, or line segments, were selected that ran above and below the joint to be examined (Figure 13). The line segments were drawn between target 12 and target 13 and target 12 and target 11. Next, two vectors were used to define the joint, vector "A" ran from target 12 to target 13 and vector "B" ran from target 12 to target 11. The dot product of these two vectors was calculated to obtain the cosine of the angle (and therefore the angle) between the vectors. Angles for the neutral standing file were

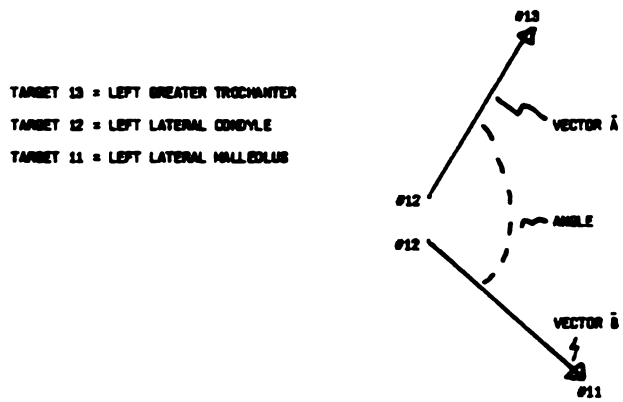


Figure 13

Calculation of Joint Angular Movement

Figure 13: Calculation of Joint Angular Movement

calculated first, as these data were used as the zero reference for all calculations of angular movement for that condition. Angles calculated for each stance trial data were then subtracted or offset from the dynamic joint angle during movement.

Flexion-extension angles and sagittal plane movement was calculated for the ankle, knee, hip and elbow.

Stride length also was calculated using the kinematic data. Stride length was measured as heel contact on one side to heel contact on the same side. The "stick" operator of the EV3D graphics program was used to image stick figures for every frame of data so that heel contact for a given stride could be determined. Once the heel contact frames were identified, the time equivalent for that frame was determined using another feature of the stick operator. With this information, stride length and cadence were measured.

It appeared, from observation of the subjects during the test, that two of the subjects frequently crossed over the midline with the limb that was in swing phase. Stride width was calculated to confirm whether this "observed" phenomenon indeed was occurring.

Finally, angular data were differentiated using the EV3D differentiation program so that angular velocity could be examined.

IV. RESULTS AND CONCLUSIONS

In chapter II it was stated that data were collected on three subjects, two females and one male. This chapter will discuss only the analysis of data collected on the two female subjects, as the male subject was unwilling to attempt ambulation without the aid of a walker. Therefore, the data obtained from his trials did not provide meaningful information for this study but may be useful if a study is attempted at a later date on assistive devices for parkinsonian patients.

The analysis and presentation of results will be separated into two parts, the first part dealing with force and the second part with motion. Although the two parts can be combined to give a full dynamic profile, the purpose of this initial study was to isolate parameters that are clinically relevant and, for this relevance, it is necessary to seek significant parameters first.

The three components of the ground reaction force can be examined in a temporal sense and also from a spatial perspective. The temporal data can be presented in real time (milliseconds) or normalized by time (percent of stance). Both Parkinson's patients deviated from the norm patterns. For ease in discussing data analysis, subject P33EMG (stage IV Parkinson's disability rating) will be

referred to in this chapter as Subject 1. Subject P35AWG (rated stage III) will be discussed as Subject 2.

The vertical force (F_z) is the dominant component of the total ground reaction force and in normal gait rises from zero to a maximum deceleration value in the first 15 to 20% of stance phase. This is the period of transference of load from one limb to the other or from double stance phase to single stance phase. Parkinson's patients exhibited a decreased ability to effect that transfer, more pronounced on one limb, with the progression of the disease. The left and right vertical force patterns for Subject 1 are shown in Figure 14, plotted in percent of stance phase. Transference of load from right foot to left foot required over 40 percent of stance phase. This was evidenced by a delay in reaching peak deceleration on left foot and an increase of acceleration phase on the right foot. Swing phase was shorter than normal for both limbs, 30 to 35 percent, as compared to the 40 percent norm. Of additional interest was that once the left limb was in single stance, a more normal deceleration to acceleration function was observed. Load decreased from 110 percent of body weight (BW) to 90 percent BW, and then back to 110 percent BW. The right limb during single stance phase exhibited a more "crutch-like" response, bearing full body weight but with minimum deceleration or acceleration. This gait phenomena has been observed in the prosthetic side of amputees and the involved side of patients with unilateral limb pathology.

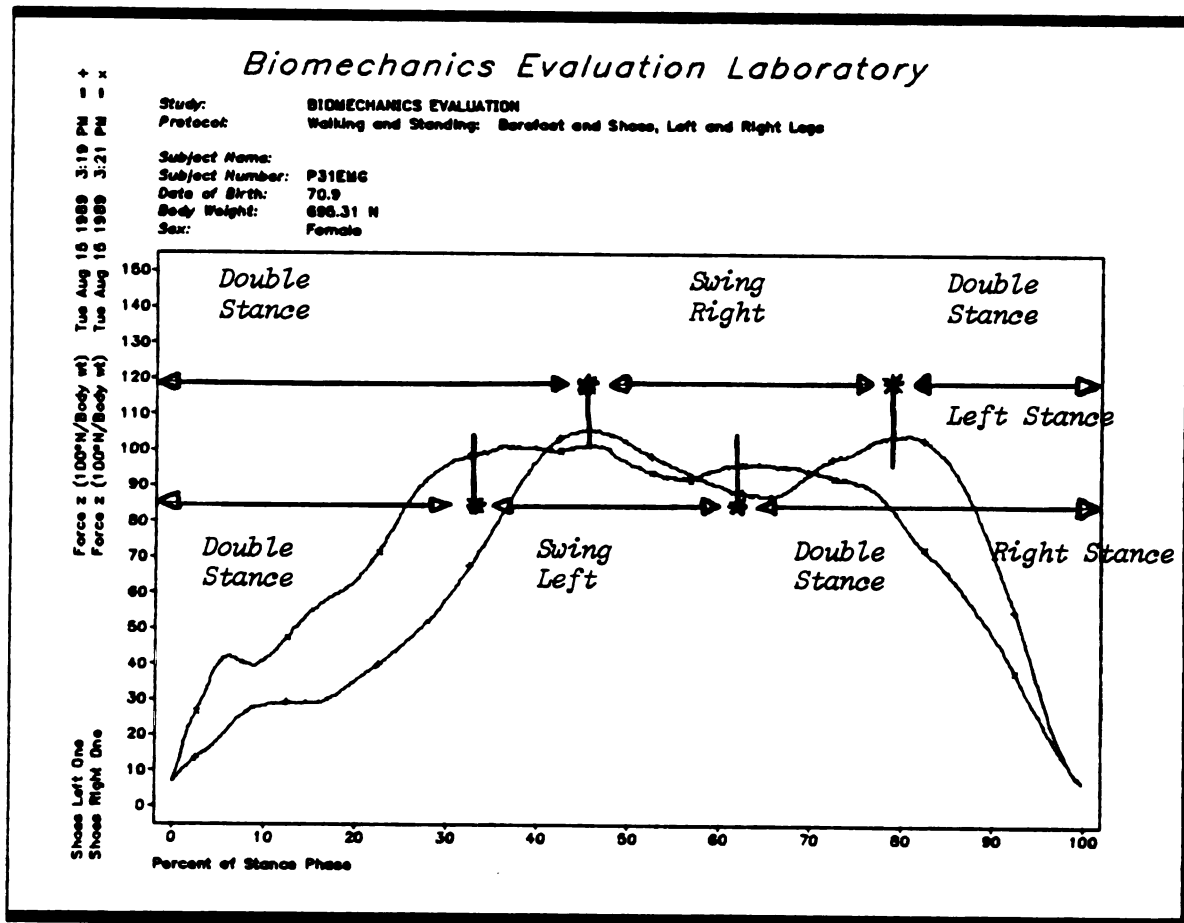


Figure 14: Subject 1, Left and Right Vertical Ground Reaction Force

A similar characteristic was noted on Subject 2 (Figure 15) but it was not as pronounced. It was of interest that in both these subjects, the increased transference time was for right foot to left foot with decreased function of the right during single stance phase.

For Subject 1, the same phenomenon of transition from right to left is evident in the anterior-posterior force (F_y), which measures braking and propulsion forces (Figure 16). A decrease is seen in the propulsion force on the right limb with a corresponding decrease in the required braking force on the left. This decrease in braking and propulsion forces was not as evident with Subject 2 (Figure 17). The increased propulsion on the left side required an increased braking on the right to effect the transfer left to right. Therefore, Subject 1 clearly showed that the changes on the left side were compensatory to the loss of function in the right limb.

As mentioned, Subject 2 did not display significant variations right to left, although the peak magnitudes were below normal (seven to 15 percent as compared to the 25 percent norm) for both limbs. This decrease has been observed by this researcher in other elderly patients who do not display parkinsonian symptoms.

Examination of the forces generated in the medial-lateral direction, (F_x), showed some deviation from normal patterns (Figures 18 and 19). Normal F_x gait patterns show a medial force for the first 10 to 25 percent of stance

