TRUNK CONTROL CORRELATES WITH GAIT AND BALANCE MEASURES
IN ELDERLY SUBJECTS INCLUDING HIGH FUNCTIONING INDIVIDUALS
WITH PARKINSON DISEASE

Thesis

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By

Santhosh Kachanathu Philip

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The Ohio State University

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Thesis Committee:

Dr. Deb Kegelmeyer, Advisor

Dr. Anne Kloos

Dr. Deborah Givens

Dr. Karen Thomas

Approved By

______________________________

Advisor

Allied Medicine Graduate Program
ABSTRACT

The study evaluated the correlation between trunk control and gait and balance measures in elderly subjects with and without PD. Trunk control was assessed utilizing the wobble chair. Gait characteristics were assessed utilizing GAITRite and Tinetti Mobility Test (TMT) gait subscale. Balance was measured utilizing TMT balance subscale, Single Limb Stance time and Sit to Stand time. The groups showed differences in TMT total score, TMT gait subscale and step length. In elderly subjects with and without PD trunk control showed significant correlation with age, best single limb stance time, sit to stand time, TMT total score, TMT gait subscale, step length, mean velocity and cadence. The findings of the study indicate that there is a significant relation between trunk control and functional mobility. This study supports further investigation into trunk control and its relationship to gait and mobility in individuals with PD and the aged.
Dedicated to my father
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VITA

April 27, 1983……………….. Born- Kerala, India

2000- 2004…………………….BS in physiotherapy, Christian Medical College, India

2005-2007……………………. Physiotherapist, Fellowship Mission Hospital, India

FIELDS OF STUDY

Major Field: Allied Medicine.

  Physical Therapy.
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CHAPTER 1

INTRODUCTION

Parkinson’s disease (PD) is a chronic progressive disease of the central nervous system, commonly observed in older populations across the world. It occurs in about 1 percent of the population older than 55 years of age and becomes increasingly common with advancing age reaching proportions of 2.6% of the population by the age 85 years [1]. The mean age of onset is 58-62 years with the majority of the cases having their onset between 50 to 79 years of age [1]. Ten percent of individuals with PD show young onset of PD with symptoms appearing before age 40 [1]. In the USA 50,000 new cases are appearing annually and the rate is expected to rise with the aging of the population [1].

Studies show that up to 70% of patients with PD fall annually and 13% of them fall more than once weekly [1]. Alterations in postural control strategies are documented in standing and become obvious when responding to an unexpected destabilizing perturbation or performing voluntary tasks [2, 3]. Although studies have indicated that fear of falling is a contributing factor to the postural instability [4], the major problem lies in the impaired balance mechanism in the central nervous system, which eventually causes impaired postural reactions and altered gait patterns [1]. Postural reactions to perturbations in standing normally involve a coordinated sequence of muscle activations
occurring at the ankle, knee, hip, pelvis and spine [5]. In sitting the postural reactions mostly involve activation of muscles controlling the pelvis and spine, i.e. trunk [5]. Individuals with PD respond to altered balance demands with an abnormal pattern of muscle co-activation of the postural muscles. They demonstrate reduced muscle torque production, reduced rate of torque production and impaired trunk movements [1].

**Significance of the problem.**

Sufficient trunk stability and control of trunk movements is essential for postural stability and normal gait as the upper body constitutes two thirds of the total body weight. The majority of falls in individuals with PD and elderly occur due to an inability to control the body mass during activities such as turning around, standing up and bending forward. These are all activities where trunk postural control is necessary [1].

An in-depth study is needed to evaluate the relationship between trunk postural control to the balance and gait deficits observed in high functioning individuals with PD and elderly subjects as they have an increased risk of falling. Trunk control, used interchangeably with the words “trunk stability” in this thesis, is defined as the ability of the trunk to maintain upright posture in sitting during altered balance demands (e.g.: unstable sitting). In the present study trunk stability is evaluated in two ways using a device referred to as the ‘wobble chair”. First: stability will be measures as the number of times subjects are unable to maintain dynamic balance with the chair adjusted to 60 percent of their base of support (BOS). Second: stability will be measures as the minimum BOS needed for the subject to maintain balance on the wobble chair which is referred as threshold value.
A positive correlation between trunk control measures and clinical tests of balance and gait performance in individuals with PD and elderly subjects would indicate the need for further studies to examine more fully the degree that trunk postural control impairments contribute to impairments in balance and gait in these populations. This may yield insight into novel therapeutic interventions that promote trunk stability in the treatment of gait and balance impairments in those with PD and the elderly.

**Purpose of the study.**

The purpose of this pilot study is to evaluate the association of trunk stability with balance control and gait in high functioning individuals with PD and elderly subjects. This study is based on the theoretical evidence that the ability of a subject to maintain postural stability in unstable sitting with progressive reduction of the base of support is an indicator of trunk stability and control over trunk movements [5, 39, 41, 52]. A correlation between subjects’ ability to control the trunk in unstable sitting and their performance on tests of functional mobility and balance will suggest that trunk stability influences overall functional mobility and balance in high functioning individuals with PD and elderly subjects. Knowledge gained from this correlation study will help researchers to better understand the contribution of trunk stability to functional performance in high functioning individuals with PD and elderly subjects and may lead to the development of new treatment techniques aimed at improving trunk stability.

**Research approach and objectives**

This correlation study is designed to 1) investigate the relationship between trunk control (i.e. wobble chair parameters), functional measures of gait (i.e. spatial and
temporal parameters of gait obtained with GAITRite and gait subscale of Tinetti Mobility Test) and balance (balance subscale of the Tinetti Mobility Test, Single Limb Stance Test and Timed Sit to Stand Test scores) in high functioning individuals with PD and elderly subjects; and, 2) Compare trunk control, balance and gait measures obtained in high functioning individuals with PD to age matched normal subjects. We hypothesize that:

1. Age matched healthy controls will demonstrate significantly better (p<.10) trunk control, balance and gait measures than high functioning individuals with PD.

2. In high functioning individuals with PD and elderly subjects there will be correlations between trunk control measures and gait measures so that better performance on trunk stability measures correlate with better performance on gait measures.

3. In high functioning individuals with PD and elderly subjects there will be a correlation between trunk control and balance measures so that better performance on trunk stability measures correlate with better performance on balance measures.
CHAPTER 2

LITERATURE REVIEW

The pathology associated with PD is located in the sub-cortical structures collectively called the basal ganglia (BG) [1, 53]. The basal ganglia are a collection of interconnected gray matter masses deep within the brain. The structures that combine to form the BG are the striatum (caudate and putamen), globus pallidus [external (GPe) and internal (GPi) segments] and substantia nigra. The BG play a major role in the production of voluntary movements and motor control of postural adjustments associated with voluntary movements. Neural activity of the BG is initiated by input into the main input-nuclei, the caudate and putamen, from the cerebral cortex and thalamus. Widespread cortical areas are involved in sending signals to the BG including sensory, motor and association areas. The striatum also receives input from the substantia nigra and pedunculopontine tegmental nucleus of the midbrain. Output is channeled primarily through the globus pallidus and substantia nigra via thalamocortical projections to prefrontal and premotor cortex areas. Within the BG information is integrated and modulated through multiple parallel circuits [1]. These complex circuits are divided into direct and indirect pathways that have opposite actions. Activation of the direct pathway
leads to GPi inhibition and thus thalamocortical motor facilitation, whereas increased activity in the indirect pathway results in GPi excitation and resultant thalamocortical motor inhibition [53].

The motor symptoms of PD are primarily associated with degeneration of dopaminergic neurons that have their cell bodies in the substantia nigra and their axons in the striatum. The dopamine, produced by substantia nigra, is absorbed by dopamine receptors located in corticostriatal terminals. Dopamine has the function of regulating glutamate activity [53]. These structures have the function of controlling and coordinating the body movements. Collectively they play a major role in maintaining equilibrium in standing by regulating the postural reflexes. A degeneration of 80 percent is estimated to occur before the signs of the disease become clinically evident [1].

The major motor symptoms of PD are rigidity, tremor, bradykinesia, postural instability and impaired coordination, gait disturbance and increased falls, loss of automatic movements, dysphagia, hypographia, hypophonia, lack of facial expression and muscle pain/cramps. Patients also present with complaints of fatigue, cognitive and perceptual disturbances, autonomic dysfunction, visual and sensory motor impairments, cardiopulmonary dysfunction, depression, dementia, loss of smell, sexual dysfunction, bowel and bladder problems and sleep disturbances [1]. The postural instability and frequent falls in patients with PD has become a major concern for physical therapists as it limits the functional independence level of the patient leading to secondary complications. Medical interventions are found to be less effective in controlling motor symptoms [90]. Although deep brain stimulation procedures improve the motor function
for a short period, the symptoms especially postural instability continue to deteriorate over a long term course [89, 90].

There is a growing interest in the relationship between trunk stability and functional impairments in individuals with PD. Studies to date have examined gait and balance in individuals with PD as well as trunk stability in unimpaired adults. Very little literature exists that examines trunk stability of those with PD or its relationship to functional mobility.

