

**A Biomechanical Analysis of the Sit-to-Stand transfer in  
Parkinson's disease**

By

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A thesis submitted to the School of Rehabilitation Therapy  
in conformity with the requirements for  
the degree of Master of Science

Queen's University  
Kingston, Ontario, Canada  
January, 2008

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## ABSTRACT

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**Objectives:** This study aimed to compare the sit-to-stand (STS) transfer in normal elderly subjects and people with Parkinson's disease, using kinematic and kinetic analysis. **Design:** A cross-sectional cohort study using a control group and a group of individuals with Parkinson's disease. **Background:** Parkinson's disease (PD) is a progressive neurological condition that is characterized by hypokinesia, akinesia, tremor, rigidity and postural instability. In individuals with PD, falling is a common risk and occurs most frequently during walking or other locomotor activities that involve a shift in the centre of mass, an example being the daily STS transfer. This study aimed to help the clinician gain a better understanding of the biomechanical analysis of the STS transfer in individuals with PD. **Methods:** Fourteen subjects with PD and fourteen age matched healthy individuals performed the STS transfer at their self-selected speed from a height-standardized seat in a laboratory setting. Analysis was based on ground reaction forces, joint angles calculated from two-dimensional kinematic data, and time to complete the task. **Results:** Subjects with PD took longer than control subjects to complete the STS. Also, there were differences in the ground reaction forces between individuals with PD and their age-matched controls. **Conclusion:** In line with other findings about movement in PD, the individuals with PD were slower, exerted less force and used different strategies than age-matched controls.

## Acknowledgements

Firstly, I would like to acknowledge the support of my supervisor Dr. Kathleen Norman who provided constructive and helpful comments on the many drafts of this thesis and ultimately the steps to reach the final destination.

I would also like to thank the following

:

- God, for giving me the courage and strength to undertake this study,
- Mr. Sacco, Mr. Agius, Mr. Steve Lungaro Mifsud and Ms. Nadine Galea for being the first people to make me love this amazing profession - Physiotherapy.
- Dr. Elsie Culham and Dr. Alice Aiken, for valuable feedback on my thesis proposal.
- All subjects who participated in this study.
- Dr. Pari, The Parkinson's Society in Kingston and Pro-Active Rehabilitation Centre for helping in subject recruitment.

Finally, I would like to thank my parents for their enduring support and encouragement during this long and challenging intellectual endeavour. Without them, this thesis would have been just another dream.

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## Chapter 1: INTRODUCTION

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Parkinson's disease (PD) belongs to a group of neurological conditions called movement disorders. It is characterized by muscle rigidity, tremor, a slowing of physical movement (bradykinesia) and, as the disease progresses, problems with initiation of movement (akinesia). The primary symptoms are the results of decreased stimulation of the motor cortex by the basal ganglia, arising from insufficient dopaminergic input to the basal ganglia from the substantia nigra. These characteristics affect the activities of daily living of these individuals, one example being the Sit-to-Stand (STS) transfer.

Rising from a sitting position is one of the most common tasks one does everyday. Whether after sitting down in the library, after watching a film, after waking up everyday in the morning; all these would involve standing up from a sitting position. It is of utmost importance to try and establish the dynamics of the STS transfer in individuals with PD as it gives further insight on how to address any abnormalities these individuals have and restore functionality as much as possible.

Musculoskeletal, movement control and balance impairments are all factors which affect the sit-to-stand (STS) transfer. The accurate control of the Centre of Pressure (COP) position in relation to the Centre of Mass (COM) is important as it allows a controlled transfer and aims the maintenance of postural stability.

Problems with range, flexibility and strength in the lower limbs (Ramsey et al. 2004) and trunk, together with movement control impairments will impact speed, COG position and control during the task (Inkster & Eng, 2004).

The purpose of this present study was to contribute to knowledge about the STS in individuals with PD, and to study any differences that might be present in relation to age-matched controls. Specifically, this study examined the time for the individuals in the 2 groups to go from sitting to standing, together with forces they were exerting and any alternative strategies that the individuals with PD might have used during the transfer. By comparing people with and without PD, we aimed to gain more information on how this task is performed and ultimately help develop ideas for individuals with PD to correct any abnormalities they might be exhibiting, whether it is a problem with their angles, timing or positioning of the joints at the start of their task.