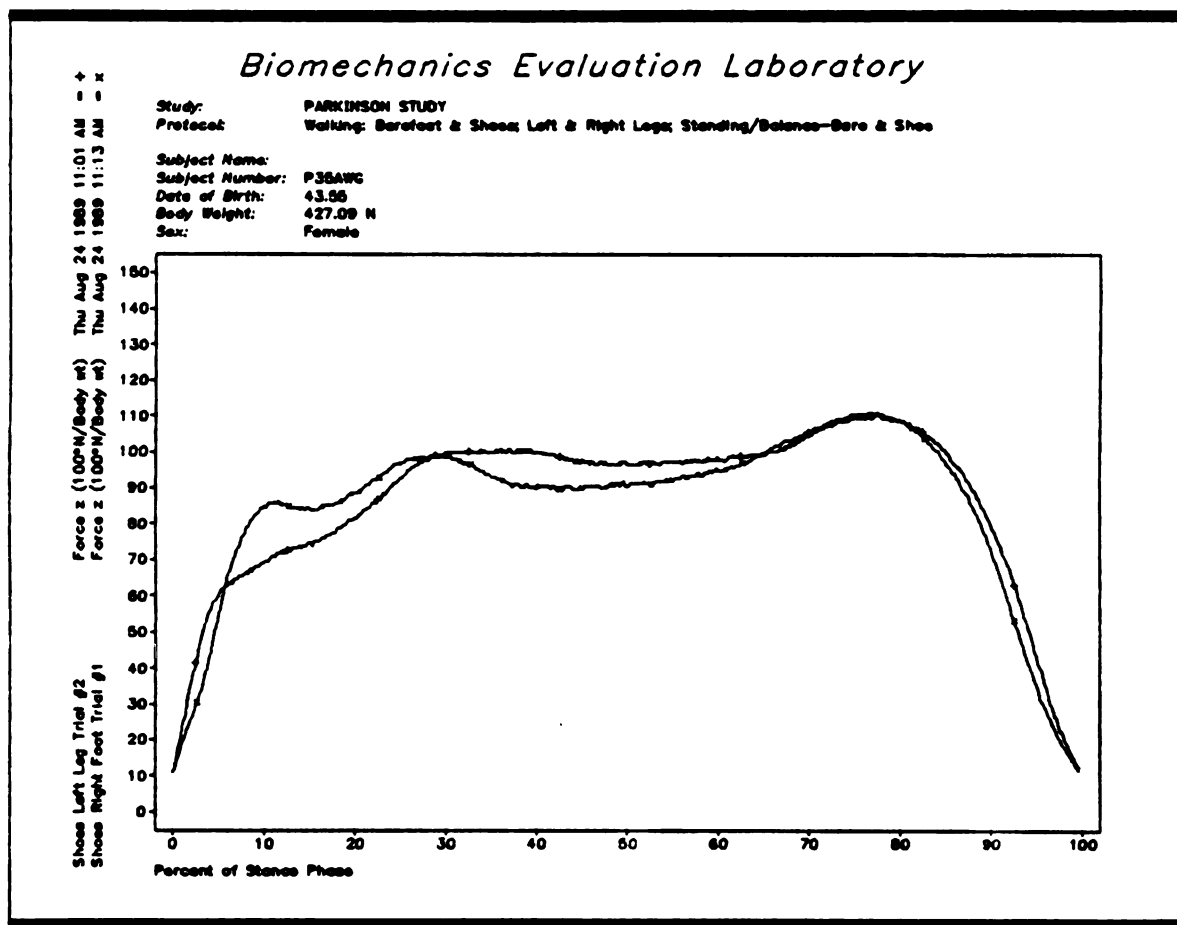


Figure 15: Subject 2, Left and Right Vertical Ground Reaction Forces

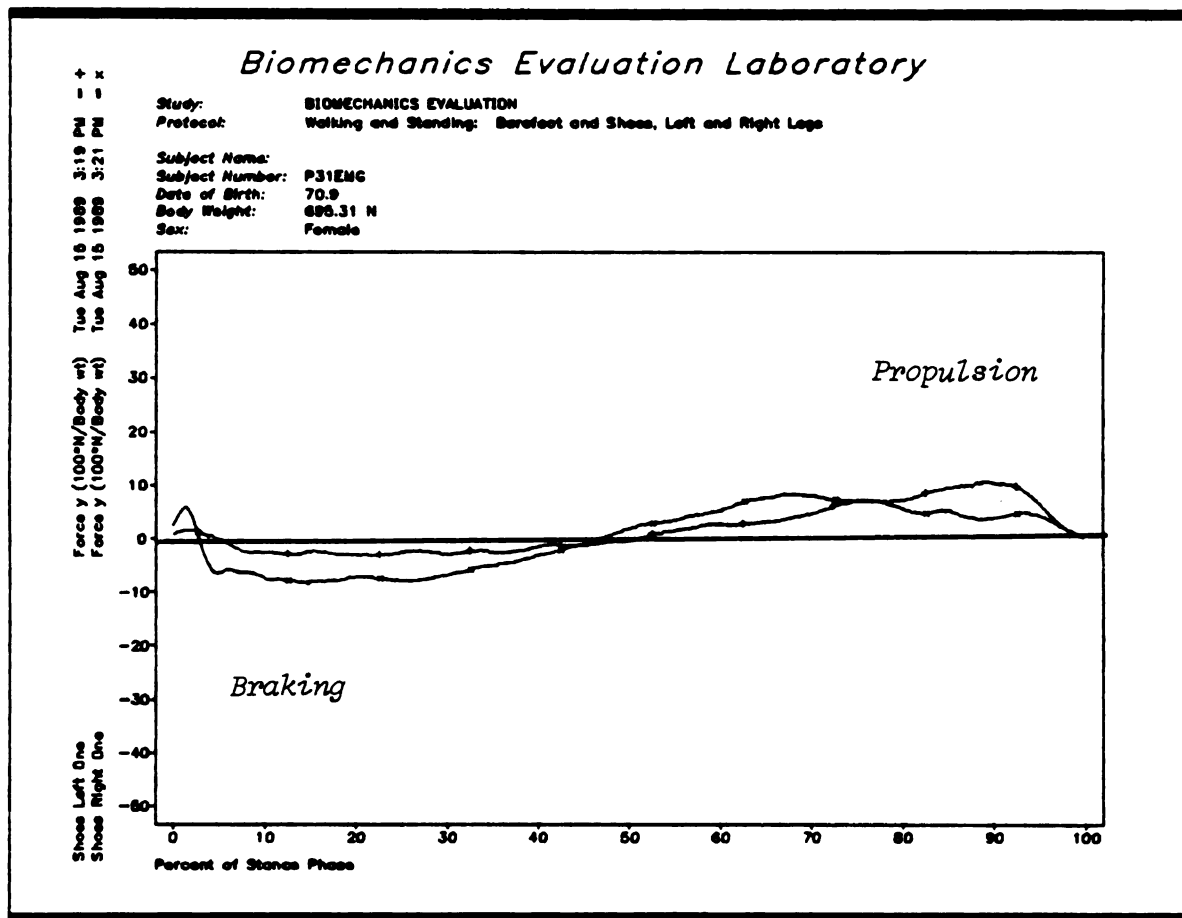


Figure 16: Subject 1, Left and Right Anterior-Posterior Ground Reaction Forces

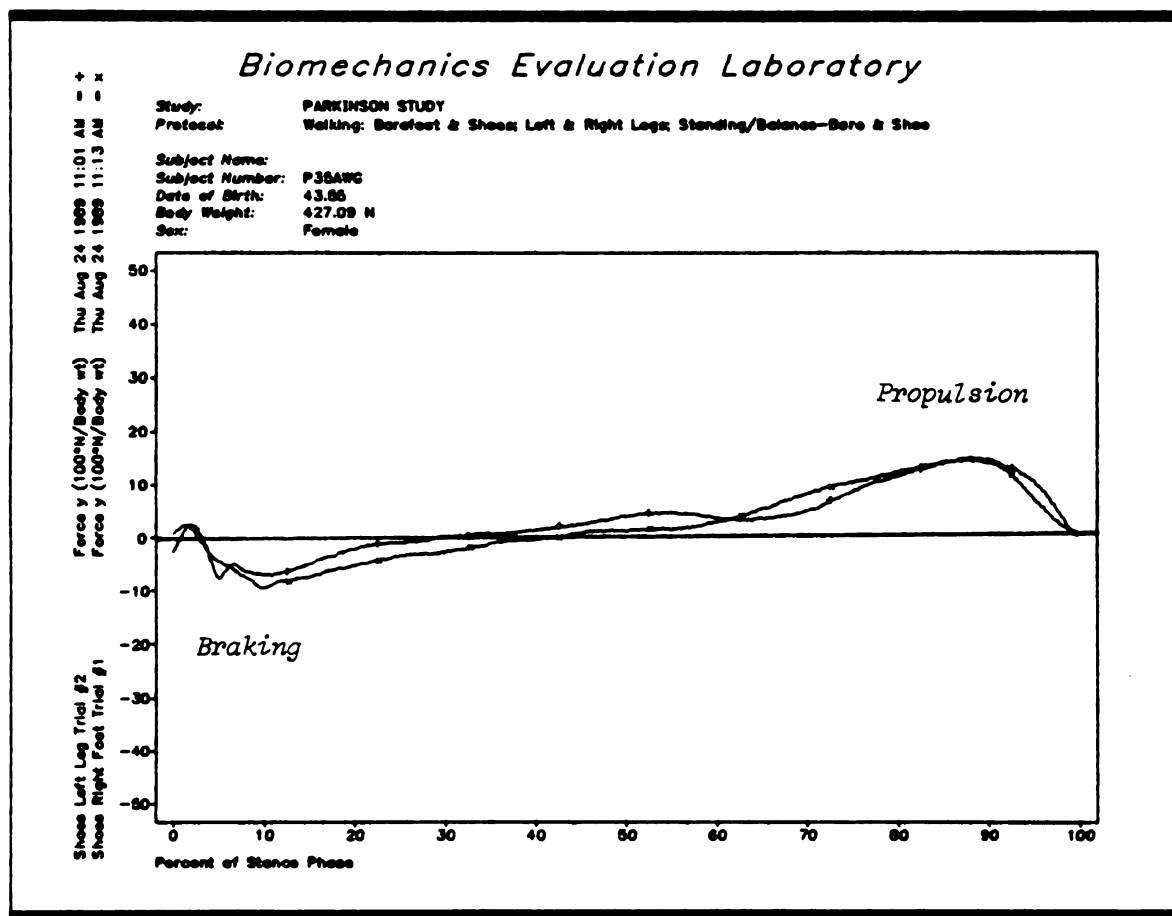


Figure 17: Subject 2, Anterior-Posterior Ground Reaction Forces

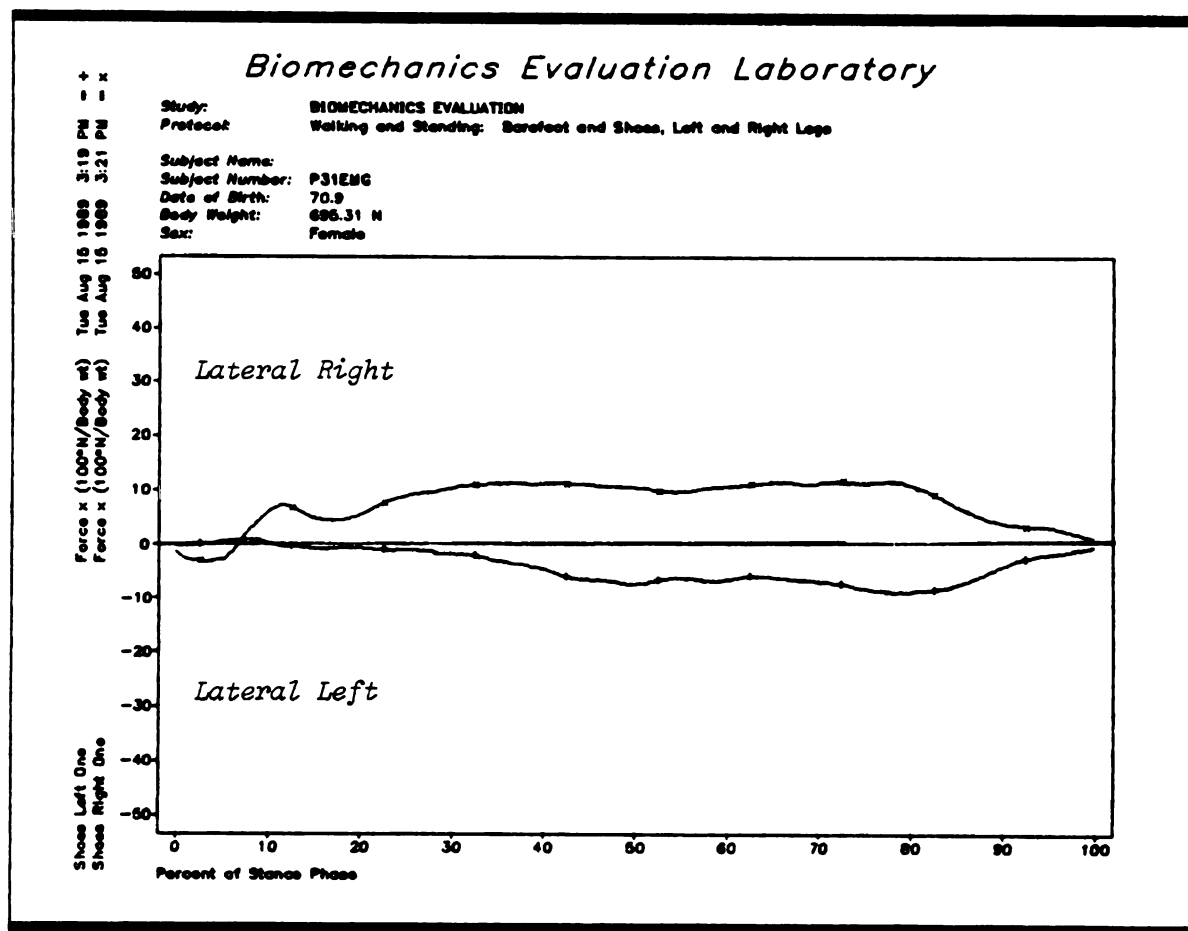


Figure 18: Subject 1, Medial-Lateral Ground Reaction Forces

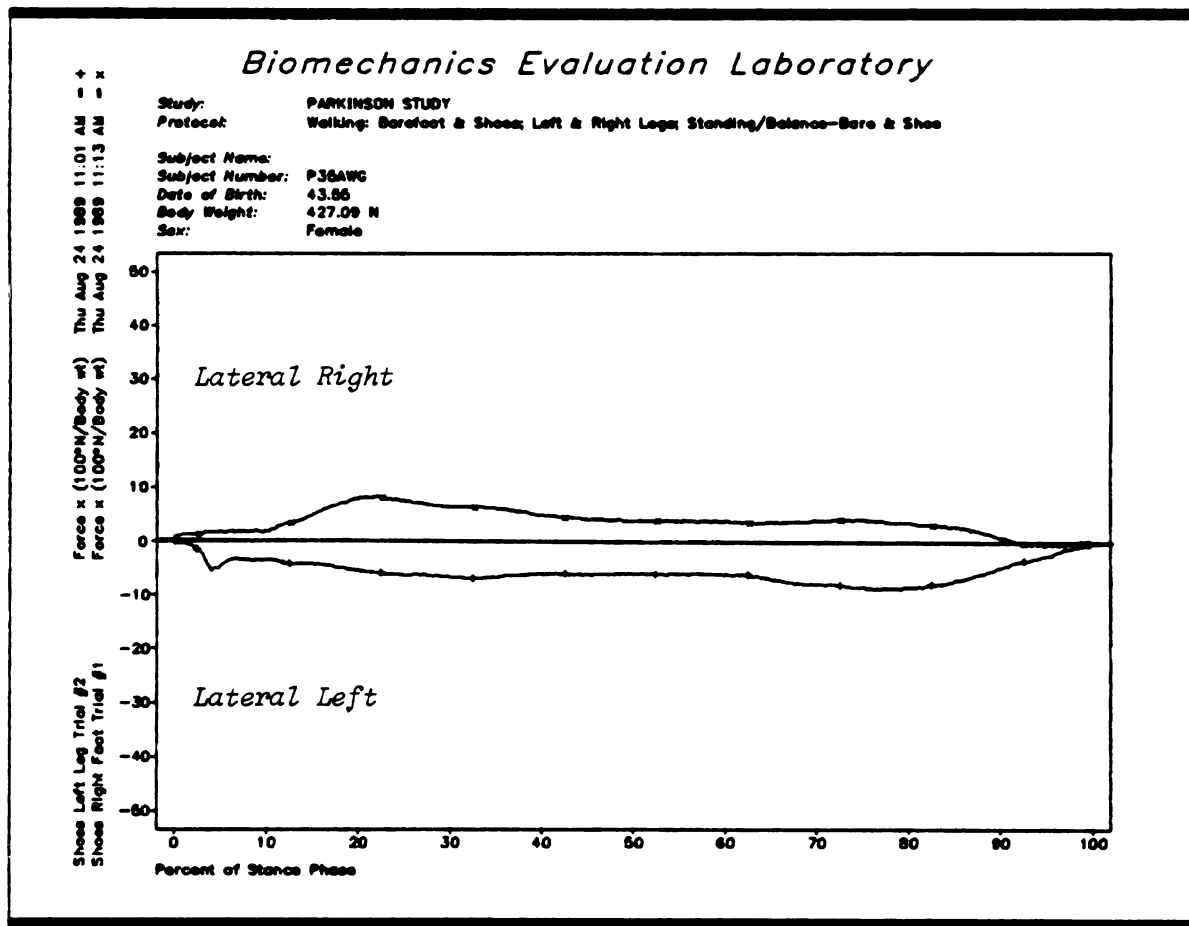


Figure 19: Subject 2, Medial-Lateral Ground Reaction Forces

followed by a lateral force. It is not uncommon to see a medial force reoccur at the end of the stance phase of gait. It also is not unusual to see only lateral force generation for the entire stance phase. Magnitudes for normal populations range between two and five of percent body weight. Both subjects showed a predominantly lateral force throughout stance phase. The peak lateral force magnitudes were higher for both subjects than the norm, and there is a slight increase in magnitude on the right side compared to the left. Subject 1 had lower magnitudes than Subject 2 in the barefoot condition, measuring six to eight percent BW, left and right; but had higher magnitudes when wearing shoes, 10 to 11 percent BW, left and right. Magnitudes for Subject 2, both left and right limbs barefoot and shoe conditions, measured eight and nine percent BW.

The spatial plots of the Resolved Ground Reaction Forces and Moments (RGRFM) Figure 20 confirmed the transfer difficulties seen in the temporal data for Subject 1. The RGRFM plots also showed an additional deviation from normal transfer patterns when the transfer began. In normal gait, double stance occurs with the heel contacting the ground on one limb while the other foot is pushing off on the metatarsal heads. The right foot of Subject 1 is flat on the ground (foot-flat) when the left heel contacts the ground. While the right foot still remains in foot flat stage, the subject begins her transfer from right to left limb, which can be seen in the spike which occurs in the

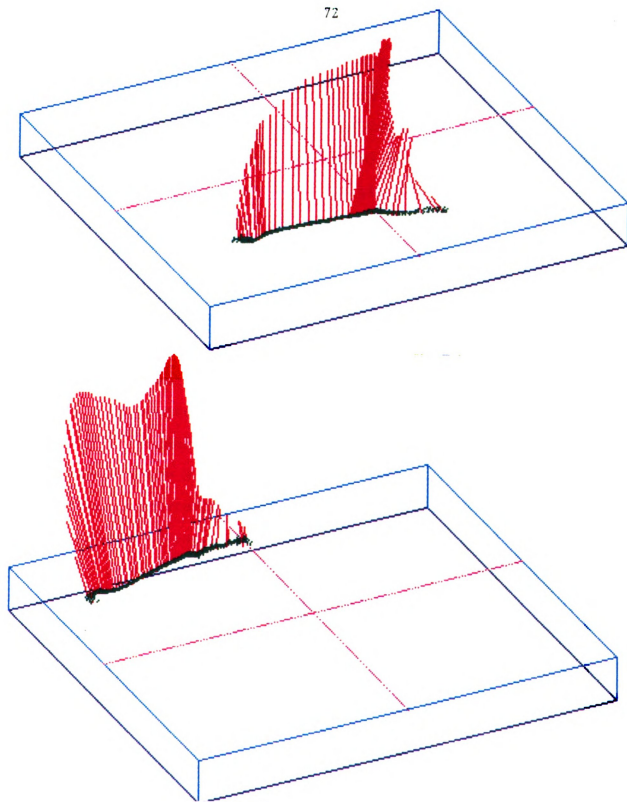


Figure 20: Subject 1, Resolved Ground Reaction Forces

spatial data plots both left and right (Figure 20). The "vaulting over" or "crutch-like" behavior described in the temporal data is seen in the magnitudes of the vectors, which are of constant value. The progression of the unique line of intercepts (shown in green) varied greatly for left to right trials (Figure 21). On the left leg, the pattern deviated medial to lateral, and lack of stability was evidenced by periods of rocking backward, seen as a thickening of the green line of intercepts where the force data folds back upon itself (areas are circled). This medial to lateral deviation was typical of patterns seen with other neurological diseases. However, on the right side, the progression of the line of intercepts was almost straight, although the subject still had some roll-back due to instability at the point of transfer. This straight pattern is characteristic of resolved force patterns seen on the prosthetic side of amputee patients, where the limb is simply used as a crutch and vaulted over. This would suggest the right limb was almost dysfunctional in terms of assisting her in ambulation.

The shift in when transfer occurred in the foot contact phase that was seen in Subject 1 also was exhibited by Subject 2, but to a lesser degree (Figure 22). Subject 2 was still in foot-flat when she began her transfer from right to left limb. However, soon thereafter she rolled onto her forefoot. The deviation of the line of intercepts was more typical of patterns seen in other neurological

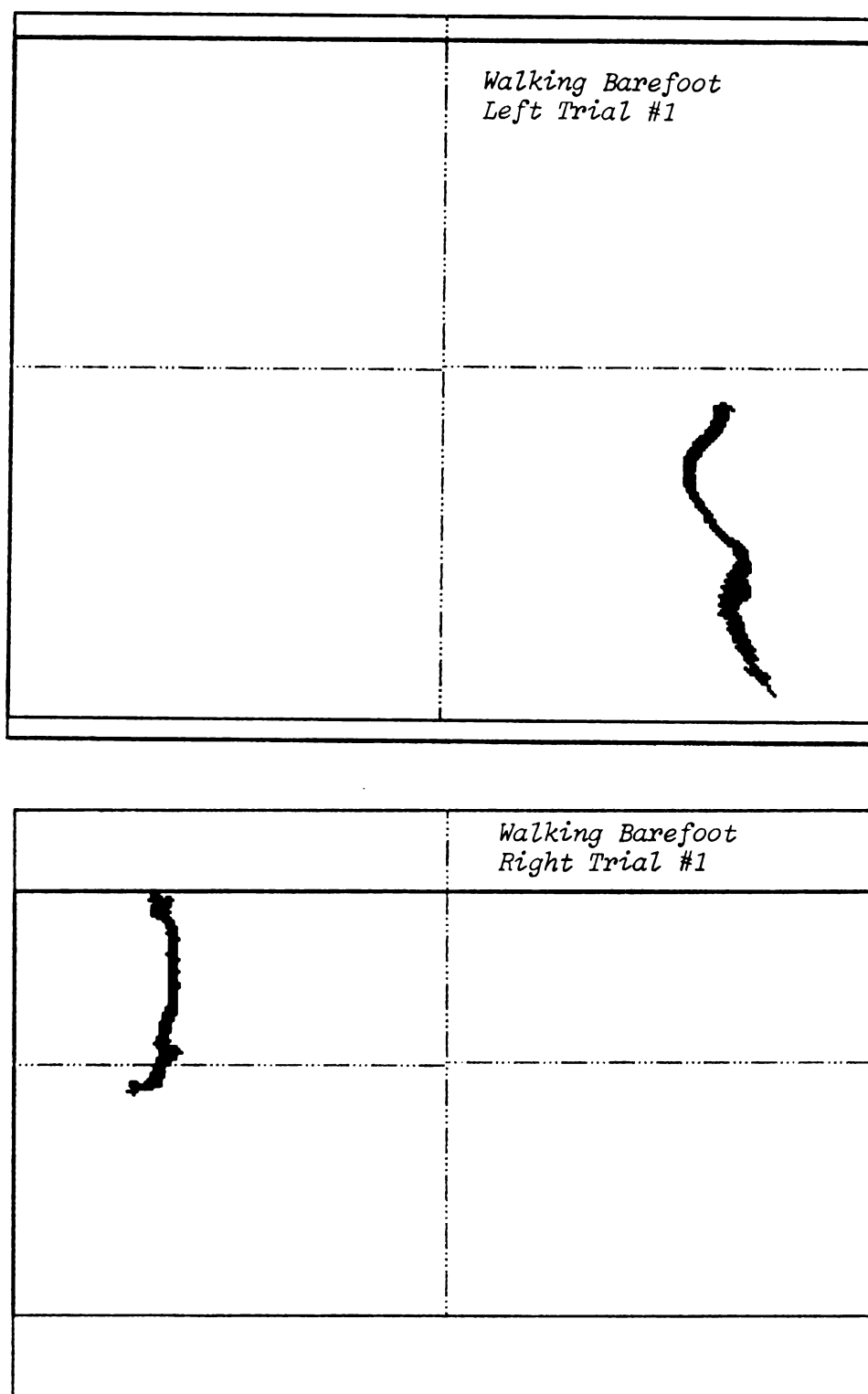


Figure 21: Subject 1, Progression of the Unique Line of Intercepts for Left and Right Trials

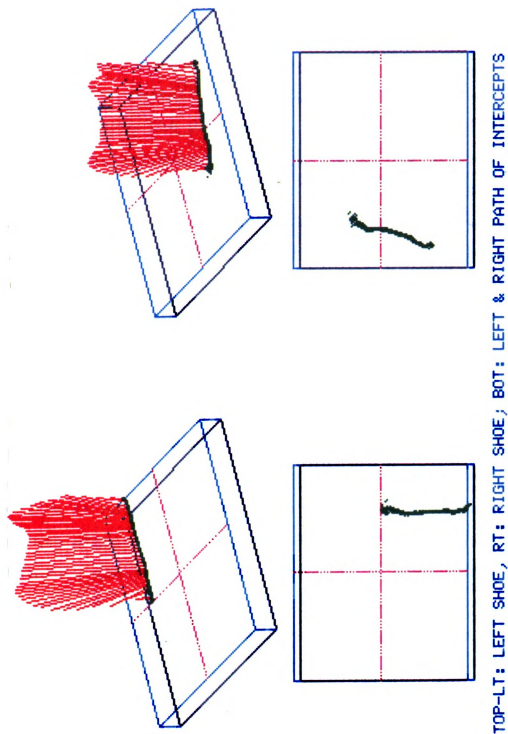


Figure 22: Subject 2, Resolved Ground Reaction Forces (Top) and Progression of the Unique Line of Intercepts for Left and Right Trials (Bottom)

pathology. Again, roll-back was seen at transfer points left and right, represented by a thickening of the green line (areas are circled on Figure 22).