2.1. Gait in individuals with PD

Human ambulation or gait is one of the basic components of independent functioning that is commonly affected by a disease process or injury. Gait is assessed by examining kinematic and kinetic parameters [45]. Kinematic gait analysis is utilized to describe movement patterns without regard for forces involved in producing the movement. A kinematic analysis consists of a description of movement of the body segments in relation to each other during gait. This usually includes both spatial and temporal parameters such as step length, step width, angular motion, angular velocity and gait velocity. Kinetic gait analysis is utilized to demonstrate the forces involved in gait [45]

Numerous studies have examined the gait characteristics of the elderly as compared to young and middle aged adults. Aged subjects have shorter stride length and slower walking speed. They also demonstrate altered kinematics such as reduced peak knee extension [11]. The stride length in older subjects has been found to be 1.35-1.53 m compared to 1.51-1.70 m in younger subjects [11]. Older individuals exhibited decreased
gait velocity ranging from 1.18-1.45 m/s compared with 1.43-1.60 m/s in the younger population [11].

The biomechanics and motor control of gait in individuals with PD is a topic of growing interest for researchers and clinicians. Although individuals with PD can perform straight line walking relatively easily, they experience considerable difficulty while walking and turning or walking in a more challenging environment [47]. Basal ganglia dysfunction leads to difficulty in performing sequential and complex motor tasks with movements becoming excessively slow and under scaled, which in turn alters the gait pattern [47, 72]. The following list illustrates common abnormalities observed in people with PD during straight line walking:

- Reduced arm swing and trunk rotations [27, 28, 46, 66, 67].
- Reduced stride and step length, reduced gait velocity and normal cadence [46, 27-32].
- Decreased ground reaction forces and sagittal plane kinematics in the knee [68].
- Increased step to step variability of all gait parameters [44, 49, 70, 86].
- Marked axial rigidity and lack of pelvic and thoracic movement coordination [7].
- Freezing of gait [86, 87].

Individuals with PD walk more slowly than usual, typically in the range of 0.6-1 m/s rather than the normal 1.25-1.5 m/s. Cadence values are more or less within the normal range of 100-110 steps/min. Stride length values vary from 1.2-1.5 m for healthy older people compared to only 0.4-0.9 m for individuals with PD [47].
Marked reduction in joint angular excursions can be observed with parkinsonian gait. Hip extension and ankle plantar flexion range is found to be reduced in subjects with PD. [45, 47]. Ankle joint moment at loading response is reduced in PD resulting in reduced ankle power generation in the pre-swing phase [45].

Studies demonstrate that during walking subjects with PD move the pelvis and thorax in a more “in-phase” manner in the transverse plane [7]. These “in-phase” movements indicate that the pelvis and thorax move together in the same direction and at the same time. On the contrary, age matched control subjects move the pelvis and thorax more “out-of-phase”, indicating that the movements are more in opposite directions in a counter rotation. In individuals with PD these in-phase movements are indicative of axial rigidity [7].

The gait pattern in PD is characterized by sub-maximal movements. Hip, knee and ankle movements are reduced with a generalized lack of extension in all joints [45]. Trunk and pelvis movements are also reduced resulting in reduced arm swing and decreased stride length [7]. There is a loss of normal heel-toe progression [45]. Stance phase and double support time are prolonged while single leg support time is reduced. Gait asymmetries are very common [69, 70]. Abnormal stooped posture can contribute to development of a festinating gait, characterized by a progressive increase in speed with a shortened stride [1]. Turning or changing directions is particularly difficult and typically accomplished by taking multiple small steps [50]. Difficulty in controlling posture and balance has a negative impact on gait and safety [50].
2.2. Balance and postural control in individuals with PD

Balance is maintained by the combined functioning of individual components of brain and spinal structures using peripheral feedback to maintain equilibrium. Effective integration of sensory inputs (visual, auditory and proprioceptive) is essential for postural control [64, 73, 74]. The basal ganglia have the following roles in postural control:

- Maintain the motor cortex in a readiness of action to enable the postural muscles to fire in a feedforward manner so that when movement occurs the person can maintain the center of gravity within the base of support. [21, 64, 72]
- Selection of automatic postural reactions generated in response to motor and sensory perturbations [75].
- Motor control flexibility and adaptability [75].
- Regulation of muscle tone [75].
- Modulation of the impact of cognitive factors on balance and gait, e.g. attention, dual task performance, and fear of falling [75].

Postural instability in upright stance is common in PD and compromises the ability to maintain balance during everyday tasks such as walking and standing up from sitting [3, 7, 21]. The disorders of balance and postural control observed in people with PD are mainly related to the disruption of the feed forward anticipatory adjustments and normal postural synergies because of basal ganglia dysfunction. [1, 72, 75]. Although the sequencing of activation in lower limb and trunk muscles in response to unexpected perturbations appears to remain intact, the timing of muscle activation is slower than usual and the size of movement responses is diminished [21].
Individuals with PD tend to respond to instability with an abnormal pattern of co-activation resulting in a rigid body and an inability to utilize normal postural synergies to recover balance. They also demonstrate difficulty in maintaining the feed forward postural adjustments of postural muscles during voluntary movements. The contributing factors include rigidity, decreased muscle torque production, increased latency and decreased range of motion [1]. Abnormal forward flexed posture results in a significant change in the center of alignment, positioning the individual at the forward limits of stability [1, 63].

Individuals with PD also demonstrate an inability to adapt movement strategies to changing sensory conditions, a problem in sensory-motor adaptation. Visuo-spatial impairment has been identified in patients with PD and correlated with lower scores in mobility [1]. Some patients are unable to accurately perceive the upright or vertical position in standing which may indicate an abnormality in processing vestibular, visual and proprioceptive information [81]. Mallikarjuna et al [81] utilized the sensory organization protocol to test the phenomenon on subjects with PD and showed that vestibular, visual and proprioceptive information processing was impaired in individuals with PD as compared to the control subjects. The individuals with PD who were classified as fallers performed even more poorly. They concluded that impairments in processing of sensory inputs most likely play a role in altered balance control in individuals with PD [81].

Compared to healthy aged subjects, individuals with PD also demonstrate poor performance in tandem stance, single limb stance and functional reach [3]. Performance
degrades even further in individuals with PD with a history of falls [3]. For example during the tests fallers required external support from the examiner to prevent falling whereas PD non-fallers displayed impaired responses yet were able to regain stability [3].

Normal trunk movements are essential for postural control especially during dynamic tasks. Individuals with PD exhibit impaired trunk movements [7]. Adkin and associates [2] quantified trunk movements in both “pitch” (anterior – posterior) and “roll” (medial – lateral) directions during clinical stance and gait tests. The quantitative measurement of trunk sway during stance tasks revealed significant differences between PD and non PD subjects. PD subjects displayed greater amplitudes of trunk angle and angular velocities in both roll and pitch directions [2]. The measurements were greatest during standing on foam with eyes closed. When Adkin and associates [2] examined the balance recovery strategies using a shoulder retropulsion test with and without prior warning the difference in trunk sway between PD and non PD were marginal when the test was performed without a prior warning. However, with prior warning the researchers noticed no improvement in the balance recovery strategies in the PD group whereas the control group had better balance recovery strategies. A possible explanation for these findings is that subjects with PD fail to habituate to the test or failed to benefit from the prior warning [2]. Evaluation of balance performance during standing and dual task showed that both control subjects and subjects with PD exhibited a decline in performance when asked to perform a dual task; however the subjects with PD tended to
cease the cognitive task [3]. Individuals with PD appear to sacrifice the cognitive task in order to focus on maintaining balance and preventing falls [3].

Research suggests that fear of falling (FOF) may also significantly contribute to the alterations in postural control strategies in PD [4, 86]. There is mounting evidence to suggest that psychological factors have observable effects on balance performance. Elderly individuals who reported FOF demonstrated larger postural sway when blindfolded and poorer scores on a single limb stance test [83]. A relationship between anxiety and postural control has been observed in an animal model with anxious strains of mice demonstrating poorer balance compared to non anxious strains [82]. In healthy young adults FOF induced by providing a significant threat to posture has been shown to have an influence on postural control when standing and when responding to an unexpected push applied to the upper back [4]. FOF is an important issue in PD. FOF is more evident in individuals with PD compared to normal subjects [4]. For example PD subjects reported less confidence in their ability to perform ADL without falling. Individuals with PD who displayed a greater degree of gait impairment reported lower confidence in their balance abilities [4].

The evidence to date demonstrates that subjects with PD have significant postural instability compared to normal subjects. The contributing factors are CNS dysfunction, visuo-spatial impairments, psychological factors and musculoskeletal factors including axial rigidity.
2.3 Trunk control in individuals with PD

Individuals with Parkinson disease demonstrate impaired trunk stability. They tend to respond to instability with an abnormal pattern of muscle co-activation resulting in a rigid body and an inability to utilize normal postural synergies [1, 6, 7]. As the disease advances, subjects show axial rigidity [1, 7, 60, 65], decreased muscle force production [1, 6, 60], loss of available ROM [1, 6, 60] and muscle weakness [1, 63]. Extensor muscles of the trunk demonstrate greater weakness than the flexor group contributing to the adaptation of a flexed, stooped posture [1]. Stooped posture is a destabilizing posture [63]. Subjects also demonstrate difficulty in maintaining feedforward anticipatory adjustments [1]. The impaired CNS function, along with abnormal muscle co-activation and reduced trunk ROM are believed to account for this phenomenon [55, 60, 61, 65, 72].