An examination of the resolved ground reaction torques provided perhaps another parameter for analyzing the compensation mechanism occurring during transfer and for characterizing the progression of the disease. In nonpathological gait, the torque pattern is an inward (medial) rotation of the tibia, relative to the ground, for approximately 50 percent of stance phase followed by an outward (lateral) rotation of the tibia for the balance of stance. Resolved torque magnitudes for normal populations ranges between two to five Newton-meters.

Subject 1 exhibited an outward tibial rotation during nearly the entire foot contact period (Figure 23). On the left side, for both barefoot and shoe conditions, the subject twisted medially (1 to 1 1/2 Nm) for about the first 200 milliseconds of stance. Of greatest importance was the change in magnitudes for the outward torque right to left. On the right side outward rotation, torques measured 9 Nm barefoot and 10 Nm in shoe condition occurring at 64 and 67 percent of stride, respectively. On the left side there was much more deviation in the magnitudes, with peak magnitudes reaching 4.25 Nm barefoot to 5.5 Nm shoes, about half the magnitudes seen in the right limb. This would indicate that there is considerable compensation occurring in order to

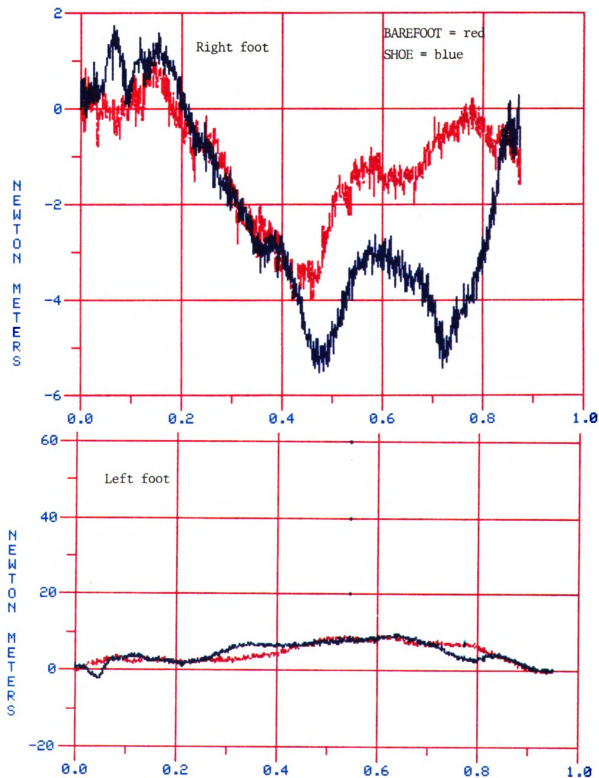


Figure 23: Subject 1, Resolved Ground Reaction Torques

rotate the pelvis and swing the left limb forward in preparation for left heel contact.

Subject 2 also exhibited an external torque for the majority of stance, but did have some medial torque at the start of stance phase in the shoe condition (Figure 24). The magnitudes for this subject were within normal ranges, and quite comparable left to right. This would indicate either better control due to medication or differences seen due to disease progression between Subjects 1 and 2.

The motion data collected included two or more gait cycles for each trial. A full gait cycle is considered to be from heel contact to heel contact of the same limb. As discussed in Chapter III, gait cycle is divided into two phases, swing and stance. Swing phase constitutes that portion of the cycle from toe off on one limb to heel contact of the same limb, and represents 38 to 40 percent of the full cycle. Stance phase is measured from heel contact on one side to toe off on the same limb and represents 60 to 62 percent of the full gait cycle.

Using the three-dimensional coordinates for the heel and toe targets in conjunction with the imaged stick figures for each subject, the times at which heel contact and toe off occurred were identified (Figures 25 and 26). Depending upon the exact frame of data selected as heel contact or toe off, the coordinates of the heel and toe targets could shift 0.1 inches or 2.5 millimeters. The frames identified are a

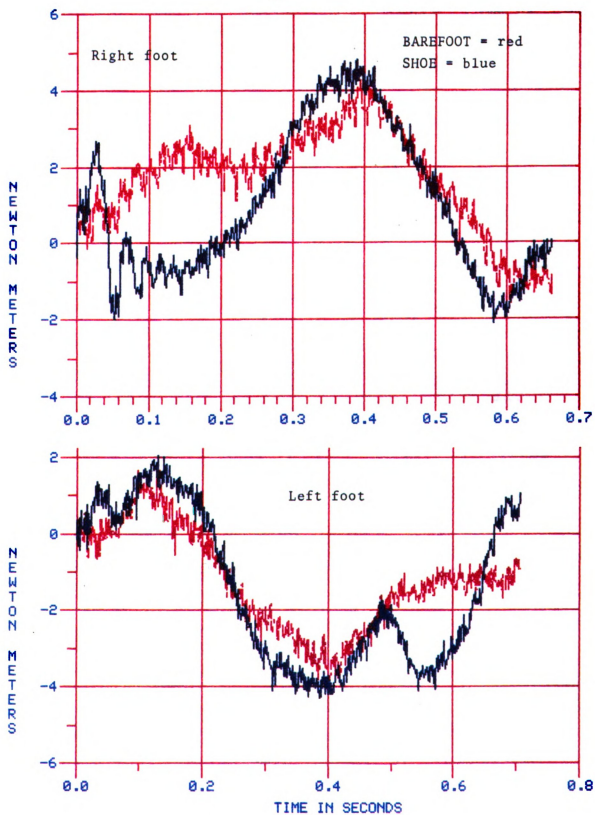


Figure 24: Subject 2, Resolved Ground Reaction Torques

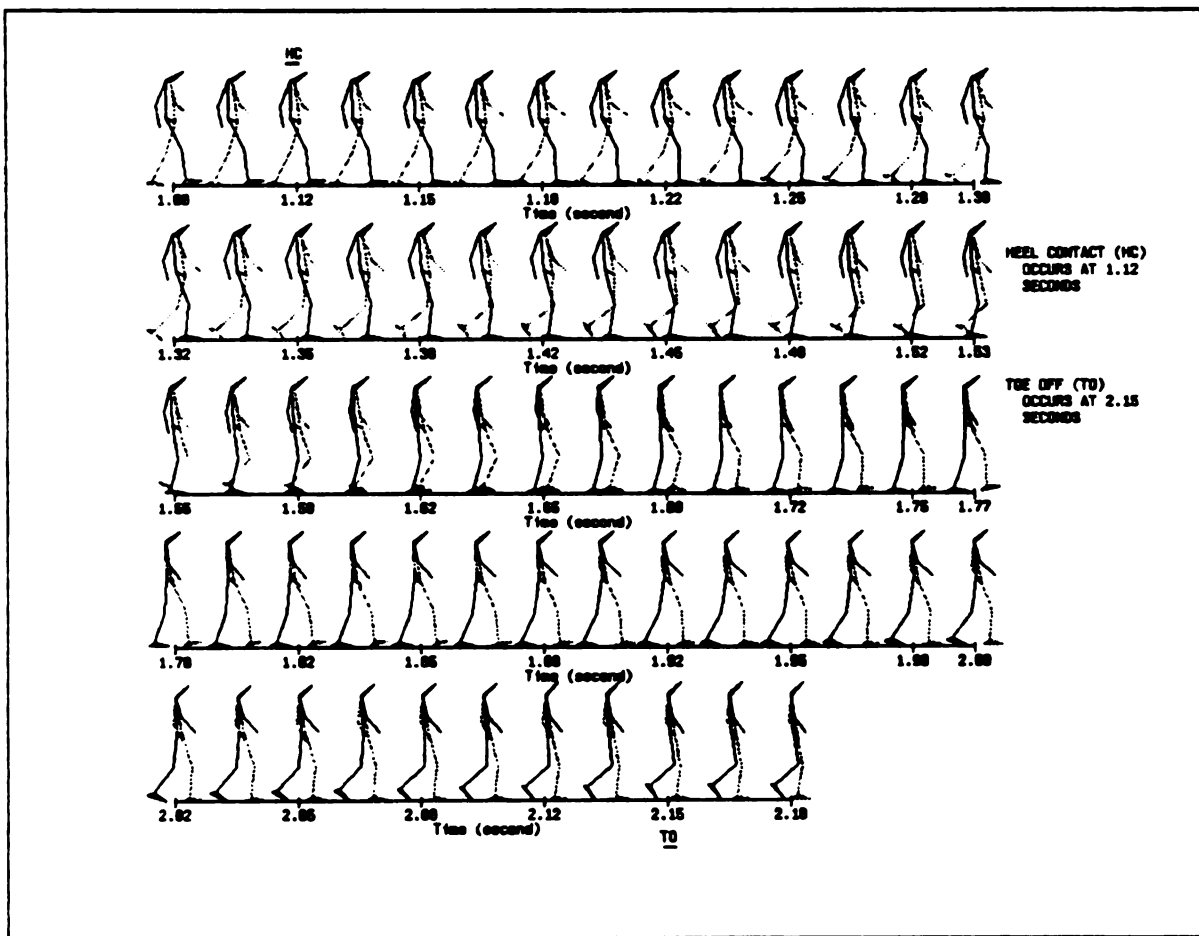


Figure 25: Subject 1, Right Foot Stance During Force Platform Contact

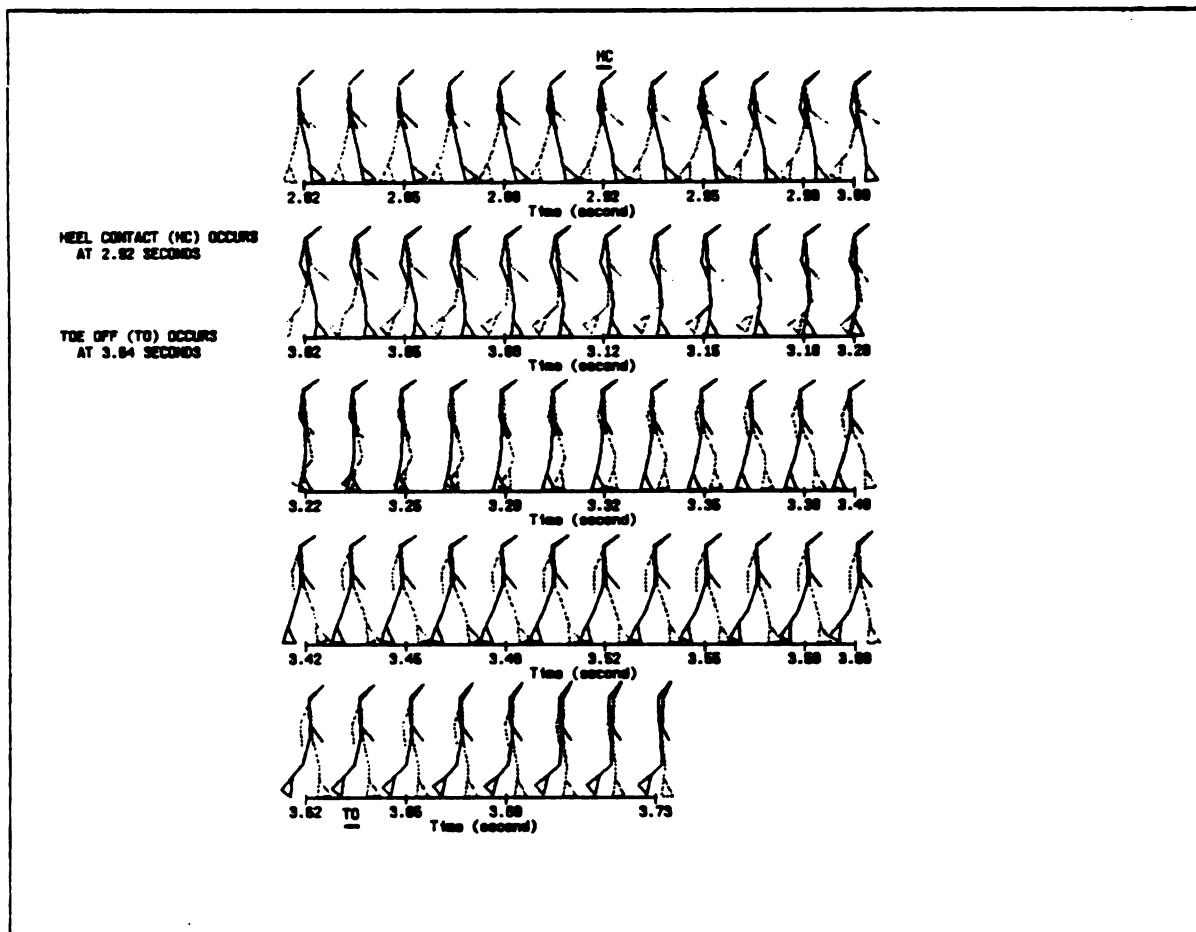


Figure 26: Subject 2, Right Foot Stance During Force Platform Contact

best estimate using the subject data and knowledge of normal patterns.

Overall, Subject 1 exhibited an increase in stance phase on both limbs compared to norms, 64 to 65 percent, (see Table 1) and a faster swing phase of 35 to 36 percent. Stance phase for Subject 2 on the right side approximated normal values, 62 to 63 percent, as compared to norms following her initial stance phase which was 68 percent of her full gait cycle. On the left side, stance phase was consistently longer than norms, 66 to 67 percent of cycle, with a faster swing phase 34 to 33 percent.

Based on the frames identified for heel contact and toe off, it appeared that the stance times and full gait cycle times for Subject 2 decreased over a series of cycles for a given trial. For example, her initial stance time on the right limb was 880 milliseconds, her second stance was 750 milliseconds and her last stance time in that trial was 700 milliseconds. This may suggest the characteristic of festinating gait described in Chapter I. It was not possible to examine this same parameter with Subject 1 because her data contained only one or two cycles per trial.

Figure 27 shows the progression of gait, both left and right limbs, for Subject 2. Kinematic data for calcaneal and fifth metatarsal head targets were plotted in order to examine stride length and width during gait. The square represents the force platform, with the right foot striking the plate in this trial. Stride length for each limb is

Table 1

Stance Time and Percent of Gait Cycle for Subject 1 and Subject 2

TIME OF HEEL CONTACT AND TOE OFF				
SUBJECT 1		SUBJECT 2		
	<u>LEFT</u>	<u>RIGHT</u>	<u>LEFT</u>	<u>RIGHT</u>
1st Heel Contact :		1.12 sec	1.07 sec	0.56 sec
1st Toe Off :	1.32 sec	2.15 sec	1.90 sec	1.35 sec
Total Stance Time :		1.03 sec	0.83 sec	0.79 sec
Percent Gait Cycle:		64%	66%	65%
2nd Heel Contact :	1.80	2.72 sec	2.33 sec	1.77 sec
2nd Toe Off :	3.00		3.07 sec	2.50 sec
Total Stance Time :	1.2 sec		0.74 sec	0.73 sec
Percent Gait Cycle:	75%		67%	63%
3rd Heel Contact :			3.43 sec	2.92 sec
3rd Toe Off :			4.17 sec	3.64 sec
Total Stance Time :			0.74 sec	0.72 sec
Percent Gait Cycle:				64%*
4th Heel Contact :				4.05 sec*

GAIT CYCLE
(Heel Contact to Heel Contact)

1st Cycle	:	1.60 sec	1.03 sec	1.26 sec	1.21 sec
2nd Cycle	:			1.10 sec	1.15 sec
3rd Cycle	:				1.13 sec

* Subject 2 turned on 4th heel contact

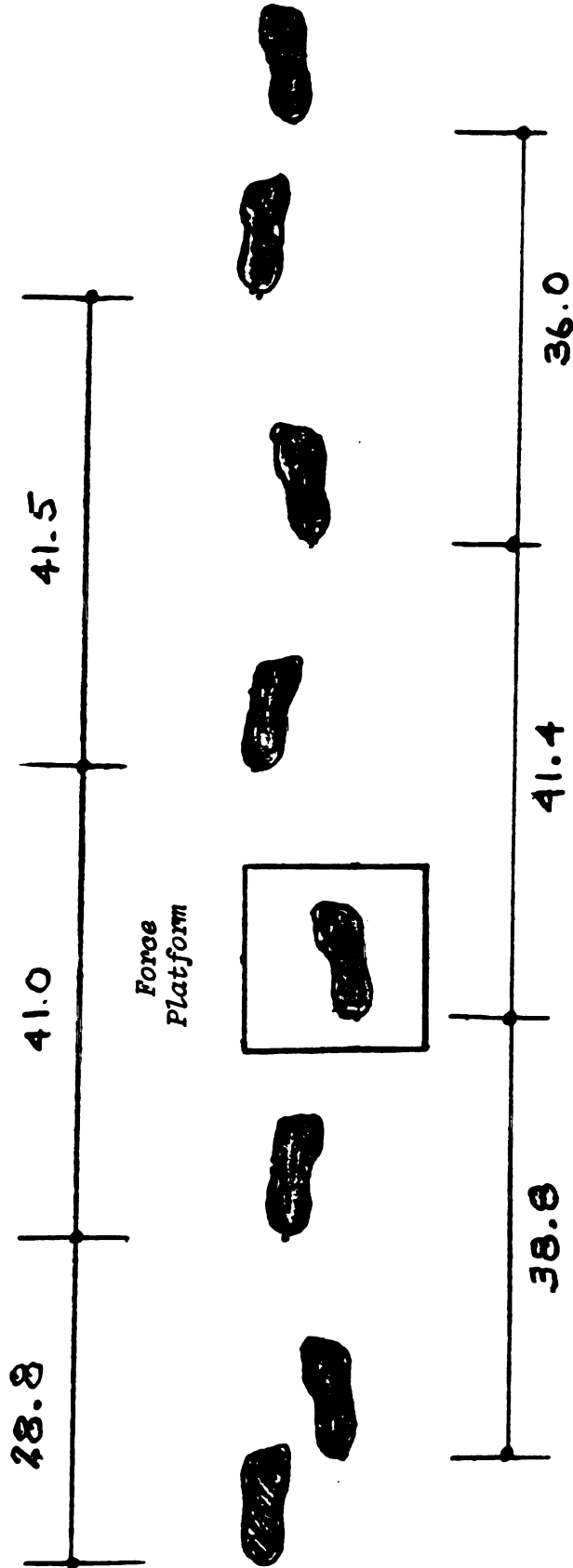


Figure 27: Subject 2, Comparison of Stride Length and Stride Width for Left and Right Foot

given from heel contact to heel contact of the same limb. Of particular note is the shortening of stride width that occurred as Subject 2's gait progresses, decreasing her base of support (which plays a major role in stability during gait). Again, an examination of this parameter for Subject 1 was not possible due to insufficient cycles of data per trial.