Voluntary torque production is reduced in individuals with PD compared to the control group [6]. Torque production in individuals with PD progressively reduces during repetitive movement tasks [6]. A repetitive isotonic motor test revealed that the torque production in upper limb muscles was reduced over second, third and fourth repetitions when the subjects were asked to move a set of weights through a given range [6]. Studies using a tri-axial dynamometer showed a reduction in maximal voluntary isometric contraction and resisted iso-inertial performance of the trunk [6]. The rate of muscle torque production is also impaired in individuals with PD [1, 6, 60]. CNS impairment in PD partially explains the mechanism behind the impaired muscle function. Motor unit discharge, influenced by supraspinal, spinal and peripheral inputs is deficient in subjects.
with PD [1]. The disease results in the initial delay of motor recruitment, reduction in the rate of motor unit recruitment and motor unit asynchronization [1, 72]. The BG function to ‘set’ the nervous system in readiness of action which in turn controls the skeletal muscle performance according to the balance demands [1, 72]. Set is the state of the nervous system that reflects the tendency to behave or respond in a particular way due to prior experience and/or task context [72]. The setting mechanism involves neural transmission pathways that are stimulated or suppressed depending on the context of the task. The ability to change set quickly is important for the flexible adaptation in response to change in condition/context. The BG dysfunction in PD disrupts the ability to quickly change set to match a change in task condition or context. This impairment mainly affects reciprocal movements as in walking [72].

In balance activities and gait, where more trunk control is required, less co-activation and a flexible spine is desirable for better performance [39]. Increased trunk stiffness seems to have a negative effect on normal trunk function. During unstable sitting, when trunk stiffness was induced in normal subjects by active muscle co-contraction or a belt (brace), Cholewicki and associates [39] observed impaired trunk control and poor performance. The researchers concluded that increased and abnormal trunk muscle activity and trunk stiffness degrade postural control in unstable sitting [39]. Increased trunk stiffness is a common feature in PD [7]. Studies have found that in individuals with PD there is a reduction in spinal flexion, extension, right rotation and left rotation ROM and a loss of normal reciprocal relationship between the trunk muscle
group activations [6, 7]. The impaired trunk function can presumably be related to these deficits.

Postural control in standing can be accomplished by a wide range of responses at the ankle, knee, hip and trunk joints independently or combined [85]. In sitting postural control is accomplished predominantly by postural reactions of the trunk without the influence of lower extremity responses. Studies to assess the postural control of the trunk during unstable sitting have found large difference in balance performance between individuals with PD and healthy controls [8, 9]. The performance of PD fallers was even poorer. The researchers used an unstable paradigm (39 cm diameter aluminum hemisphere, attached to the bottom of the seat) to alter the balance. Subjects were asked to maintain sitting balance on the paradigm for 15 seconds. Center of Pressure (CoP) excursion was measured using signals from the force plates and two dimensional trunk angular deviations using a goniometer and also counted the number of successful trials. The data analysis revealed that CoP excursion values consistently increased from controls to PD non-fallers to PD fallers. Trunk angular deviations were significantly smaller (P>0.001) in the individuals with PD compared to normal subjects. The percentage of successful trials was significantly less (p>0.027) in the individuals with PD compared to the healthy controls. The differences between the PD-fallers group and non-fallers group were not significant [9]. The base of support provided was fixed and the apparatus couldn’t be calibrated according to the subject’s anthropometric measurements.
2.4. Summary

Numerous studies have been done to examine trunk stability, balance and gait in subjects with PD and the elderly. These studies have established that there are impairments in each of these areas. A recent study has determined that trunk stability and postural control of subjects with PD during unstable sitting is poor compared to an age matched control group [9]. The performance of PD subjects with a history of falls was even worse. It is clear from the literature that trunk stability and postural control of the trunk is impaired in subjects with PD [9]. Another study correlated trunk control as measured as trunk reposition error [RPE] with functional balance measures and found significant correlations in elderly individuals [12]. But it is debatable whether RPE measures the construct of trunk control fully. It is unclear from the literature whether impaired trunk stability significantly contributes to the altered gait pattern and balance performance in individuals with PD and elderly subjects. The present study will evaluate all three domains of the two groups concurrently to determine whether or not these domains are correlated.
CHAPTER 3

METHODOLOGY

3.1. Subjects

A total of 20 subjects will be recruited; ten individuals with a diagnosis of Parkinson disease confirmed by a neurologist and ten age-matched healthy controls. Subjects will be recruited from the Parkinson exercise group run by the Movement Disorders Clinic. Healthy control subjects will be the spouses and friends of the individuals with Parkinson disease who agree to participate in the study. Inclusion criteria specific to individuals with Parkinson disease are: 1) diagnosis of PD with onset in adulthood; and, 2) a score of 3 or below in Hoehn&Yahr Parkinson disease progress rating scale. General inclusion criteria are: 1) at least 21 years old; 2) an ability to walk minimum of 10 meters without any assistive devices; 3) ability to maintain sitting balance on a firm surface without arm support for at least one minute; and, 4) no documented dementia. Exclusion criteria for all subjects are: 1) a diagnosis of other neurological disorders including vestibular disorders; 2) musculoskeletal injuries that impact gait and/or balance including acute lower back pain; 3) history of brain surgery or deep brain stimulation; and, 4) morbid obesity (Body Mass Index >40).
Instrumentation and Procedure

After being recruited into the study subjects will sign consent forms and then will be required to attend one testing session in 232 Atwell Hall, 10th Avenue, The Ohio State University. The testing session will take approximately 2 hours. Subjects will be permitted to rest whenever necessary. Testing will include measures of trunk control (wobble chair parameters), gait (GAITRite and gait portion of Tinetti Mobility Test) and balance (balance portion of Tinetti Mobility Test, Single Limb Stance Test and Timed Sit to Stand Test).

Unified Parkinson’s disease Rating Scale (motor section) (UPDRS)

The UPDRS is a standardized rating scale for assessing disease severity in Parkinson disease [13, 14]. It consists of six sections and a maximum score of 199 which denotes absolute worst. This test will be administered by one of the investigators to all individuals with a diagnosis of PD to determine severity of their disease. Subjects will be asked to complete motor tasks such as finger tapping and the rater rates these on a scale of 0 to 4 with 0 being no deficit and 4 being severely impaired. 108 is the maximum score for motor subscale (Appendix. C 2).

Hoehn&Yahr Parkinson disease progress rating scale.

Hoehn&Yahr Parkinson disease progress rating scale is a commonly used tool to assess disease progress in PD [15]. It divides the disease progress into five stages according to the level of disability with 0 being normal and 5 being maximum disability.
3.2. Wobble chair (Measurement of trunk control in unstable sitting).

The wobble chair was designed to evaluate the ability to balance the trunk using lumbar and pelvic motions (figure A.1). The device consists of a seat mounted on a plywood platform supported by a ball joint. This allows the seat to pivot freely in 2-dimensions about its geometric center. The seat can be adjusted forward and backward in order to place the subject’s center of mass directly over the pivot point of the ball joint. Four steel springs are located to the front, rear, left and right of the ball joint. The distance of the springs from the ball joint can be adjusted by sliding the springs inward and outward which changes the available base of support. The platform allows 10 degrees of tilt or inclination forwards and 10 degrees of inclination backwards. The base of the seat with springs is attached to a wooden base (30 inches tall). The platform rests on a force plate (Model 4060-10, Bertec, Worthington, OH). The force plate measures the 3-dimensional ground reaction forces. Infrared light emitting diodes (IREDs) from the Optotruk motion measurement system (model 3020, Northern digital, Waterloo, Ontario) are attached to the platform. Using this set–up allows recording of the 3-dimensional position of the subject’s trunk relative to the chair. The data from the IREDs will allow determination and recording of the angular movement of the subject in 3-dimensional plane. The wobble chair is calibrated relative to the subject’s height and weight using data from force plates and IREDs and procedures established by Granata et al [16]. Wobble chair measurements have been found to be reliable and valid in healthy young people [17].
After explaining the procedure, the subject is assisted into a seated position on the wobble chair and secured with a seat belt. The lower limbs will be placed on a foot rest so that the movements to control balance are limited primarily to the trunk. When the subject is not tested, the seat is stabilized by placing four wooden blocks between the seat and the platform. Safety is assured by a railing adjacent to the chair on all four sides and a physical therapist guarding the subject in case he/she experiences a loss of balance.

Data are collected to calibrate the spring distances to the subject’s anthropometrics by placing the chair in 10 degrees forward tilt and then 10 degrees backward tilt. Data are collected for five seconds from the force plates and IREDs. The data are transferred to the computer and processed using custom software (MATLAB Tool box, Mathworks Inc, Natick, MA). The software output provides settings for adjustment of the springs relative to the pivot point of the chair. The data from force plates and IREDs will be used only for the calibration of the wobble chair.

The output of the MatLab program will provide settings for adjustment of the springs relative to the pivot point of the chair. The distance of the springs from the ball joint (L) is solved utilizing the equation of equilibrium from basic Newtonian physics. When the subject is positioned in a forward or backward inclination angle of 10 degrees and stays still without moving, the force applied by the subject in the downward direction is equal and opposite to the ground reaction force in the upward direction. The force, \( F_1 \), created by the subject is proportional to the subject’s weight, height and the angle between the chair surface and the subject’s center of mass (CoM). The ground reaction force, \( F_2 \), is proportional to the spring constant, the distance of the spring from
the socket joint (L) and the angle of the platform. At equilibrium these two forces are equal and opposite ($F_1 = F_2$). Solving these equations will provide the distance ‘L’.