The motion analysis allowed a joint-by-joint examination of the upper and lower extremities. Although there is little quantitative data on upper extremity motion during walking, the data allowed comparisons on left and right sides of each patient's upper extremities. In contrast, joint motion at the ankle, knee and hip has been well documented during gait cycles for normal populations [15].

As would be expected, the general characteristics of flexion and extension at all joints in the lower extremities exhibited grossly similar patterns to norms. Therefore, a detailed examination of these patterns at each joint was required to seek parameters which may characterize parkinsonian gait.

ANKLE

In normal gait, the heel contact occurs with the ankle in a neutral position (roughly a 90 degree angle between the plantar surface of the foot and the shank axis, (Figure 28). The plantar flexion angle represents an increase of this angle greater than 90 degrees. A dorsiflexed position would

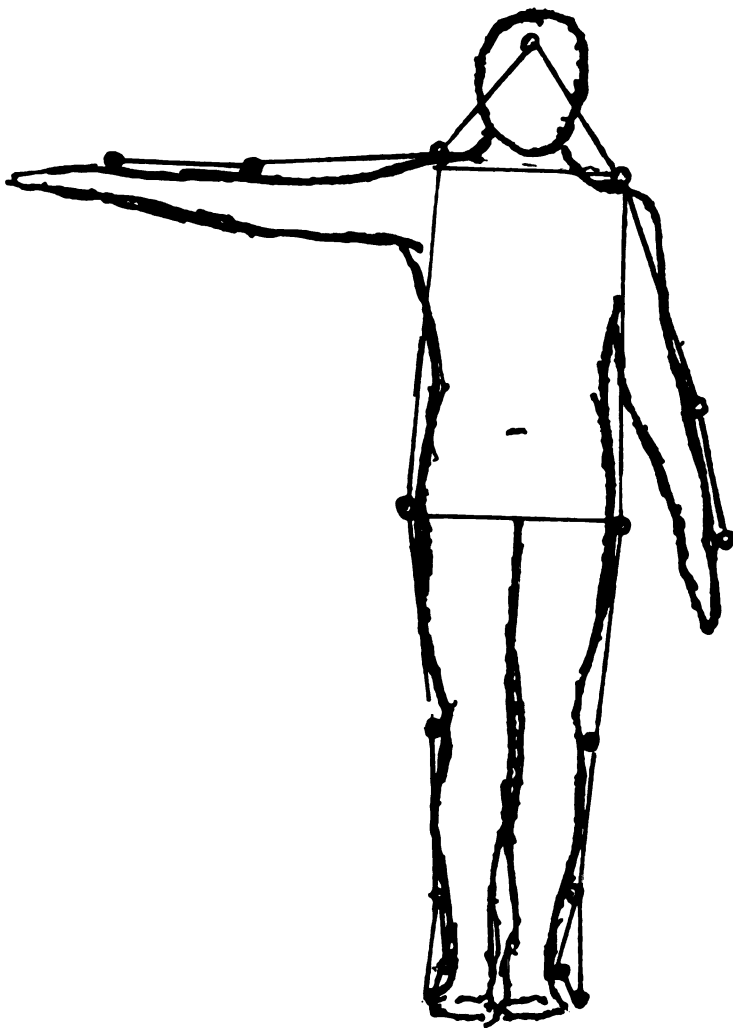


Figure 28: Nonpathological Gait, Neutral Standing

decrease that angle to values below 90 degrees. Therefore, if the angle were 85 degrees, the foot would be said to be 5 degrees dorsiflexed. If the angle between the shank and the plantar surface of the foot was 95 degrees, the foot would be in a 5 degree plantar flexed position.

The angular data for Subjects 1 and 2 will not be presented as relative to the subject's neutral standing position even though neutral standing data were collected. Figures 29 and 30 show the stick figures for neutral standing, imaged every frame for Subjects 1 and 2. In order to maintain balance, both subjects assumed a stance that deviated considerably from what would be considered anatomically neutral standing position.

In normal gait at heel contact, the foot is in a neutral position. This is followed by a plantar flexion, then the foot dorsiflexes as the shank passes over the foot. This is followed by plantar flexion of the foot during propulsion stage to toe off. During swing phase, the foot again dorsiflexes to about half of the maximum dorsiflexion during stance phase in order to permit the foot to swing through. This is then followed by plantar flexion back to a neutral position at heel contact [15]. See Figure 31 for normal ankle dorsi/plantar flexion patterns.

Subject 1 exhibited a similar pattern left to right. However when dorsiflexing during major dorsi/plantar flexion of stance phase, the motion was characterized by an almost saw-tooth appearance rather than sinusoidal as with norms

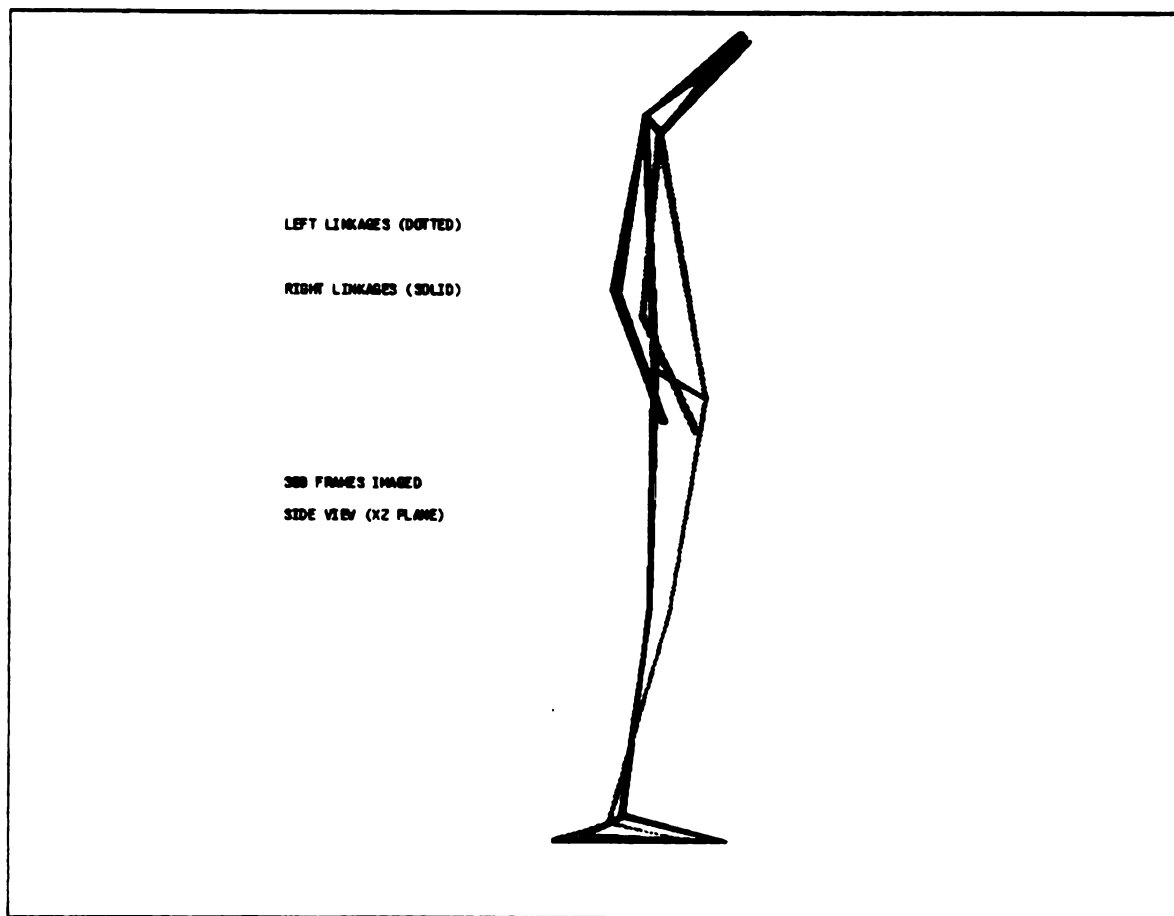


Figure 29: Subject 1, Neutral Standing

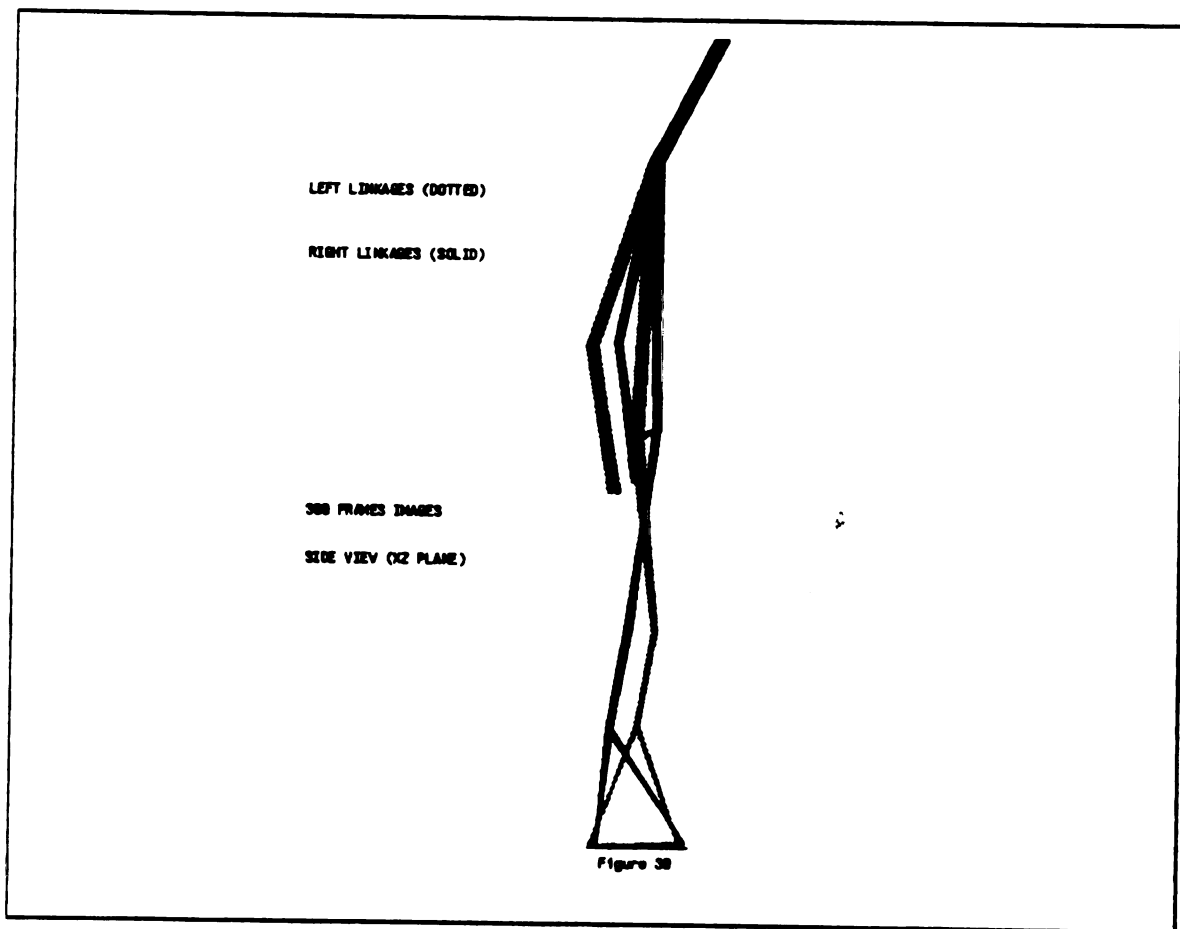


Figure 30: Subject 2, Neutral Standing

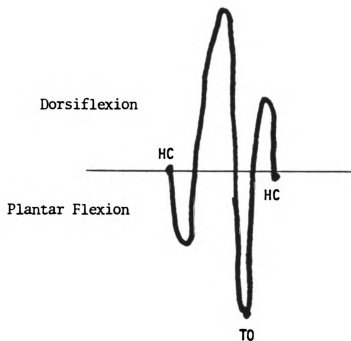


Figure 31: Normal Pattern of Ankle Dorsi/Plantar Flexion

(Figure 32). Also, the right side showed a dorsi/plantar flexion change just prior to actual heel contact, the explanation of which is unknown. This may be evidence of the problem of instability exhibited during transfer discussed earlier in this chapter and would provide some explanation of the roll-back seen in the unique line of intercepts on the force data.

Dorsi/plantar flexion ankle data for Subject 2 followed normal patterns more consistently but showed a greater degree of dorsiflexion during swing stage on her right limb compared to her left (Figure 33).

Based on personal communications from R. Soutas-Little¹⁸, a Fourier analysis was done on the motion data at each joint. There is no base normal data with which to compare this analysis but comparisons could be made left side to right side and between the two subjects.

A frequency spectrum of ankle motion for Subject 2 is shown in Figure 34. There were spikes, with the largest at 0.85 Hz (cycles per second) on the right limb. The corresponding period at this frequency equals the time for one complete gait cycle. Thus frequency concentrations represent movements reoccurring during gait cycle to gait cycle. Additional frequency spikes were seen at 1.75, 2.65 and 3.35 Hz. Examination of periods of ankle motion within stance and swing phases gave an indication that these frequencies corresponded to dorsiflexion during stance,

¹⁸Personal communication, Fourier Analysis of force and kinematic data, R. Wm Soutas-Little, Ph.D., 2/3/90.



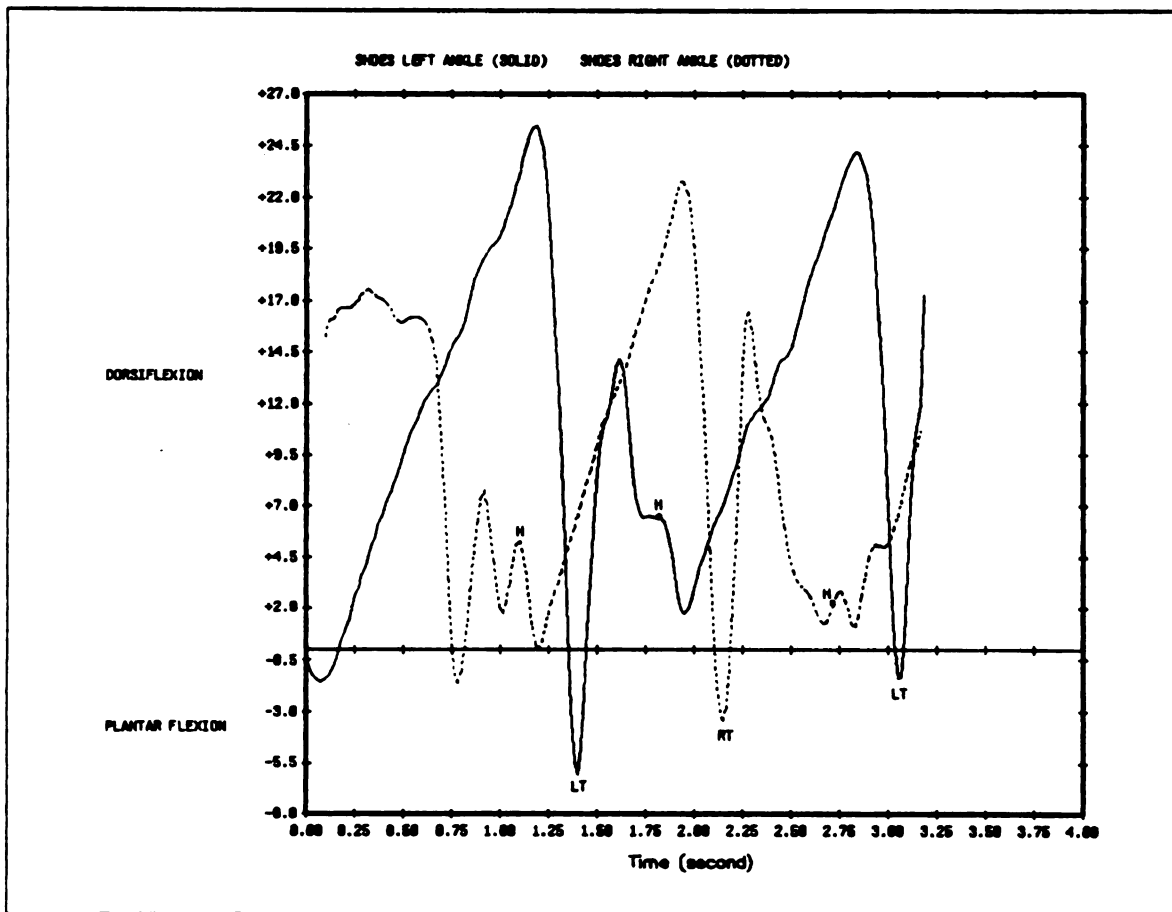


Figure 32: Subject 1, Left and Right Ankle Dorsi/Plantar Flexion with Heel Contact and Toe Off Indicated

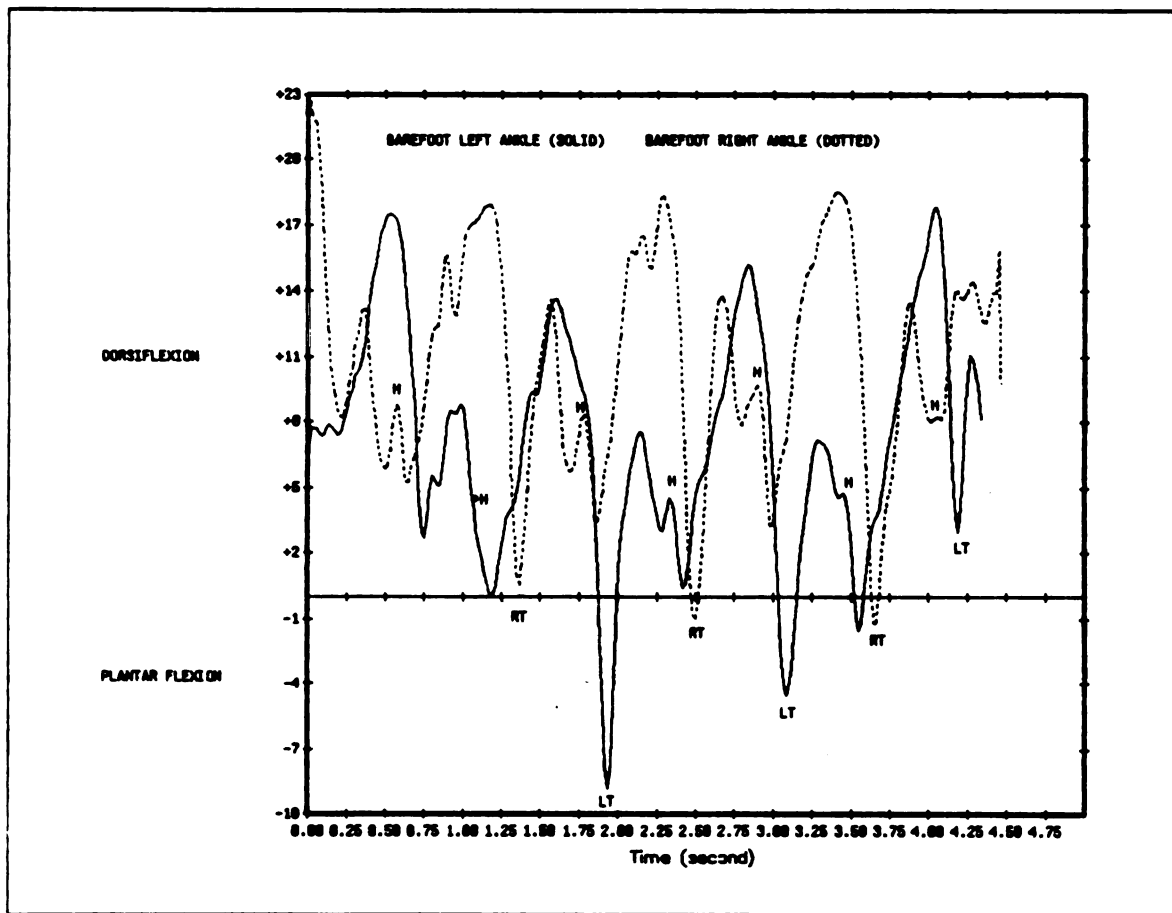


Figure 33: Subject 2, Left and Right Ankle Dorsi/Plantar Flexion with Heel Contact and Toe Off Indicated

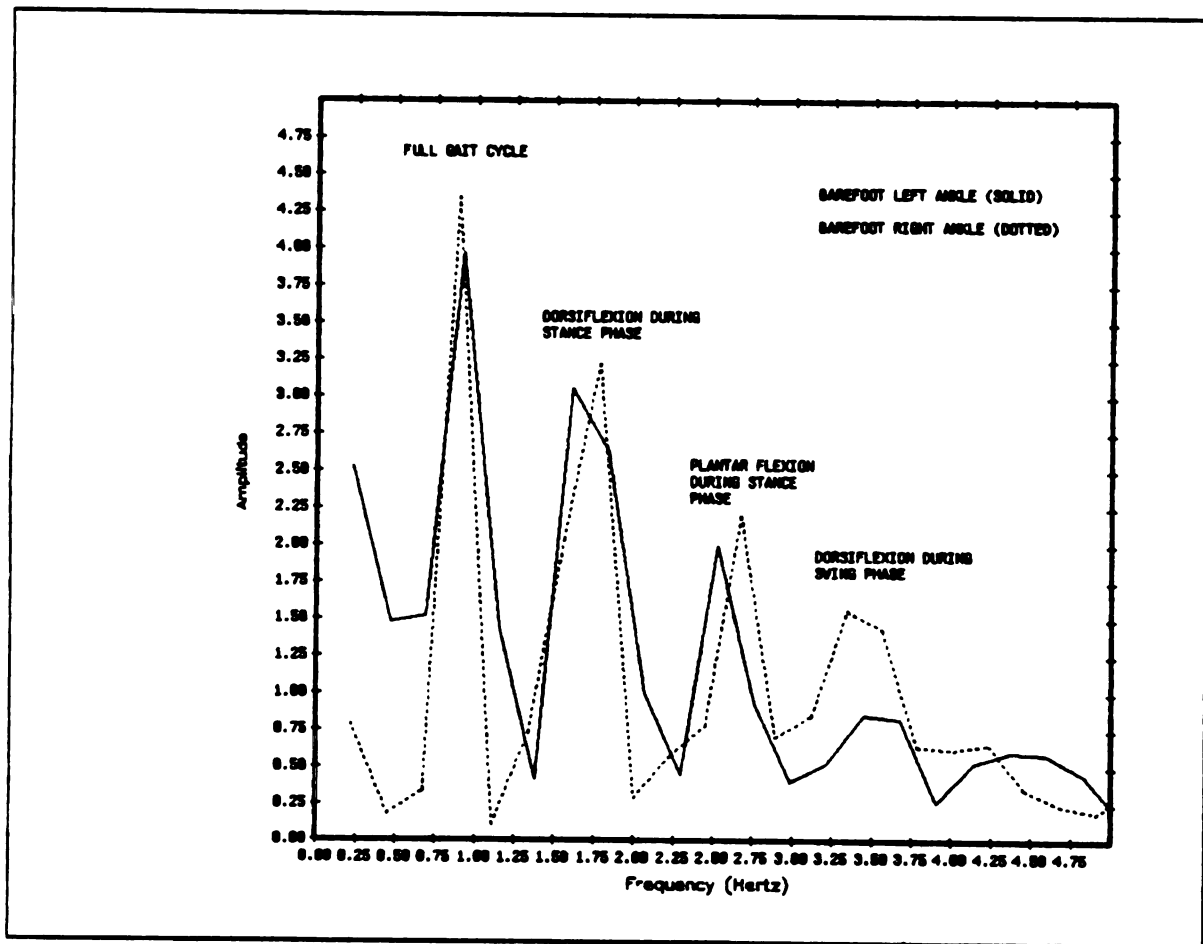


Figure 34: Subject 2, Frequency Spectrum of Left and Right Ankle Dorsi/Plantar Flexion

plantar flexion during stance and dorsiflexion during swing, respectively.

A frequency spectrum for subject one's ankle motion, displayed a dominate frequency of 0.6 Hz representing her full gait cycle movement which was slower than that of Subject 2 (Figure 35). Her frequency data did not show other high amplitude frequency spikes. However, there were a number of low amplitude spikes at higher frequencies, 1.30, 2.25, 2.90, 3.55, and 4.20 Hz. No correlation between these frequencies and ankle movement was found.

KNEE

Normal knee flexion and extension during walking gait showed the knee fully extended at heel contact, followed by approximately 10 degrees of flexion during the first third of stance phase. The knee then extends, reaching full extension at about two-thirds of stance phase and then flexes to toe off and continues flexing into swing phase, then extending to maximum extension to heel contact [15] (Figure 36).

The largest deviation from norm in knee flexion and extension data for both subjects occurred through the first two-thirds of stance phase where a smooth curve was evidenced for normal data and a very erratic pattern was exhibited by the Parkinson's subjects (Figures 37, 38 and 39). Also, they exhibited less flexion during this phase than normal. The reported norm for maximum knee flexion

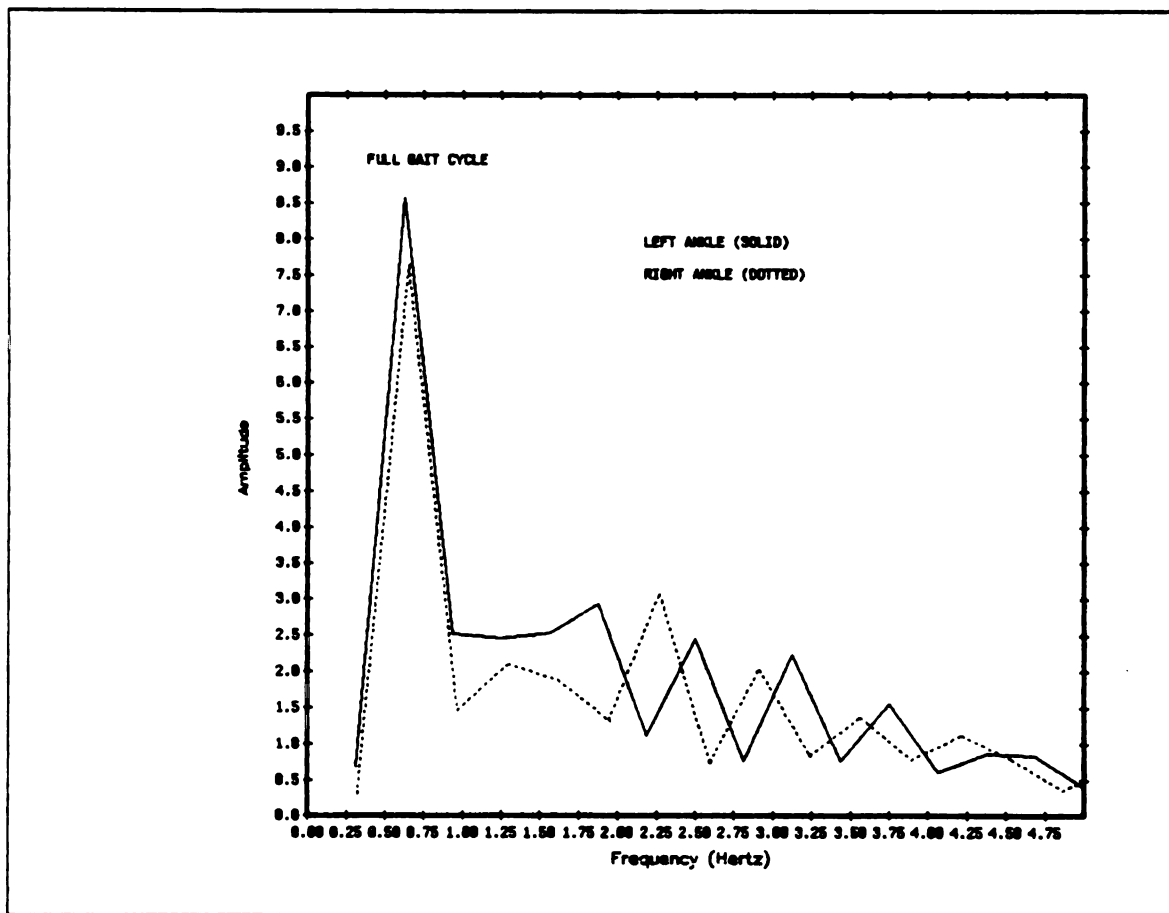


Figure 35: Subject 1, Frequency Spectrum for Left and Right Ankle Dorsi/Plantar Flexion

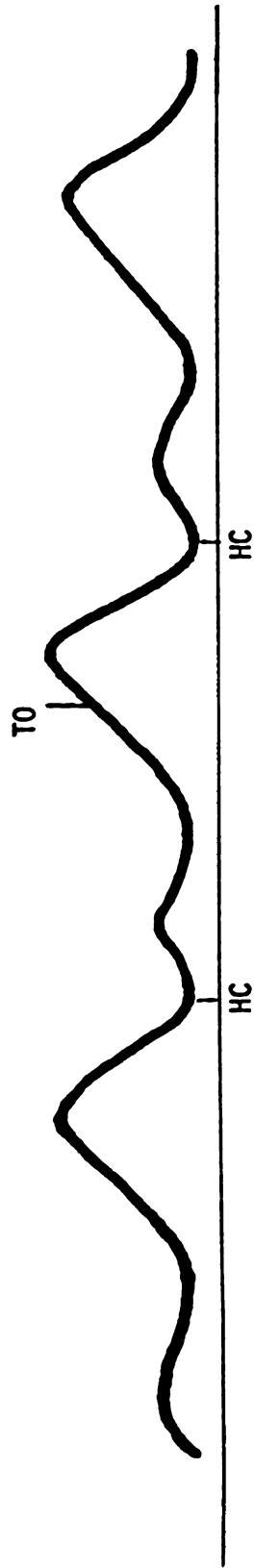


Figure 36: Normal Pattern of Knee Flexion and Extension

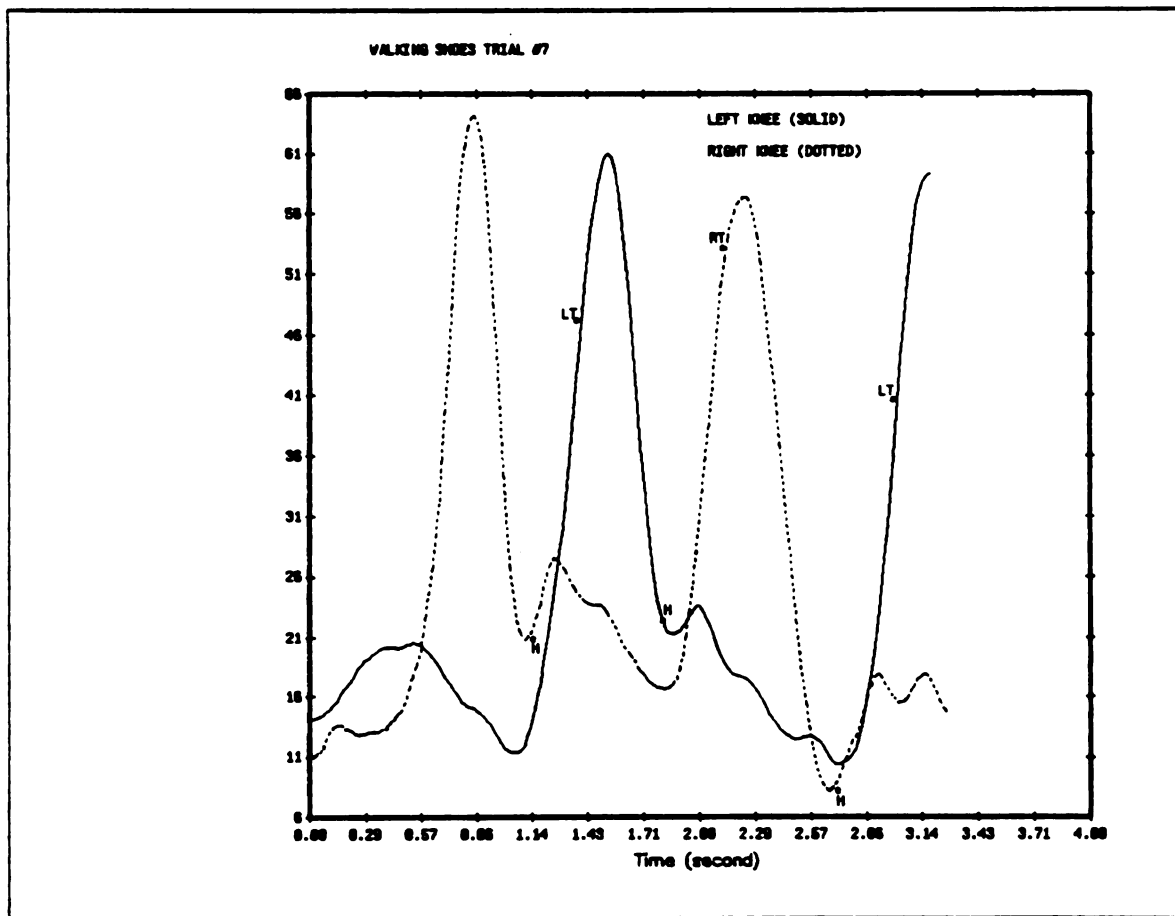


Figure 37: Subject 1, Left and Right Knee Flexion and Extension with Heel Contact and Toe Off Indicated