Placing the springs at a distance ‘L’ will provide a relative indicator of the base of support (BOS) as a percentage, which was calibrated to each subject. The wobble chair calibration procedure has been found to be reliable and valid in young, healthy subjects [17].

After calibration of the wobble chair, data will be collected to determine the ability of the subject to maintain sitting balance at 100% BOS. The subject will sit with arms across the chest and will be asked to balance on the wobble chair by maintaining the chair steady. Each trial last 30 seconds and was repeated three times. A 30 second break will be provided between trials in an effort to minimize the effects of fatigue. All subjects will be given a practice trial before data collection commenced. During each trial, the number of times the subject exhibited a failure to balance will be counted and recorded. A failure was operationally defined as: 1) if the seat platform tips so far that it touches the wooden base of the wobble chair; or, 2) if the subject’s hand comes in contact with the safety railing. The number of failures will be counted using a handheld counter by two observers closely watching the platform movement. The values obtained by the two observers will be compared. When there is a difference between the numbers of failures counted by the two observers the trial will be repeated.

After testing each subject at 100% BOS, the subject will be tested to determine the level of the BOS before balance could no longer be maintained. This is referred to as the least percent BOS before failure. For this test, a successful trial is one in which the
subject maintains balance throughout the 30 seconds without a single failure. Hence, if the subject is successful at 100%, the BOS will be reduced by 20% and the test will be repeated at the new level. If the subject is successful at 80%, the BOS will be reduced to 60%. Thereafter, if the subject is successful, the BOS will be reduced by 10% increments until the subject is unable to maintain balance. For subjects who are not successful at 100% BOS, the chair will be adjusted to provide more than 100% BOS.

Performance will be quantified using the following characteristics.

a. The lowest percentage of support achieved in which there is at least one successful trial in three trials. This is the major outcome measurement.

b. Mean number of failures in a trial with the 60% base of support.

3.3 GAITRite (measurement of spatio-temporal parameters of gait).

Spatiotemporal gait parameters of the subjects will be documented using a GAITRite system. The system automates measuring temporal and spatial gait parameters via an electronic walkway connected to a Windows XP computer. The standard GAITRite electronic walkway contains seven sensor pads encapsulated in a roll up carpet to produce an active area 24 inches wide and 168 inches long. In this arrangement the active area is a grid, 48 sensors by 336 sensors placed on 0.5 inch centers totaling 16,128 sensors. As the subject ambulates across the walkway, the system continuously scans the sensors to detect objects. The area of the object is determined by the number of sensors activated, the distance between these sensors and the time of activation/deactivation. The information is transferred to the computer and analyzed. The gait parameter
measurements obtained with GAITRite have been shown to be reliable and valid in individuals with PD [18].

The leg lengths as defined as the distance from the greater trochanter to the bottom of heel will be obtained using a tape measure. Subjects will be instructed to begin walking in their normal comfortable speed 2 meters before the edge of the walkway and stop 2 meters beyond the edge of the walkway in order to allow a sufficient for acceleration and deceleration phases. The subjects will perform three trials in which the initial one will be a practice trial. The results of the second and third trials will be averaged by the GAITRite software. The following gait parameters will be measured:

1. Step length: It is the distance between the point of heel strike of one extremity to the point of heel strike of the other extremity.
2. Stride length: It is the distance from the point of heel strike of one extremity to the point of next heel strike of the same extremity.
3. Mean velocity: It is the average walking speed expressed in meters/second.
4. Cadence: It refers to the number of steps in one minute.

3.4. Tinetti Mobility Test (TMT)

The Tinetti Mobility Test (TMT) has been shown to be a valid and reliable measure of functional mobility and balance in the elderly subjects and those with Parkinson disease [19, 20]. It is a 28 point rating scale in which the individual walks and perform mobility maneuvers while being observed by the rater. Each item is rated on a scale from 0 to 1 or 0 or 2 with 0 being poor performance and higher score being normal performance. This rating scale was shown by our lab to have good inter and intra-rater
reliability and to be a valid tool for fall prediction in individuals with Parkinson disease [20]. Generally subjects who score 19 or below are at a high risk of falls.

3.5. Single Limb Stance Test

It is a measure of an individual’s ability to maintain a state of balance while standing on a narrow base [21, 22]. It has been widely utilized as an indicator of balance control in individuals with PD [21]. Subjects will be instructed to stand on one foot with the opposite knee held at 45 degrees of flexion and both hips in the neutral position. The end point of trial is defined as: 1) Subjects changing their stance position; 2) the examiner providing an external support to maintain balance; or, 3) the subject maintains the maximum testing period of 30 seconds. Time that the subjects stand on single limb will be measured with a stop watch. The best of 3 scores will be recorded if all 3 trials are less than 10 seconds. If the subject maintains the testing posture for more than 10 seconds in any trial; that time will be recorded without further trials [21]. This is to minimize the effect of fatigue. The test will be performed on both the extremities and the best time among all the trials, termed as best single limb stance time, will be used for statistical analysis.

3.6. Timed sit to stand Test

The timed sit to stand test is a valid measure of functional ability in people with balance disorders [23, 24]. It will be utilized to correlate trunk stability, measured with the wobble chair, with functional trunk stability during transfers. All subjects will begin by crossing their arms on their chest and sitting on a height adjustable chair without arm rests. The seat pan of the chair will be adjusted so that it comes to the level of the head of
fibula. The subjects’ feet will be placed so that his/her lower legs are vertical with the feet under the buttocks and approximately shoulder width apart. The thigh length will be determined as the distance from the lateral aspect of the knee joint to the greater trochanter. The subjects will be seated such that the distance from the greater trochanter to the front edge of the seat is 30 percent of the thigh length so that the buttock will be supported by the seat but with little of the thigh area supported [25]. The examiner will provide the following instructions: "I would like you to stand up and sit down 5 times as quickly as possible when I say 'Start'." Timing will begin when the examiner gives the instruction and says” Start” and will be stopped when the subject comes back to the sitting position on the fifth repetition. The rater will be standing beside the subject so that he/she can steady or catch the subject should any loss of balance occur. If a subject is unable to complete 5 repetitions, the number of repetitions completed and time to complete will be recorded.

3.7. Statistics

Performance of control subjects and subjects with PD will be compared utilizing the Mann Whitney U test for nonparametric data and t-tests for parametric data (p<.10). Spearman’s rho will be utilized to analyze the correlation of ordinal parameters. The criteria used to evaluate spearman correlation coefficients were: fair (values of 0.25-0.50), moderate to good (values of 0.50 to 0.75) and excellent (values of 0.75 and above) [26].
4. 1. Introduction

Parkinson disease is a progressive neurological disease characterized by bradykinesia, tremor, rigidity and postural abnormalities [1]. The pathology lies in the subcortical structure known as basal ganglia [1]. Impairment of trunk control is an important area of concern in individuals with Parkinson Disease (PD) as it negatively affects the gait patterns and dynamic balance of the individual. This eventually causes frequent falls and related complications [1]. Postural impairments weaken the confidence level of individuals resulting in fear of falling [2, 3, 4]. Individuals with PD tend to avoid leaving their homes which leads to social isolation [3].

Postural reaction strategies are important to maintain balance. In standing, postural reactions are achieved by the sequential muscle actions occurring at the ankle, knee, hip and trunk [5]. Postural reactions in sitting mainly involve the activation of the trunk musculature [5]. Postural impairments and altered postural reaction strategies become obvious when an individual responds to an unexpected destabilization force [5]. Individuals with PD demonstrate impaired trunk movements, reduced muscle torque production, reduced rate of torque production [1]. Individuals with PD also demonstrate
difficulty in maintaining feedforward anticipatory postural adjustments [1]. Adkin et al. [2] tested the postural reactions of individuals with PD and healthy controls by having an examiner pull backward on the shoulder of the subject using a procedure call the “shoulder retropulsion test” and found no difference between control subjects and individuals with PD when the test was administered without a prior warning. However the control subjects performed better on the test when a prior warning was given while the performance of the individuals with PD remained unchanged. The inability of subjects with PD to stabilize the body to a sudden perturbation even when warned is attributed to their inability to benefit from sensory feedback and make necessary anticipatory postural adjustments [2]. The single limb stance test and functional reach test also require feedforward postural adjustments. Individuals with PD demonstrate poorer performance in single limb stance test and functional reach compared to age matched control subjects [3].

Individuals with PD tend to demonstrate an abnormal pattern of co-activation of postural muscles in the lower limbs and trunk resulting in rigidity and inability to utilize the normal postural reaction patterns to maintain or regain balance [1, 6, 7]. These individuals also demonstrate axial rigidity [6]. Experiments to evaluate trunk control in quite sitting on an unstable seat show differences in performance between individuals with PD and control subjects. Individuals with PD demonstrate reduced angular deviations which is an indicator of axial rigidity [8, 9]. Subjects with PD also demonstrate poor performance in terms of endurance time and number of successful trials.
when asked to repeatedly maintain quiet sitting balance on an unstable seat for 15 seconds without touching a nearby safety rail [9].