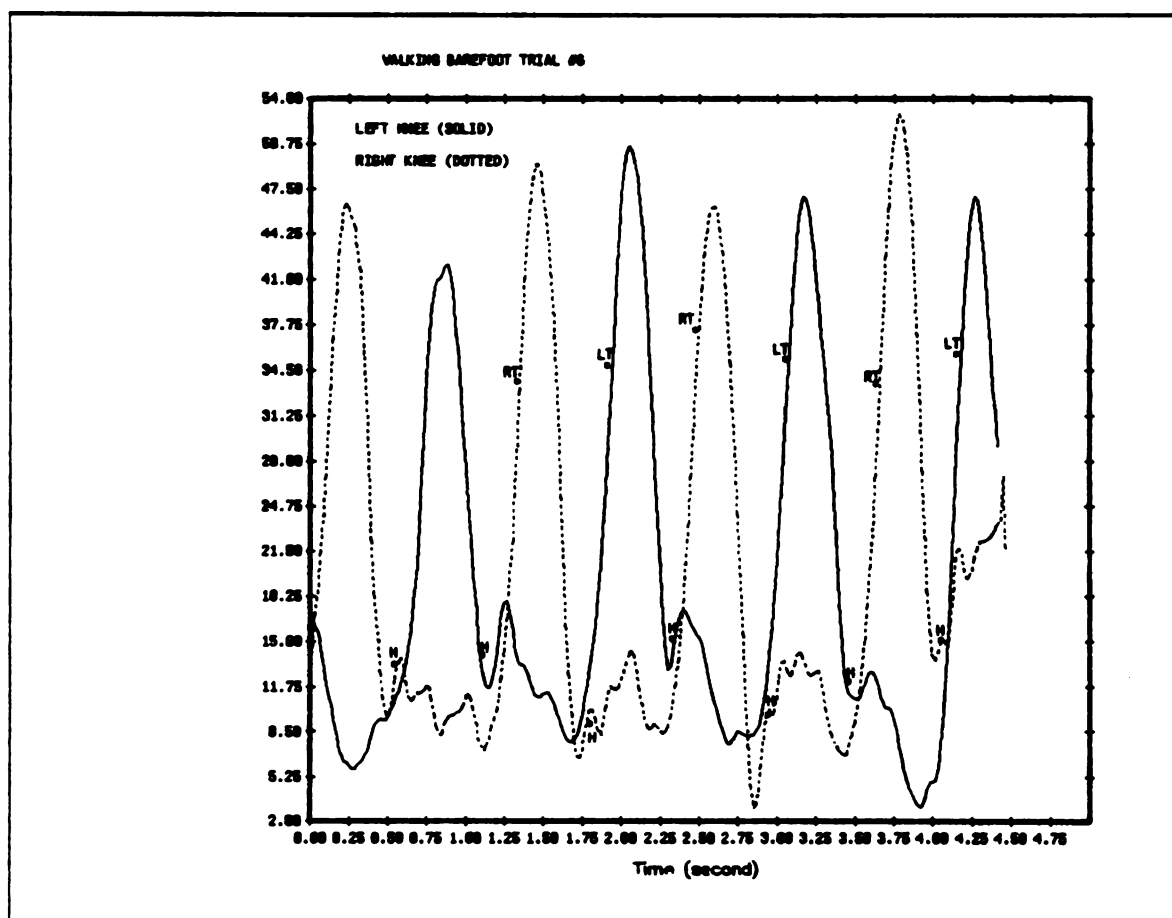


Figure 38: Subject 2, Left and Right Knee Flexion and Extension with Heel Contact and Toe Off Indicated

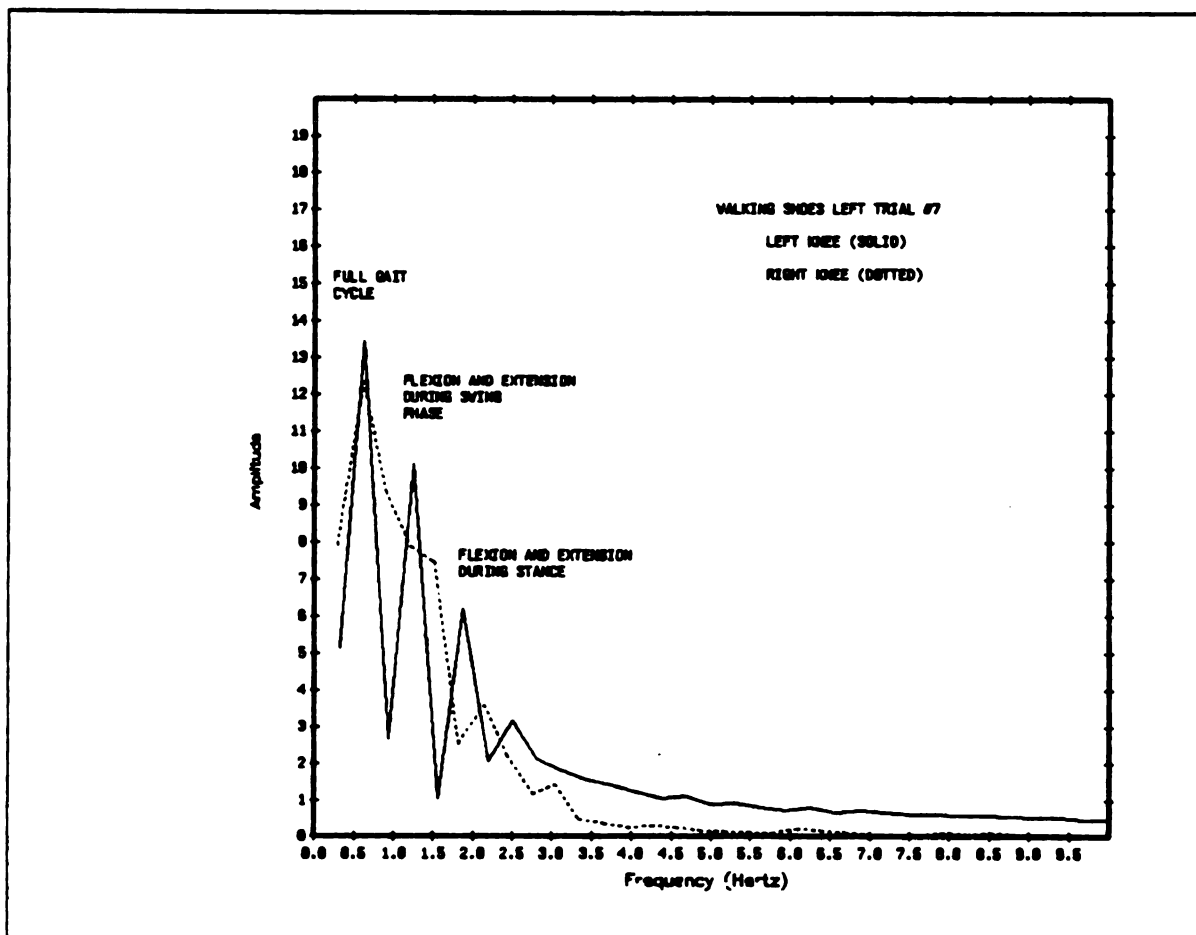


Figure 39: Subject 1, Frequency Spectrum for Left and Right Knee Flexion and Extension

during swing is 60 to 70 degrees. While Subject 1 is close to norm, Subject 2 has less, 50 to 55 degrees.

The Fourier analysis of knee flexion and extension again showed high amplitude at the full gait frequency on both subjects, and two higher frequency responses (Figures 39 and 40). The second higher frequency spike, which occurred at approximately twice the full gait frequency, was felt to correspond to flexion and extension during swing phase. The third appeared to correspond to flexion and extension during the initial part of stance phase. Additional low amplitude high frequency spikes were observed on both subjects, which may correspond to the erratic knee movement during stance phase. If indeed, the third spike corresponds to the knee flexion and extension during stance phase, then the lower amplitude on the right on Subject 1 and on the left with Subject 2 is in agreement with other functional observations.

HIP

Normal flexion and extension patterns at the hip indicate that the hip is in a flexed condition at heel contact and generally displays a slight increase in flexion in the first 10 percent of stance phase. This is followed by extension to full extension at about 85 percent of stance, which is mid point in the gait cycle. The hip then flexes to toe off, continues flexing to maximum flexion during swing phase and then begins extending to heel contact [15] (See Figure 41). With the exception of the absence of

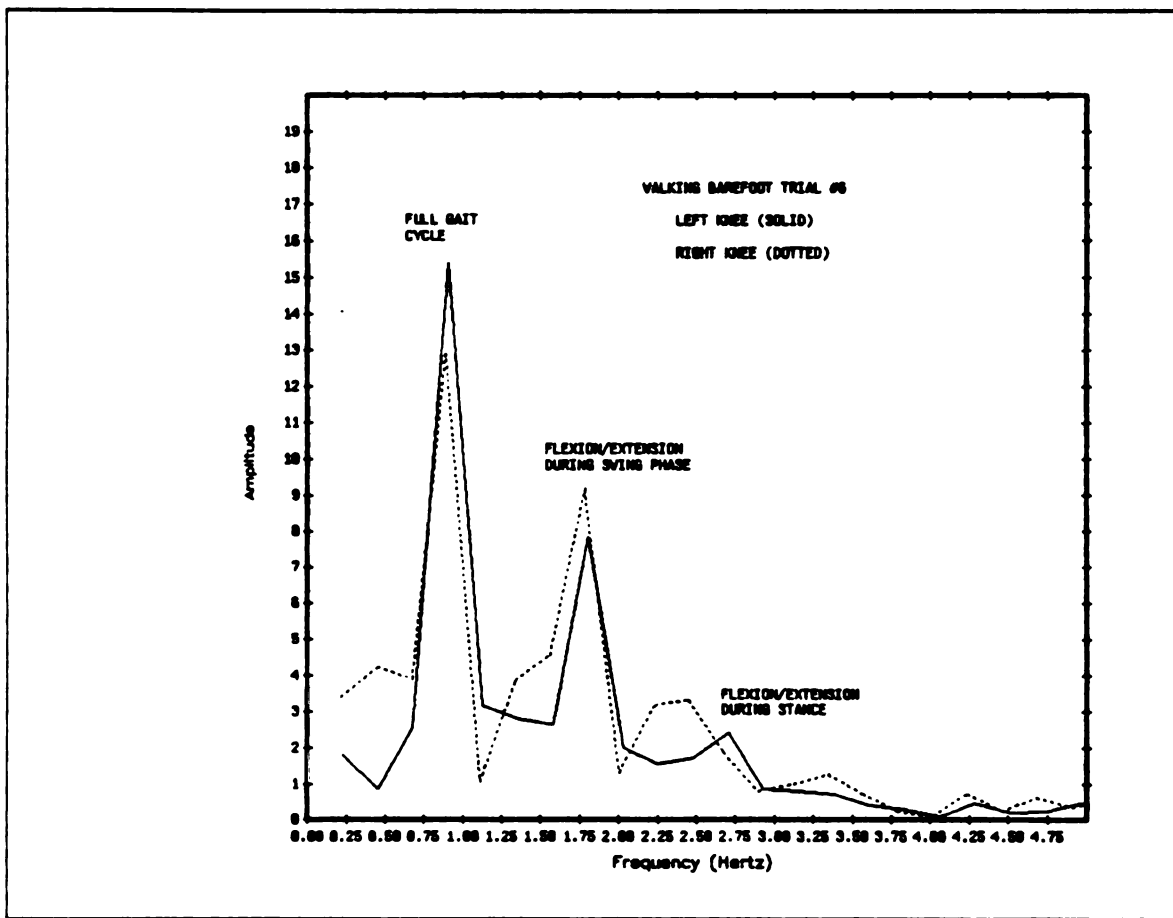


Figure 40: Subject 2, Frequency Spectrum for Left and Right Knee Flexion and Extension

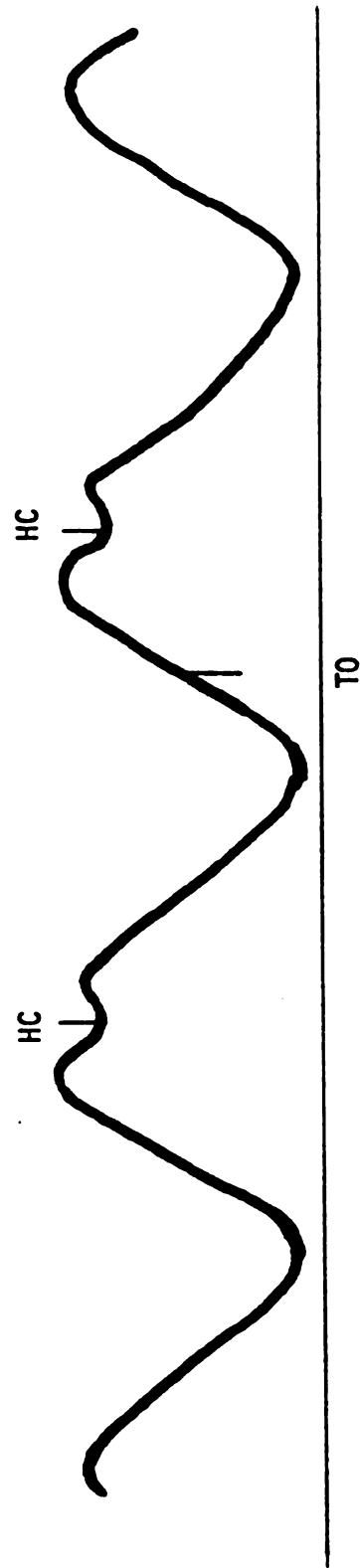


Figure 41: Normal Pattern of Hip Flexion and Extension

slight increased flexion after heel contact, both subjects exhibited relatively normal hip function (Figures 42 and 43). In examining total functional range of motion, the hip action on the right side of Subject 2 showed a range of about 35 degrees, while normal ranges are 40 to 50 degrees.

The frequency spectrum again showed the dominant frequency to be consistent with the full gait cycle. The absence of high amplitude spikes at higher frequencies indicated that the gross human movement at the hip is at the basic gait frequency (Figures 44 and 45).

SHOULDER AND ELBOW

Examination of both flexion and extension data at the shoulder showed the dominant frequency to be that of the full gait cycle, indicating that gross upper arm movement, as with hip movement, occurred at that frequency (Figures 46, 47, 48 and 49). On Subject 2 there was a greater upper arm movement on the left compared to the right side. On Subject 1, the reverse was true and, although not as pronounced, there was greater movement on the left than on the right. Since arm swing has been suggested as a parameter for the diagnosis of Parkinson's disease, this difference, left to right, must be considered to be important.

Subject 2 exhibited no change in elbow angle during the entire test. Subject 1 showed elbow movement on both the left and right side (Figure 50). The frequency spectrum for this subject showed that the movement on the left was greater and at the same frequency as the gait cycle, while

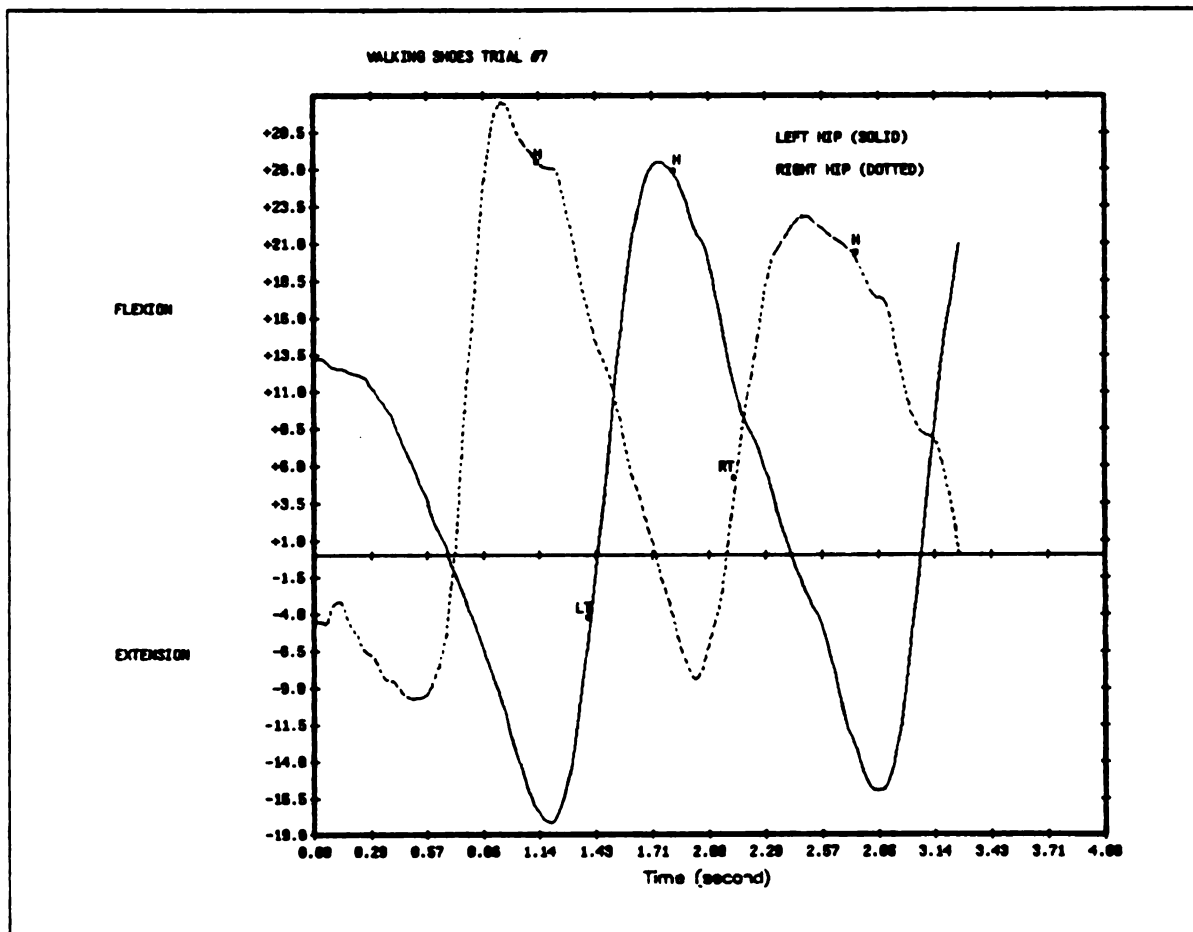


Figure 42: Subject 1, Left and Right Hip Flexion and Extension with Heel Contact and Toe Off Indicated

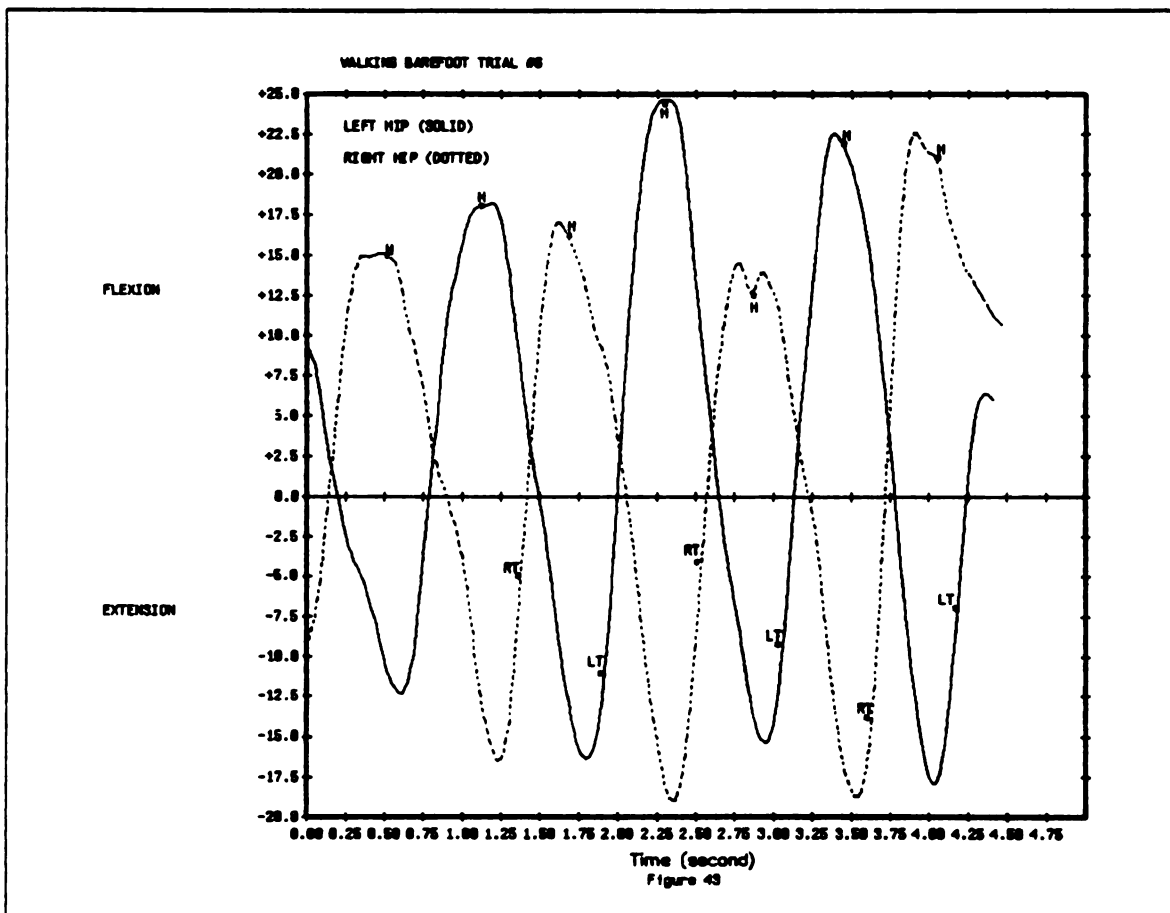


Figure 43: Subject 2, Left and Right Hip Flexion and Extension with Heel Contact and Toe Off Indicated

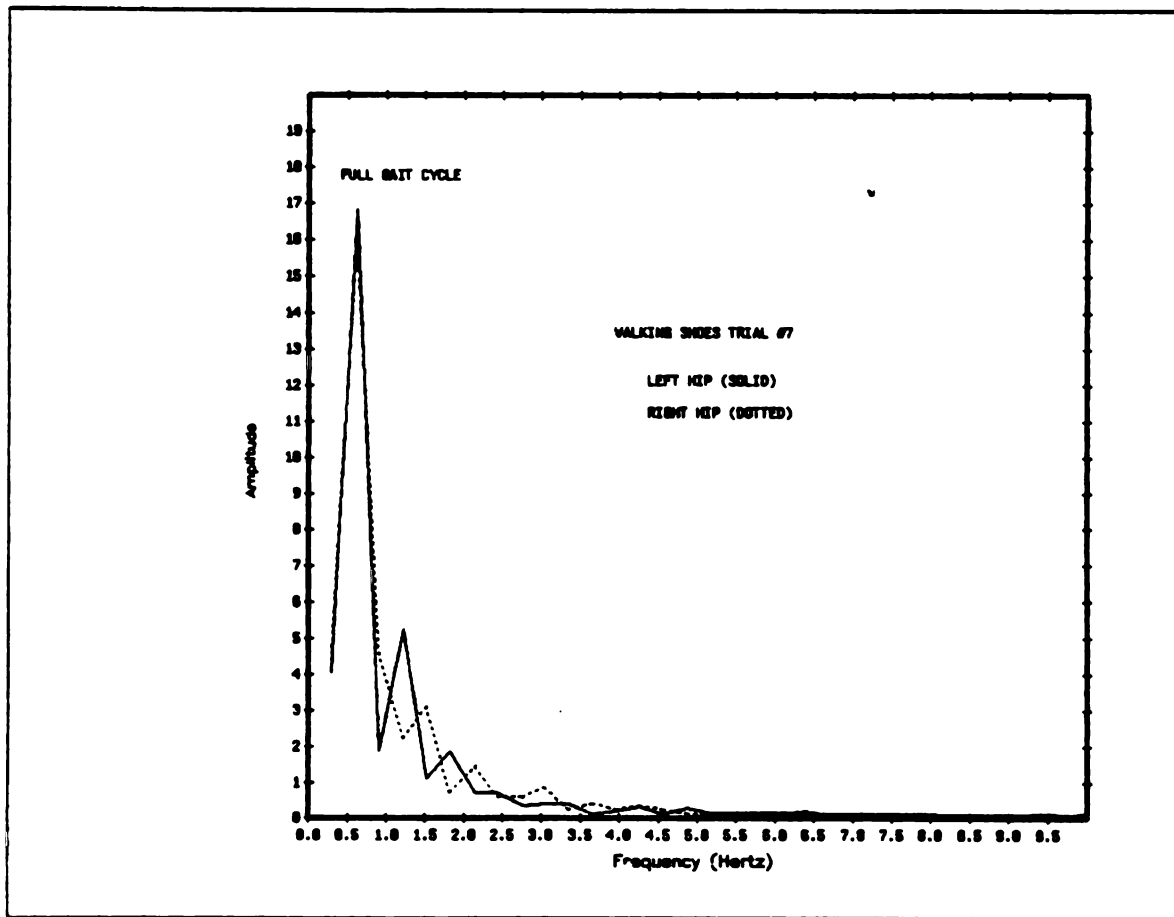


Figure 44: Subject 1, Frequency Spectrum of Left and Right Hip Flexion and Extension

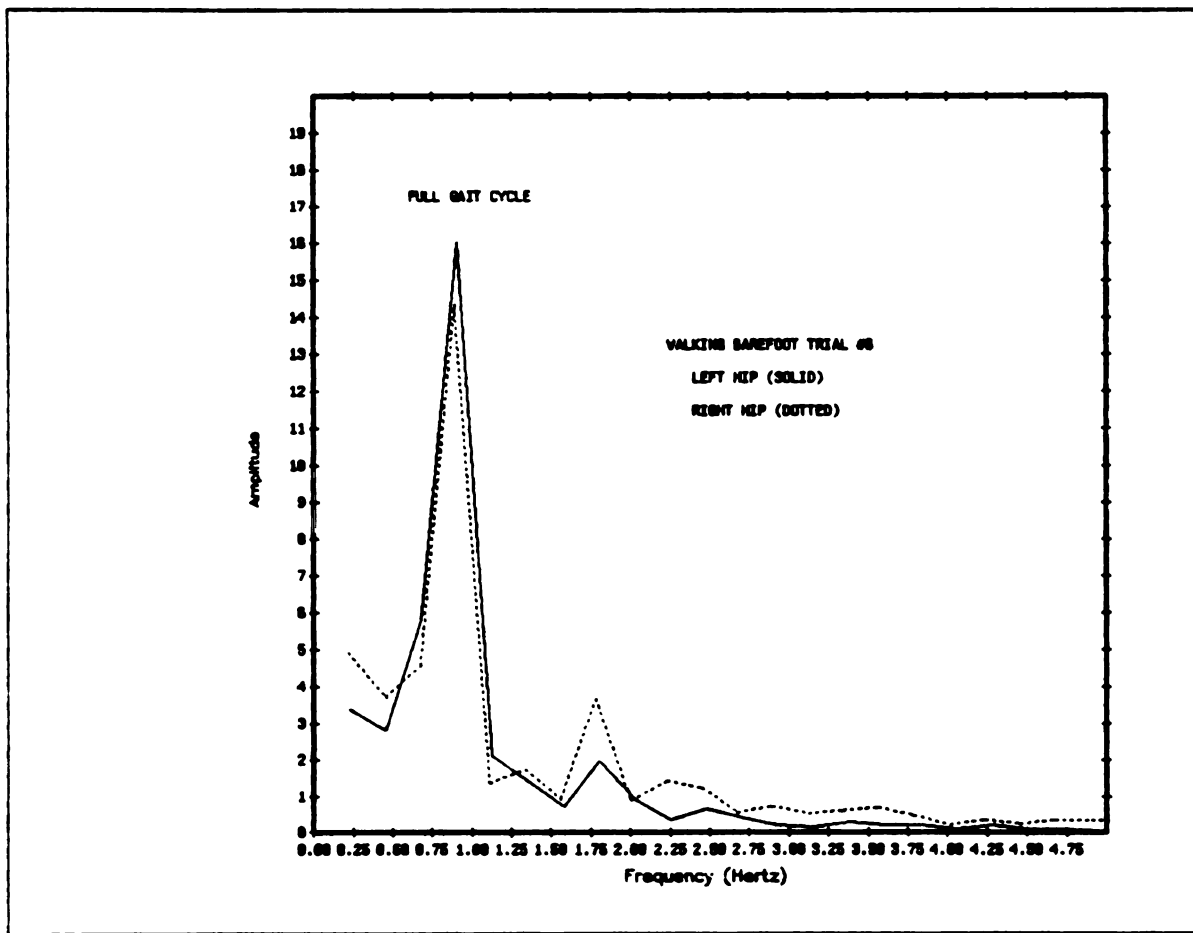


Figure 45: Subject 2, Frequency Spectrum of Left and Right Hip Flexion and Extension

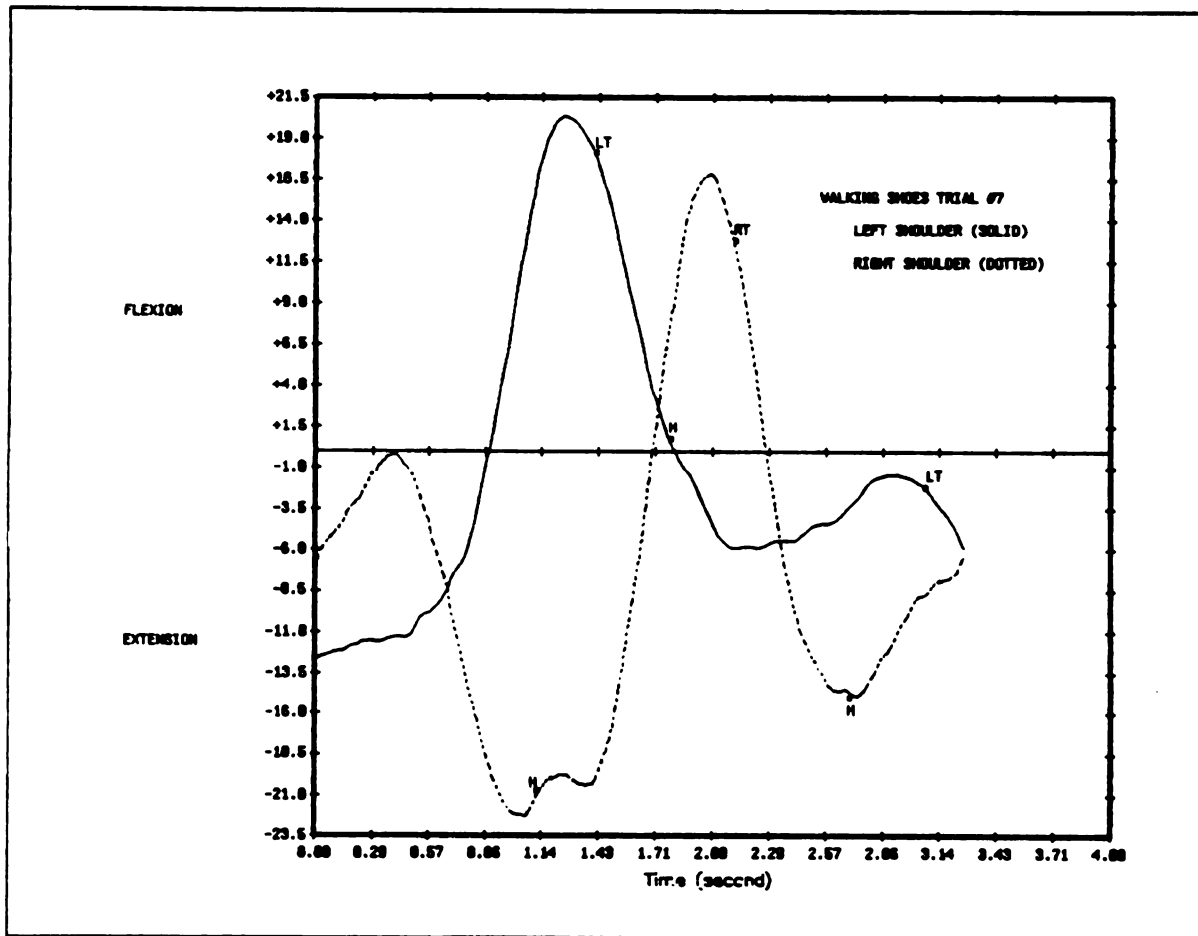


Figure 46: Subject 1, Left and Right Shoulder Flexion and Extension with Heel Contact and Toe Off Indicated