Other parameters measured by researchers suggest that aging alone can have a detrimental effect on postural control and gait. The magnitude of angular deviation in the trunk, another indicator of trunk control, is greater in older adults compared to young adults [10]. The older adults walk slower and with shorter steps [11]. In elderly individuals, trunk control as measured by trunk repositioning error (TRE), demonstrates a negative association with single limb stance time, timed up and go test scores, and maximum step length [12]. That is, increased TRE is associated with poorer functional balance.

There is evidence in the literature to indicate that individuals with PD and elderly subjects have impairments in trunk control, balance and gait patterns. Since the head, neck and trunk make up more than 50 percent of the mass of the body, it is logical to propose that impaired postural control of the trunk in sitting is associated with impaired control of whole body balance and gait. To date, there are no published studies that have examined the degree of association between trunk postural control in sitting and commonly used clinical tests, such as the Tinetti Mobility Test and single leg stance test, that require the control of whole body balance. Moreover, we are interested in determining whether measures of trunk control in sitting and standardized clinical tests are able to discriminate between high functioning persons with PD and age matched controls. Therefore, the purpose of the present study was twofold. The first was to compare the outcomes from tests of seated postural control, whole body balance, and gait
in high functioning persons with PD to an age matched group of healthy controls. The second was to examine the association between seated tests of postural control and clinical tests of balance and gait performance in elderly subjects. The findings would help clinicians to better understand the association between impairments of trunk control and upright whole body functional tasks as indicated by clinical balance tests and gait measures. We hypothesized that:

1. Age matched healthy controls will demonstrate significantly better (p<.10) trunk control, balance and gait measures than high functioning individuals with PD.

2. In high functioning individuals with PD and elderly subjects there will be a correlation between trunk control measures and gait measures so that better performance on trunk stability measures correlate with better performance on gait measures.

3. In high functioning individuals with PD and elderly subjects there will be correlations between trunk control and balance measures so that better performance on trunk stability measures correlate with better performance on balance measures.

4. 2. Methods

Subjects

Subjects with PD were recruited from a community exercise class for individuals with PD. The control subjects were spouses and friends of the individuals with PD who agreed to participate in the study. The inclusion criteria specific to subjects with PD were: 1) diagnosis of PD with the onset in adulthood; and, 2) a score of 3 or below in
Hahn and Yahr Parkinson disease progress rating scale. The inclusion criteria for all subjects were: 1) at least 21 years old; 2) able to walk a minimum of 10 meters without any assistive devices; 3) able maintain sitting balance on a firm surface without arm support for at least one minute; and 4) no documentation of dementia. Exclusion criteria for all subjects were: 1) a diagnosis of other neurological disorders including vestibular disorders; 2) musculoskeletal injuries that could impact gait and/or balance, including acute lower back pain; 3) history of brain surgery or deep brain stimulation; and, 4) morbid obesity (Body Mass Index >40).

Instrumentation and procedure

The testing session took approximately 2 hours for each subject. Subjects were permitted to take a rest break whenever necessary. Testing included measures of trunk control (wobble chair parameters), gait (GAITRite and gait portion of Tinetti Mobility Test), balance (balance portion of Tinetti Mobility Test and Single Limb Stance Test) and function (Timed Sit to Stand Test).

The Unified Parkinson Disease Rating Scale (UPDRS) motor subscale was administered to all individuals with a diagnosis of PD. The UPDRS is a standardized rating scale for assessing disease severity in Parkinson disease consisting of six sections. The motor subscale has a maximum of score of 108 with higher scores indicating increased disease severity [13, 14]. Subjects were asked to complete motor tasks such as finger tapping and these were rated on a scale of 0 to 4 with 0 being no deficit and 4 being severely impaired. The Hoehn and Yahr scale was utilized to stage the disease
progress in individuals with PD [15]. The stages go from 0 which indicates minimal
disability to V which indicates highest disability.

**Wobble chair (measurement of trunk control in unstable sitting)**

The wobble chair is a device designed to evaluate the ability to balance the trunk
in quiet sitting by using lumbar and pelvic motions (figure. A.1). The device consists of a
seat that is mounted on a plywood platform which is supported by a ball joint. This
configuration allows the seat to pivot freely in 2-dimensional dimensions about its geometric center.
The seat can be adjusted forward and backward in order to place the subject’s center of
mass directly over the pivot point of the ball joint. Four steel springs are located to the
front, rear, left and right of the ball joint. The distance of the springs from the ball joint
can be adjusted by sliding the springs inward and outward which changes the available
base of support (BOS). The platform allows a maximum of 10 degrees of tilt in each
direction of the sagittal (forward and backward) and frontal (left and right) planes. The
seat and platform is attached to a wooden base (30 inches tall) that rests on a force plate
(Model 4060-10, Bertec, Worthington, OH). The force plate measures the 3-dimensional
ground reaction forces. Infrared light emitting diodes (IREDS) from the Optotrac motion
measurement system (Model 3020, Northern digital, Waterloo, Ontario) are attached to
the platform.

After explaining the procedure, the subject was assisted into a seated position on
the wobble chair and secured with a seat belt. The lower limbs were placed on a foot rest
so that the movements to control balance were limited primarily to the trunk. Safety was
assured by a railing adjacent to the chair on all four sides and a physical therapist guarding the subject in case he/she experienced a loss of balance.

Prior to the tests of postural control, the wobble chair was calibrated relative to each subject’s height and weight using data from the force plate and IREDs and following the procedures established by Granata et al [16]. The result of the calibration procedure provides the linear distance settings for positioning the springs relative to the pivot point of the chair. In brief, data were collected for 5 seconds with the chair plus subject first in 10 degrees of forward tilt and then in 10 degrees of backward tilt. The data were transferred to the computer and processed using custom software (MATLAB Tool box, Mathworks Inc, Natick, MA).

The equation of equilibrium from basic Newtonian physics was used to solve for the appropriate spring distance (L) from the pivot point of the chair. Hence, when the subject is positioned in a forward or backward inclination angle of 10 degrees and stays still without moving, the force applied by the subject in the downward direction is equal and opposite to the ground reaction force in the upward direction. The force, $F_1$, created by the subject is proportional to the subject’s weight, height and the angle between the chair surface and the subject’s center of mass (CoM). The ground reaction force, $F_2$, is proportional to the spring constant, the distance of the spring from the socket joint (L) and the angle of the platform. At equilibrium these two forces are equal and opposite ($F_1 = F_2$). Solving these equations provided the distance ‘L’, a relative indicator of the base of support (BOS) as a percentage for individual subjects. The wobble chair calibration procedure has been found to be reliable and valid in young, healthy subjects [17].
After calibration of the wobble chair, data were collected to determine the ability of the subject to maintain sitting balance at 100% BOS. The subject sat with arms across the chest and was asked to balance on the wobble chair by maintaining the chair steady. Each trial lasted 30 seconds and was repeated three times. A 30 second break was provided between trials in an effort to minimize the effects of fatigue. All subjects were given a practice trial before data collection commenced. During each trial, the number of times the subject exhibited a failure to balance was counted and recorded. A failure was operationally defined as 1) if the seat platform tipped so far that it touched the wooden base of the wobble chair; or, 2) if the subject’s hand contacted the safety railing. The number of failures was counted using a handheld counter by two observers closely watching the platform movement. The values obtained by the two observers were compared. When there was a difference between the numbers of failures counted by the two observers the trial was repeated.

After each subject was tested at 100% BOS, the subject was tested to determine the level of the BOS before balance could no longer be maintained. This was referred to as the least percent BOS before failure. For this test, a successful trial was one in which the subject maintained balance throughout the 30 seconds without a single failure. Hence, if the subject was successful at 100%, the BOS was reduced by 20% and the test was repeated at the new level. If the subject was successful at 80%, the BOS was reduced to 60%. Thereafter, if the subject was successful, the BOS was reduced by 10% increments until the subject was unable to maintain balance. For subjects who were not successful at 100% BOS, the chair was adjusted to provide more than 100% BOS.
The subject’s ultimate performance on the wobble chair was quantified using the following two parameters:

a. The least percentage of the BOS achieved in which there was at least one successful trial in three trials. This was the major outcome measurement for trunk control in sitting.

b. Mean number of failures from the three trials at the 60% BOS. 60% was chosen considering the fact that the majority of the subjects had successful trials with failures at 60% BOS. Most of the subjects performed all three trials successfully without a single failure at 80% and many of the subjects did not have even a single successful trial at 50% or below

**GAITRite (measurement of temporal and spatial parameters of gait)**

The spatial and temporal gait parameters of the subject’s gait were documented using the GAITRite system. The system automates measuring temporal and spatial gait parameters via an electronic walkway connected to a Windows XP computer. The gait parameter measurements obtained with GAITRite have been shown to be reliable and valid in individuals with PD [18]. Subjects were instructed to begin walking in their normal comfortable speed two meters before the edge of the walkway and to stop two meters beyond the edge of the walkway in order to allow sufficient distance for acceleration and deceleration phases. The subjects performed three trials. The initial one was considered as a practice trial. The results of the second and third trials were averaged by the GAITRite software. The following gait parameters were measured: step length, stride length, mean velocity and cadence.
Tinetti Mobility Test (TMT)

The Tinetti Mobility Test (TMT) has been shown to be a valid and reliable measure of functional mobility and balance in the elderly subjects and those with Parkinson disease [19, 20]. It is a 28 point rating scale in which the individual walks and perform mobility maneuvers while being observed by a trained rater. Each item is rated on a scale from 0 to 2 or 0 to 1, with 0 being poor performance and higher score being normal performance. This rating scale was shown by our lab to have good inter and intra-rater reliability and to be a valid tool for fall prediction in individuals with Parkinson disease [20]. Subjects who score 19 or below are at a high risk of falls.

Single limb stance time

Single limb stance is a measure of an individual’s ability to maintain a state of balance while standing on a narrow base [21, 22]. It has been widely utilized as an indicator of balance control in individuals with PD [21]. Subjects were instructed to stand on one foot with the opposite knee held at 45 degrees of flexion and both hips in the natural position. The end point of the trial was determined as, 1) subjects changing their stance position; 2) the examiner providing an external support to maintain balance; and, 3) subject maintained the maximum testing period of 30 seconds. The time that the subject stood on the single limb was measured with a stop watch. If the subject’s performance during each of the 3 trials was less than 10 seconds, the best of 3 scores was recorded. If the subject maintained the testing posture for more than 10 seconds in any trial, then that time was recorded without further trials [21]. This testing protocol was utilized to minimize the effects of fatigue on the subject’s performance. The single limb
stance test was performed on both the extremities and the best score out of the trials in both the extremities (termed as best single limb stance time) was used for statistical analysis.

**Timed sit to stand test**

The timed sit to stand test is a valid measure of functional ability in people with balance disorders [23, 24]. It was utilized to correlate trunk stability, as measured with the wobble chair, with functional trunk stability during transfers. Each subject began by crossing his/her arm on his/her chest while seated on a height adjustable chair without arm rests. The seat pan of the chair was adjusted so that it was at the level of the head of the fibula. The subject’s feet were placed such that his/her lower legs were vertical, with the feet under the buttocks and approximately shoulder width apart. The thigh length was determined as the distance from the lateral aspect of the knee joint to the greater trochanter. The subject was seated such that the buttock was well supported by the seat but with little of the thigh area supported [25]. The examiner provided the following instructions: "I would like you to stand up and sit down five times as quickly as possible when I say “Start”. Timing began when the examiner gave the instruction and said “Start” and was stopped when the subject came back to the sitting position on the fifth repetition. The rater stood beside the subject so that he/she could steady or catch the subject should any loss of balance occur. If a subject was unable to complete five repetitions, the number of repetitions completed and time to complete was recorded.
Statistical Analysis

For the first purpose, which was to compare performance of the subjects with PD to the healthy control subjects, the Mann Whitney U test was used for nonparametric data and the t-test for parametric data. The significance level was set a priori as $\leq 0.05$. In this pilot study, values between 0.05 and 0.10 were considered to approach significance and were further examined with a post hoc power analysis. For the second purpose, which was to examine the association between the tests of seated postural control, clinical tests of balance, and gait performance, the Spearman’s rho was utilized to analyze the correlations since these were ordinal level measurements. The criteria used to evaluate spearman correlation coefficients were: fair (values of 0.25-0.50), moderate to good (values of 0.50 to 0.75) and excellent (values of 0.75 and above) [26].

4.3. Results

Subject characteristics

Twelve high functioning individuals with PD and eleven age matched control subjects participated in the study. The subjects in the groups were of similar age ($t = 0.072, p = 0.943$). Subjects with PD were an average and standard deviation of 73.25 $\pm$ 8.96 years with a mean UPDRS motor subscale score of 20.92$\pm$10.36. Subjects in the control group were 74.64$\pm$7.54 years. Subjects in the PD group reported taking one or more of the following disease specific drugs: carbidopa, Mirapex, Sinemet, Amantidine, Requip and Comptan.
Comparison of PD group to the control group

Three measurements discriminated the subjects with PD from the healthy controls: the Tinetti Mobility Test (TMT), the gait subscale of the TMT, and step length (Table 1). Stride length and velocity approached significance (P = .062 to .066) and the post hoc power analysis indicated that the addition of three subjects in the control group and one subject in the PD group would have produced a significant result. The performance of the groups was equivalent (P > .10) on all other measures (Table 4.1). Therefore, the data from the 2 groups were collapsed and are presented as 1 group in the remainder of the results.

<table>
<thead>
<tr>
<th>Measure</th>
<th>PD Group</th>
<th>Control Group</th>
<th>Man Whitney U/ t-test</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>n = 12</td>
<td>n=10</td>
<td></td>
</tr>
<tr>
<td>Tinetti Gait</td>
<td>*10.17 ± 1.47 (8-12)</td>
<td>*11.44 ± 1.01 (9-12)</td>
<td>Z = -2.23</td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td>P = 0.036*</td>
</tr>
<tr>
<td>Tinetti Balance</td>
<td>13.92 ± 2.15 (10-16)</td>
<td>15 ± 1.23 (13-16)</td>
<td>Z = -1.307</td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td>P = 0.228</td>
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</tbody>
</table>

Continued

Table 4. 1. Comparison of PD group to control group on measures of trunk control, balance and gait.
Table 4. 1 continued

<table>
<thead>
<tr>
<th></th>
<th>*24.08 ± 2.97 (18-28)</th>
<th>*26.44 ± 2.07 (22-28)</th>
<th>Z = -2.22 P = 0.030*</th>
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</thead>
<tbody>
<tr>
<td>Tinetti Total</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>UPDRS</td>
<td>20.92 ± 10.36 (13-37)</td>
<td>-</td>
<td></td>
</tr>
<tr>
<td>Wobble chair, least % of BOS</td>
<td>72.50 ± 1.38 (60-90)</td>
<td>70.56 ± 17.75 (45-100)</td>
<td>Z = -0.38 p = 0.701</td>
</tr>
<tr>
<td>Number of Touches at 60% BOS</td>
<td>3.96 ± 3.45 (0-8.66)</td>
<td>2.99 ± 3.43 (0-10)</td>
<td>Z = -0.624 P = 0.573</td>
</tr>
<tr>
<td>Best single Limb Stance Time (sec)</td>
<td>14.51± 10.80 (2.13-30)</td>
<td>14.71± 12.7 (2.53-30)</td>
<td>t= -0.041 df= 19 p= 0.968</td>
</tr>
<tr>
<td>Sit to Stand Time (sec)</td>
<td>3.83 ± 3.60 (1.43-14.10)</td>
<td>3.96 ± 3.23 (2.15-12.15)</td>
<td>t = -0.006 df =20 p = 0.996</td>
</tr>
<tr>
<td>Step Length (cm)</td>
<td>*57.15 ± 11.72 (31.86-75.95)</td>
<td>*68. 84 ± 9.81 (44.70-77.17)</td>
<td>t = -2.283 df =20 p = 0.033*</td>
</tr>
<tr>
<td>Stride Length (cm)</td>
<td>*114.74 ± 23.89 (70.42-156.48)</td>
<td>135.46 ± 20.74 (86.06-154.37)</td>
<td>t = -1.977 df =20 p = 0.062+</td>
</tr>
<tr>
<td>Mean velocity (cm/s)</td>
<td>*105.55 ± 27.08 (74-156.60)</td>
<td>*129.16 ± 23.73 (84-164)</td>
<td>t = -1.948 df = 20 p = 0.066+</td>
</tr>
<tr>
<td>Cadence</td>
<td>110.18 ± 10.59 (37.6-126)</td>
<td>114. 29+ 9.70 (34.40-133.90)</td>
<td>t = -0.807 df =20 p = 0.429</td>
</tr>
</tbody>
</table>
Association between trunk control, balance performance, and gait

Trunk control, as measured by the least percentage of BOS to maintain balance and the number failures at 60% BOS, showed fair correlations with sit to stand time, best single limb stance time, TMT total score, TMT gait subscale and cadence (Table 4.2). However, the highest correlation \((r = .61)\) was found between the age of the subject and the least achieved % BOS. The trunk control measures tended to show an association with step length \((p=0.06)\) and mean velocity \((p=0.07)\) (Table 4.2).

<table>
<thead>
<tr>
<th>Balance/Gait measure</th>
<th>Trunk control measures</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>Least % of BOS (N=23)</td>
</tr>
<tr>
<td>Age</td>
<td>0.61**</td>
</tr>
<tr>
<td>Sit to stand time</td>
<td>0.42*</td>
</tr>
<tr>
<td>Best Single limb stance</td>
<td>-0.45*</td>
</tr>
<tr>
<td>TMT total</td>
<td>-0.41*</td>
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<tr>
<td>TMT gait subscale</td>
<td>-0.42*</td>
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<tr>
<td>Step length</td>
<td>-0.30+</td>
</tr>
<tr>
<td>Mean velocity</td>
<td>-0.39+</td>
</tr>
<tr>
<td>Cadence</td>
<td>-0.41*</td>
</tr>
</tbody>
</table>

**=p≤0.01, *=p≤0.05, +=p≤0.10

(BOS- Base of Support, TMT- Tinetti Mobility Test)

Table. 4.2 . Correlation of trunk control measures with gait and balance measures in elderly adults with and without PD.
4.4. Discussion

In this pilot study, high functioning individuals with PD and age matched healthy controls showed small but distinct differences in performance on the overall TMT and the gait subscale of the TMT but not on measures of trunk control in sitting. Although the differences between the groups on the TMT outcomes were statistically distinct, the average differences on the overall TMT and gait subscale were in the range of only 1 to 2 points thereby raising the question of the clinical importance of the differences. Furthermore, neither group would be considered as having a high risk of falls. Hence, the subjects’ performance may be equivalent in terms of their clinical presentation on the TMT. This factor may have contributed to the failure to detect differences in performance on measures of seated postural control on the wobble chair.