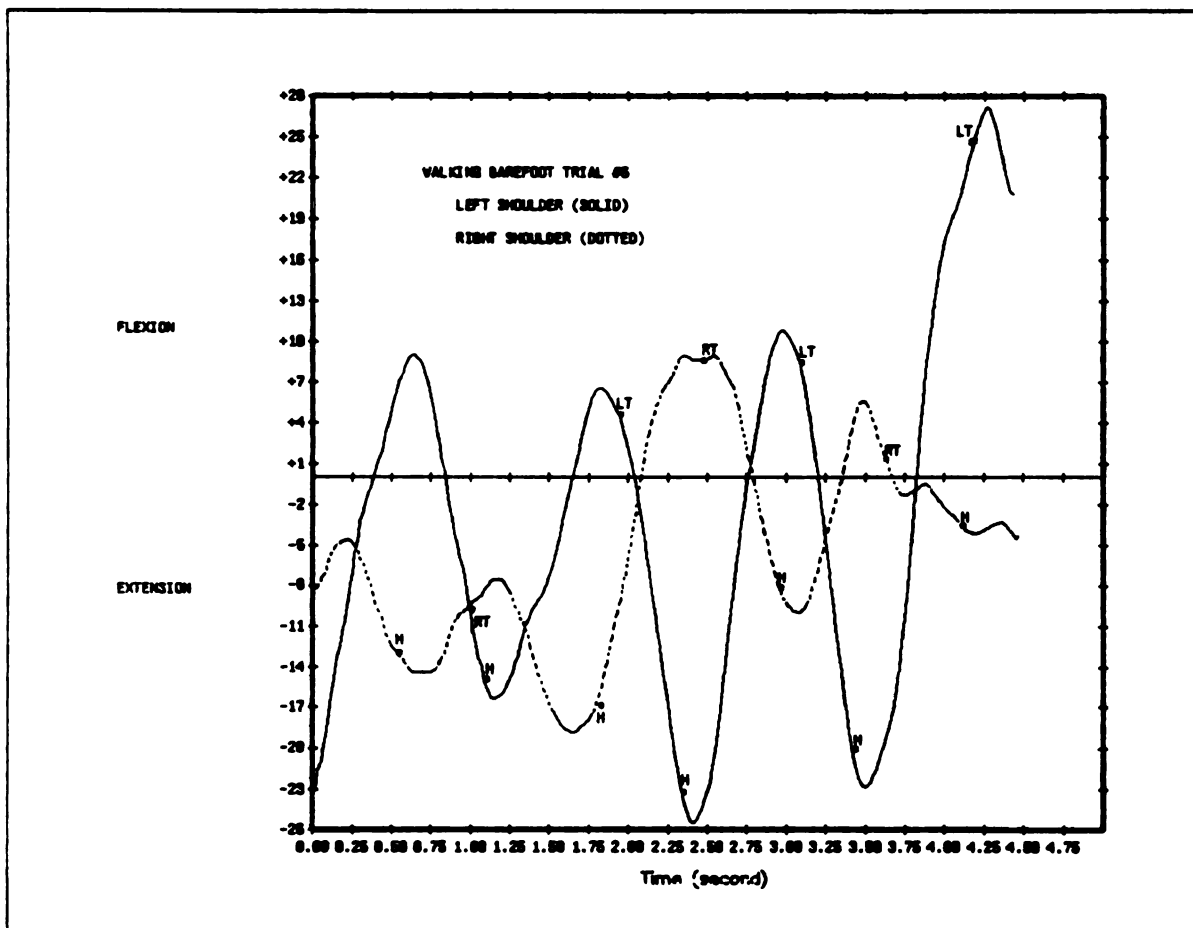


Figure 47: Subject 2, Left and Right Shoulder Flexion and Extension with Heel Contact and Toe Off Indicated

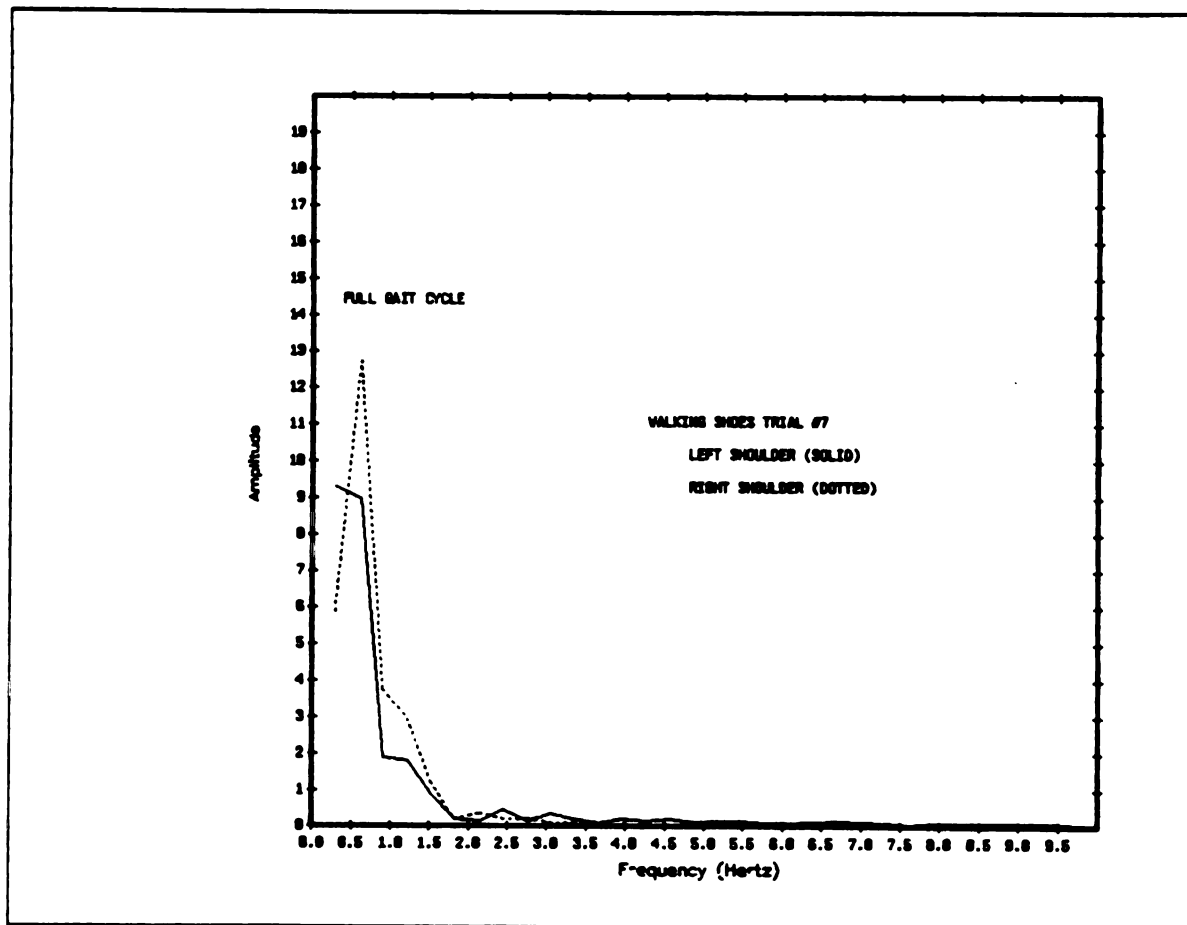


Figure 48: Subject 1, Frequency Spectrum of Left and Right Shoulder Flexion and Extension

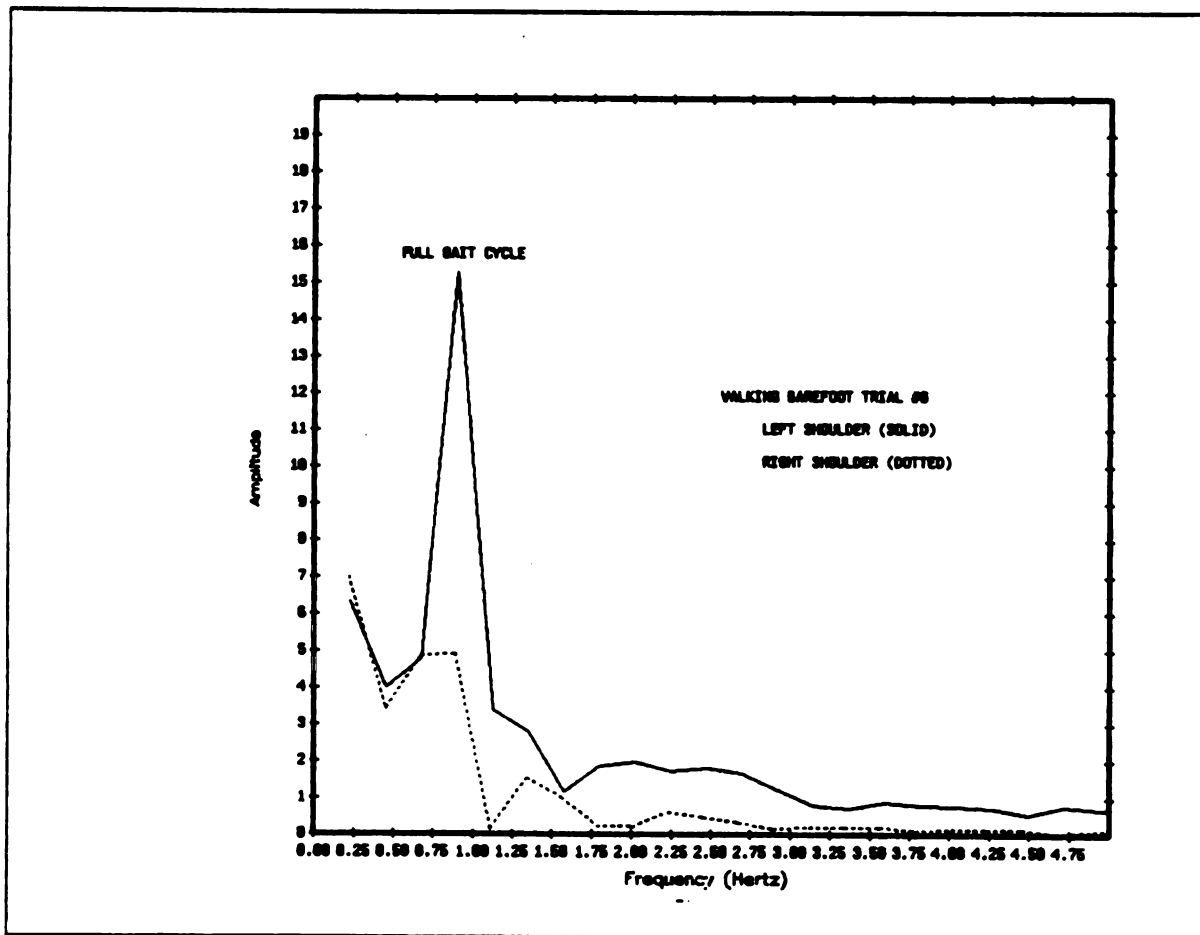


Figure 49: Subject 2, Frequency Spectrum of Left and Right Shoulder Flexion and Extension

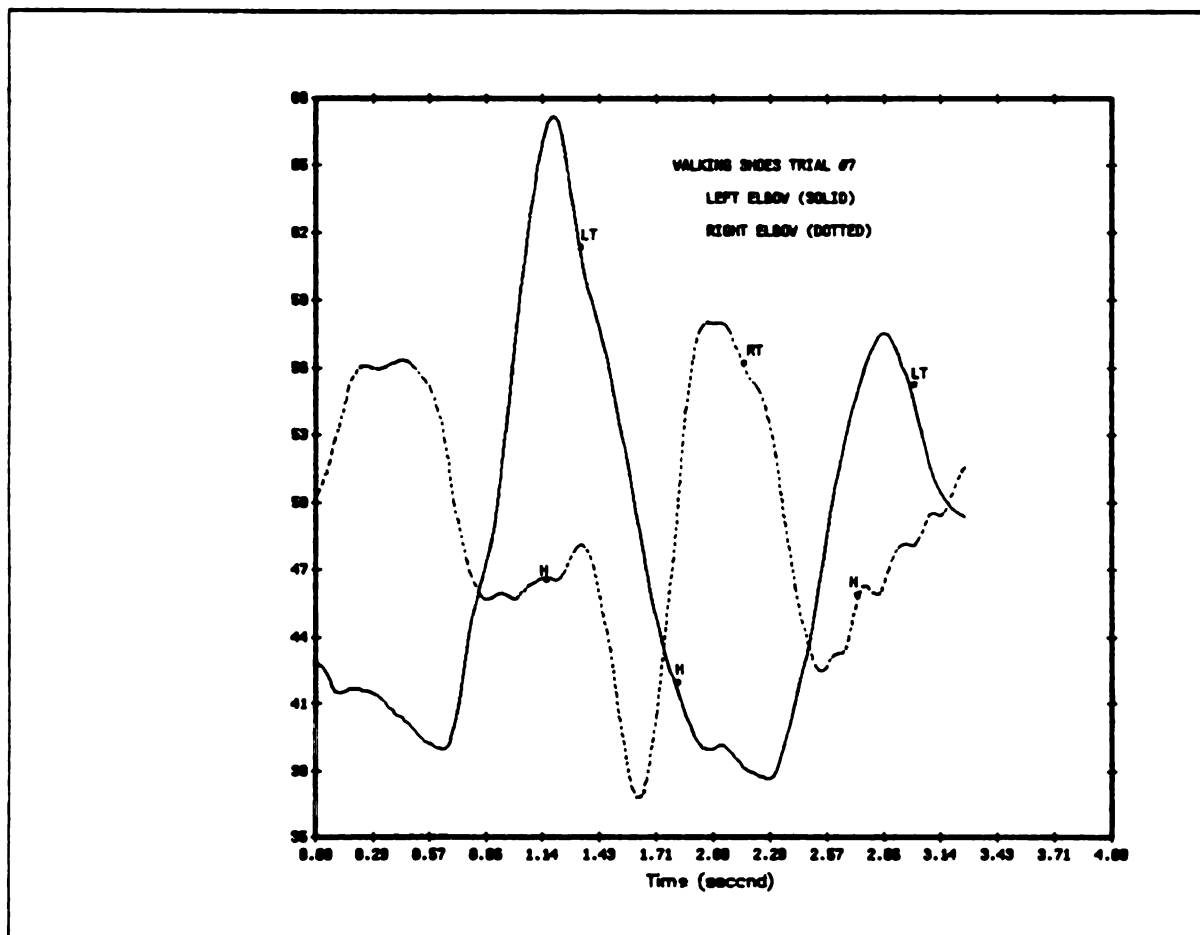


Figure 50: Subject 1, Left and Right Elbow Flexion and Extension with Heel Contact and Toe Off Indicated

movement on the right had a lower amplitude response at gait cycle frequency and a second response at a frequency of two times gait frequency, which might suggest tremor (Figure 51).

Of the large number of parameters which were examined in this study, the following have the greatest promise for further examination. The vertical force temporal distributions and the resolved ground reaction forces and moments (RGRFM) plots provide both bilateral comparison as well as the possibility of comparison at different times during the disease progress or during different points of therapy. Also the RGRFM torques may prove to be an important parameter.

Since Parkinson's disease is characterized as a movement disorder, there are more movement parameters that should be further investigated. These movements at joints, both of upper and lower extremities, should be reviewed in pattern and magnitude as well as frequency.

Areas of future research should include development of a larger data base of geriatric norms, as well as longitudinal studies of parameter variations in a Parkinson's population in order to follow disease progression and to evaluate therapy.

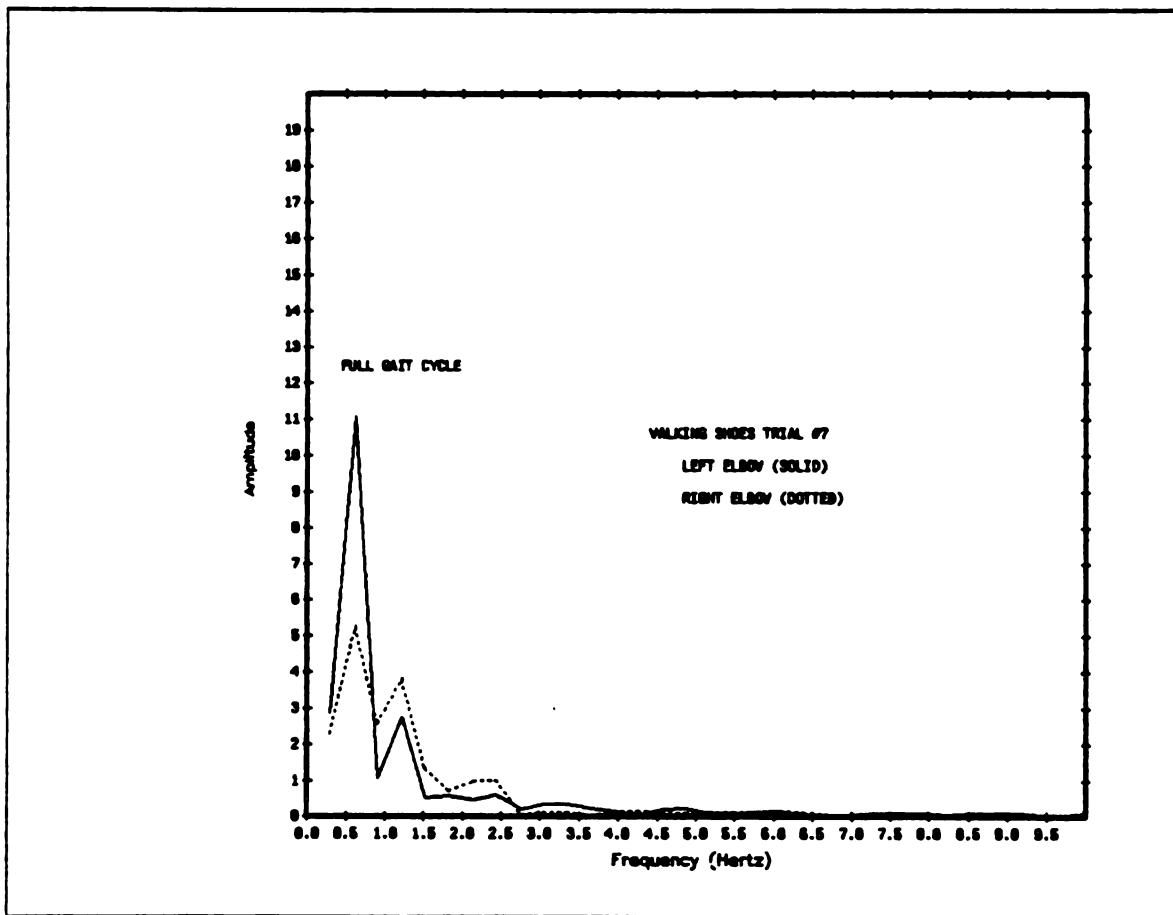


Figure 51: Subject 1, Frequency Spectrum of Left and Right Elbow Flexion and Extension

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BIBLIOGRAPHY

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