A short step length during gait, which is a stereotypical characteristic of PD, was shown to be the most sensitive measure that discriminated high functioning persons with PD from their age-matched controls. Individuals with PD walked with a step length that was on average 11.69 cm shorter compared to their age matched control. Since the cadence was similar between the two groups, the net result was a tendency for the subjects with PD to walk slower.

Previous studies of more severely involved PD subjects found differences between healthy elderly and those with PD on measures of trunk control, gait and balance. [9, 27-32]. In the study by van Wegan [9], which found between-group differences in measures of trunk control, the subjects in the PD group had a mean UPDRS score of 37.8±17.4. In comparison, the individuals with PD in the present study
had a mean UPDRS score of 20.92±10.36, indicating they experienced fewer impairments and functional limitations compared to those in the previous study. In the present study, subjects with PD were recruited from a local group exercise program. These individuals were high functioning and led an active life that included exercises to specifically target limitations known to PD. They also exercised at least 3 times per week. Although the subjects with PD in this study showed shorter step lengths resulting in a tendency toward shorter stride lengths and slower gait velocities, they performed as well as healthy elderly subjects in a previous study (Ostrosky KM) [11]. This suggests that the high functioning PD subjects in the present study were functioning at a level similar to that of healthy elderly who are of similar age. In the present study, subjects with PD also had the advantage of having undergone many of these balance tests as a part of their routine medical examination. It has been shown that practice improves performance on UPDRS, single limb stance time, sit to stand time and gait measures [33, 34, 35].

Although the TMT scores differed, the small difference is not clinically important as all but one subject scored above 20; and thus the subjects had a minimal to low risk of falls. Future investigations are necessary to evaluate the effect of exercise and active life style on trunk control, balance and gait measures in individuals with PD.

In this small sample of elderly subjects with and without a diagnosis of PD, measures of trunk control correlated with clinically relevant outcome measures of gait and balance suggesting an influence of trunk control in maintaining normal whole body balance and gait. The results of the present study are consistent with previous studies [10, 12]. Goldberg et al [12] utilized trunk reposition error (RPE) as a measure of trunk
control and found significant correlations with single limb stance test, Timed Up and Go test and maximum step length. However, how accurately the RPE values represent the actual construct of trunk control is debatable. RPE measures the individual’s perception of trunk position in space which is only one component of the construct of trunk control. Trunk muscle strength, coordination, range of motion and reflex latency may be important factors in maintaining normal control. For example, in the trunk impairment scale, which is a validated tool for measuring trunk control in subjects with multiple sclerosis, the measurement of the perception of the position of trunk contributes only 3 points on the 23 point scale [35]. Therefore RPE is not a complete measure of trunk control but measures a contributing factor (position sense) of trunk control.

The observed relationship between age and trunk control is consistent with the existing literature [5]. In the present study, the subject’s age explained 37% of the variance in performance on the wobble chair, using the least percent BOS as the outcome measure. Cholewski et al. [5] assessed the center of pressure (CoP) movements in unstable sitting and found a positive correlation \((r = 0.27)\) between CoP movements and age. CoP movements increased with age suggesting that as the age increases individuals need more trunk postural adjustments to maintain upright posture.

There is an increase in the trunk sway area and trunk angular velocity during gait and balance tasks [10]. Gill et al. [10] found a significant increase in trunk sway measures in single limb stance compared to normal stance in healthy elderly subjects. This suggests that trunk control influences the ability to maintain upright posture on a narrow base of support. Elderly subjects exhibit greater trunk angular sway area and
higher sway velocities compared to younger adults. Since the elderly subjects also showed poorer performance in clinical balance measures, trunk control may be an important factor that influences the performance of the subjects in clinical balance measures [10]. Studies of subjects following a stroke show a significant relationship between trunk control and clinical balance measures [37]. Vereeck et al. [37] utilized a trunk impairment scale (TIS) to assess trunk control in post stroke subjects and found correlations between the TIS and the TMT-total ($r=0.73$), TMT balance subscale ($r=0.71$), TMT-gait subscale ($r=0.73$), Timed up and go test ($r=0.60$), 10-m walk test ($r=0.49$), and the motor part of the Functional Independence Measure (FIM) ($r=0.71$) [89]. The TIS measures the motor impairment of the trunk and the quality of trunk movements. The score ranges from 0 to 23, with 0 being absolute worst, based on the tests of static and dynamic sitting balance and trunk coordination.

The coordination of trunk and pelvic rotations are important to the performance of a normal gait pattern [7]. When walking at a slow velocity, the pelvis and thorax move ‘in-phase’ making the trunk rigid. As gait velocity increases the pattern changes and the movements between the pelvis and thorax become more ‘out of phase’, i.e. the thorax moves in the opposite direction to pelvis [7]. The rotation of the thorax in the opposite direction is achieved via swinging of the arms [38]. The pelvis also contributes to the forward rotation of the leading lower limb. The limb movement is counterbalanced by the posterior rotation of the opposite side of the pelvis [38]. The trunk musculature also plays a major role in bearing the upper body weight during gait and balance activities [5]. Thus adequate trunk ROM, trunk muscle strength and coordination contribute to the
performance of a normal gait pattern. The present study supports the role of normal trunk control in maintaining normal gait and balance, as individuals who performed poorly on the wobble chair tended to show a negative correlation with balance and gait measurements.

4.5. Limitations

There are several limitations of the study. The most important limitation was the small sample size which may have led to the study being underpowered. This limits our freedom to generalize the results to the larger population. The wobble chair variables used in this study might not be sensitive enough to detect and differentiate changes in trunk control in high functioning PD subjects and age-matched healthy controls. Another disadvantage was that the subjects’ scores in wobble chair and balance measures tended to be similar indicating that our subjects did not represent the variability in performance that may occur with PD and in the elderly population as a whole. This reduced the statistical power, and the ability to detect relationships among the dependent variables. Another methodological concern was that subjects were instructed to sit on the wobble chair in an erect sitting posture with a normal lordosis and slight anterior pelvic tilt. None of the subjects in this study were able to achieve this posture and were tested while sitting in a posterior pelvic tilt. Sitting in posterior pelvic tilt lowers the center of mass (CoM) and increases the BOS helping the subject to achieve better stability. This may have had an adverse impact on the wobble chair as a measure of trunk control. The final concern is the confidence level of the subjects while performing wobble chair tasks. Trying to balance on an unstable platform would have induced a fear of falling which may have
adversely affected the performance of all of the subjects. The extent of fear of falling might vary from person to person and there was no method to account for this error.

4.6. Conclusions

Impairment in trunk control is a common phenomenon in older adults and individuals with PD [1, 22]. In the present study we examined the group differences between high functioning individuals with PD and age matched control subjects and failed to detect between group differences in their performance in clinical balance and gait measures. This finding may reflect the positive effects of an active life style and exercise training on the functional level of individuals with PD. Further in-depth investigations are recommended on this issue. The correlations of trunk control measures with gait and balance measures are consistent with the literature which indicates that trunk control influences gait and balance. Further investigations are necessary to substantiate the findings of the present study. Following are the recommendations made for future studies.

1. Recruit a group of inactive individuals with PD in order to evaluate how they differ from high functioning individuals with PD and normal healthy elderly.

2. Utilize surface electromyography data to assess patterns of trunk musculature recruitment.

3. Examine the COP sway area from the force plate data and the trunk angular deviations from the 3-dimensional motion measurements (IREDs). These measures are highly sensitive and would provide a clearer picture of trunk control.
4. Utilize a trunk perturbation device to measure reflex latency which may provide a better picture of reflex activity patterns and feedback control in elderly subjects and individuals with PD. (This can be a good predictor of injurious falls).

5. A cohort study to assess the effect of exercise training in trunk control, balance, gait and reflex activity measures in elderly individuals and individuals with PD.

    Should we substantiate the present findings with future investigations, new treatment protocols can be developed giving adequate importance to trunk control in treating individuals with PD and the elderly population.
BIBLIOGRAPHY


23. Whitney SL, Wrisley DM, Marchetti GF, Gee MA, Redfern MS, Furman JM. Clinical measurement of sit-to-stand performance in people with balance


Figure A.1: The wobble chair. Lateral view
Figure A.2. Position of the springs and the ball joint. These springs can be moved inward and outward to adjust the base of support.
APPENDIX-B

<table>
<thead>
<tr>
<th>Test</th>
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<td>80.00</td>
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Table B.1. Comparison of PD subjects with control group in trunk control, gait and balance measures (non parametric data).
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<th>Tinetti Balance</th>
<th>Tinetti Total</th>
<th>Wobble chair least % of BOS</th>
<th>No. of Touches at 60% BOS</th>
<th>Avg. Time Before 1st Touch at 60% of BOS</th>
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<td>0.026</td>
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<td>0.228</td>
<td>0.030*</td>
<td>0.582</td>
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<td>0.762</td>
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* = $p \leq 0.05$, + = $0.1 \geq p \geq 0.05$

Table B.2. Man Whitney U analysis of group difference
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<tr>
<th></th>
<th>Group</th>
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<th>Mean</th>
<th>Std. Deviation</th>
<th>Std. Error Mean</th>
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Table B.3. Group differences of the parametric data
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<th>Equal variances not assumed</th>
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<td>Sig. (2-tailed)</td>
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* = \( p \leq 0.05 \), + = \( 0.1 \geq p \geq 0.05 \)

Table B.4. Independent t-test for parametric data
B.4 continued

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* = p ≤ 0.05, + = 0.1 ≥ p ≥ 0.05
APPENDIX-C

C.1. Tinetti Mobility Test

Balance Tests

Initial instructions: Subject is seated in hard, armless chair. The following maneuvers are tested.

1. Sitting balance (SIT)
   Leans or slides in chair
   \[= 0\]
   Steady, safe
   \[= 1\]

2. Arises (ARS)
   Unable without help
   \[= 0\]
   Able, uses arms to help
   \[= 1\]
   Able, without using arms
   \[= 2\]

3. Attempts to arise (AR)
   Unable without help
   \[= 0\]
   Able, requires > 1 attempt
   \[= 1\]
   Able to rise, 1 attempt
   \[= 2\]

4. Immediate standing balance (first five seconds) (ISB)
   Unsteady (swaggers, moves feet, trunk sway)
   \[= 0\]
   Steady but uses walker or other support
   \[= 1\]
   Steady without walker or other support
   \[= 2\]

5. Standing Balance (SB)
   Unsteady
   \[= 0\]
   Steady but wide stance (medial heels > 4 inches
   \[64\]
apart) and uses cane or other support
   = 1
Narrow stance without support
   = 2

6. Nudged (subject with feet as close together as possible, examiner pushes lightly
   on subject’s sternum with palm of hand 3 times) (SNB)
   Begins to fall
   = 0
   Staggers, grabs, catches self
   = 1
   Steady
   = 2

7. Eyes closed (subject with feet as close together as possible) (ECL)
   Unsteady
   = 0
   Steady
   = 1

8. Turning 360 degrees (TUR)
   Discontinuous steps
   = 0
   Continuous
   = 1
   Unsteady (grabs, staggers)
   = 0
   Steady
   = 1

9. Sitting down (STD)
   Unsafe (misjudged distance, falls into chair)
   = 0
   Uses arms or not a smooth motion
   = 1
   Safe, smooth motion
   = 2

Total Balance Score:
       /16

65
**Gait Tests**

*Initial Instructions: Subject stands with examiner, walks down hallway or across room, first at “usual pace”, then back at “rapid, but safe” pace (using usual walking aids)*

10. Initiation of gait (IG) (immediately after told to “go”)
    - Any hesitancy or multiple attempts to start
      = 0 No hesitancy
      = 1

11. Step length and height (SL/H)
    a. right swing foot
        - does not pass left stance foot with step
          = 0
        - passes left stance foot
          = 1
    b. Left swing foot
        - does not pass right stance foot with step
          = 0
        - passes right stance foot
          = 1
    c. Right foot does not clear floor completely with step
      = 0
      = 1
    d. Right foot completely clears floor
      = 1

12. Step Symmetry (SS)
    - Right and left step length not equal (estimate)
      = 0
      = 1
    - Right and left step appear equal
      = 1

13. Step Continuity (SC)
    - Stopping or discontinuity between steps
      = 0
      = 1
    - Steps appear continuous
      = 1

14. Path (Pa) (estimated in relation to floor tiles, 12 inch diameter; observe excursion of 1 foot over about 10 feet of the course)
    - Marked deviation
      = 0
      = 1
    - Mild/moderate deviation or uses walking aid
      = 1
Straight without walking aid

= 2

15. Trunk (Tr)

Marked sway or uses walking aid

= 0

No sway but flexion of knees or back or spread arms

= 1

No sway, no flexion, no use of arms, and no use of walking aid

= 2

16. Walking Stance (WS)

Heels apart

= 0

Heels almost touching while walking

= 1

Gait score: __________/12

Balance + Gait score: __________/28
C.2. United Parkinson Disease Rating Scale (UPDRS), motor subscale.

III. Motor Exam

Speech
0-normal
1-slight loss of expression, diction, volume
2-mono tone, slurred but understandable, mod. impaired
3-marked impairment, difficult to understand
4-unintelligible

Facial Expression
0-Normal
1-slight hypomimia, could be poker face
2-slight but definite abnormal diminution in expression
3-mod. hypomimia, lips parted some of time
4-masked or fixed face, lips parted 1/4 of inch or more with complete loss of expression

*Tremor at Rest
Face
0-absent
1-slight and infrequent
2-mild and present most of time
3-moderate and present most of time
4-marked and present most of time

Right Upper Extremity (RUE)
0-absent
1-slight and infrequent
2-mild and present most of time
3-moderate and present most of time
4-marked and present most of time

LUE
0-absent
1-slight and infrequent
2-mild and present most of time
3-moderate and present most of time
4-marked and present most of time

RLE
0-absent
1-slight and infrequent
2-mild and present most of time
3-moderate and present most of time
4-marked and present most of time

**LLE**
0-absent
1-slight and infrequent
2-mild and present most of time
3-moderate and present most of time
4-marked and present most of time

**Action or Postural Tremor**

**RUE**
0-absent
1-slight, present with action
2-moderate, present with action
3-moderate present with action and posture holding
4-marked, interferes with feeding

**LUE**
0-absent
1-slight, present with action
2-moderate, present with action
3-moderate present with action and posture holding
4-marked, interferes with feeding

**Rigidity**

**Neck**
0-absent
1-slight or only with activation
2-mild/moderate
3-marked, full range of motion
4-severe

**RUE**
0-absent
1-slight or only with activation
2-mild/moderate
3-marked, full range of motion
4-severe

**LUE**
0-absent
1-slight or only with activation
2-mild/moderate
3-marked, full range of motion
4-severe

**RLE**
0-absent
1-slight or only with activation
2-mild/moderate
3-marked, full range of motion
4-severe

**LLE**
0-absent
1-slight or only with activation
2-mild/moderate
3-marked, full range of motion
4-severe

*Finger taps*

**Right**
0-normal
1-mild slowing, and/or reduction in amp.
2-moderate impaired. Definite and early fatiguing, may have occasional arrests
3-severely impaired. Frequent hesitations and arrests.
4-can barely perform

**Left**
0-normal
1-mild slowing, and/or reduction in amp.
2-moderate impaired. Definite and early fatiguing, may have occasional arrests
3-severely impaired. Frequent hesitations and arrests.
4-can barely perform

*Hand Movements (open and close hands in rapid succession)*

**Right**
0-normal
1-mild slowing, and/or reduction in amp.
2-moderate impaired. Definite and early fatiguing, may have occasional arrests
3-severely impaired. Frequent hesitations and arrests.
4-can barely perform
Left
0-normal
1-mild slowing, and/or reduction in amp.
2-moderate impaired. Definite and early fatiguing, may have occasional arrests
3-severely impaired. Frequent hesitations and arrests.
4-can barely perform

*Rapid Alternating Movements (pronate and supinate hands)*

Right
0-normal
1-mild slowing, and/or reduction in amp.
2-moderate impaired. Definite and early fatiguing, may have occasional arrests
3-severely impaired. Frequent hesitations and arrests.
4-can barely perform

Left
0-normal
1-mild slowing, and/or reduction in amp.
2-moderate impaired. Definite and early fatiguing, may have occasional arrests
3-severely impaired. Frequent hesitations and arrests.
4-can barely perform

*Leg Agility (tap heel on ground, amp should be 3 inches)*

Right
0-normal
1-mild slowing, and/or reduction in amp.
2-moderate impaired. Definite and early fatiguing, may have occasional arrests
3-severely impaired. Frequent hesitations and arrests.
4-can barely perform

Left
0-normal
1-mild slowing, and/or reduction in amp.
2-moderate impaired. Definite and early fatiguing, may have occasional arrests
3-severely impaired. Frequent hesitations and arrests.
4-can barely perform

*Arising From Chair (pt. arises with arms folded across chest)*
0-normal
1-slow, may need more than one attempt
2-pushes self up from arms or seat
3-tends to fall back, may need multiple tries but can arise without assistance
4-unable to arise without help

*Posture
0-normal erect
1-slightly stooped, could be normal for older person
2-definitely abnormal, mod. stooped, may lean to one side
3-severely stooped with kyphosis
4-marked flexion with extreme abnormality of posture

*Gait
0-normal
1-walks slowly, may shuffle with short steps, no festination or propulsion
2-walks with difficulty, little or no assistance, some festination, short steps or propulsion
3-severe disturbance, frequent assistance
4-cannot walk

*Postural Stability (retropulsion test)
0-normal
1-recovers unaided
2-would fall if not caught
3-falls spontaneously
4-unable to stand

*Body Bradykinesia/ Hypokinesia
0-none
1-minimal slowness, could be normal, deliberate character
2-mild slowness and poverty of movement, definitely abnormal, or dec. amp. of movement
3-moderate slowness, poverty, or small amplitude
4-marked slowness, poverty, or amplitude