## Chapter 2: LITERATURE REVIEW

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### 2.1 Epidemiology of PD

PD is one of the most common age-related neurodegenerative disorders, second in frequency only to Alzheimer's disease. The frequency of PD is expected to triple over the next 50 years as the average age of the population increases (Fall, 1996). Prevalence has been reported in a number of studies. In China, the prevalence has been reported to be 15 people per 100,000 (Li et al. 1985), in Argentina 399 to 669 (Melcon et al.1997), 100 in North America (Schoenberg et al. 1985), 257 in Europe (Morgante et al. 1992) and 328 in India (Bharucha et al. 1988). These studies were all based on door-to-door surveys. Other community-based studies in different regions show different numbers. Sutcliffe and Meara (1995) found the prevalence to be 121 in the United Kingdom, whilst Fall (1996) reported a prevalence of 115 in Sweden. Wermuth et al. (1997) reported a prevalence of 188 in the Faroe Islands.

Prevalence increases until the 9<sup>th</sup> decade (Fall, 1996), after which, the rate appears to decline. The decline among the most elderly seen in some studies probably results from the very few people in this age group and may also reflect diagnostic and ascertaining difficulties. Peak prevalence is typically reached around the 8<sup>th</sup> decade as found in most studies. PD is rare before the age of 50 in the majority of cases. Men appear to have a slightly higher risk of acquiring PD (1.2 to 1.5 times) (Marttila, 1992).

## **2.2 Pathophysiology of Parkinson's disease**

The basal ganglia (BG) plays a major role in regulating muscle contraction, muscle force, multi-joint movements, and the sequencing of movement (Elble, 2000). The BG output goes to motor areas of the cerebral cortex responsible for either automatic or voluntary movements. The BG consist of five interconnected subcortical structures, these being the caudate nucleus and the putamen, which together form the corpus striatum, the globus pallidum, the substantia nigra (composed of pars reticulata and pars compacta) and the subthalamic nucleus. In post-mortem gross examination of the external aspects of the brain, the globus pallidus, putamen and the caudate nucleus appear normal in brains of people with PD. However, decreased pigmentation of the substantia nigra is observed. It is caused by the pathological hallmark of PD, which is a loss of pigmented dopaminergic neurons of the pars compacta region of the substantia nigra, along with the presence of neural intracytoplasmic inclusions called Lewy bodies. The function of these dopaminergic neurons appears to be the modulation of the activity of the striatum (caudate and putamen), by means of two types of dopamine receptors: D1 and D2. D1 receptors are located on neurons that project directly to the internal part of the globus pallidus, and their activation normally leads to excitation of motor areas of the cerebral cortex (the direct pathway). D2 receptors are located on neurons that communicate to the internal part of the globus pallidus via connections in the external part of the globus pallidus and in the subthalamic nucleus. These receptors are important in

forming the indirect pathway through the basal ganglia. Neostriatal excitation results in inhibition of the external segment of the globus pallidus and disinhibition of the subthalamic nucleus. This inhibits the thalamus and decreases the excitation of the motor areas of the cerebral cortex, thus inhibiting movement (Eible, 2000).

Since dopaminergic projections from the substantia nigra excite the direct pathway but inhibit the indirect pathway, one of the main functions of the basal ganglia is to facilitate movement by excitation and appropriate selective inhibition in promotion of movement. As a result of this loss of dopaminergic neurons, a number of characteristic features occur in PD. Bradykinesia, slowness in performing a task (and akinesia, the slowed ability to initiate a task), rigidity, the increased tone present in muscles noted by resistance to passive movement, resting tremor and postural instability are the four main characteristics that individuals with PD usually exhibit. The combined effects of these features can affect the individuals' ability to perform activities of daily living and can lead to other problems, an example being an increased risk of falling.

### **2.3 Falls in PD**

Falls cause a number of medical and psychological complications. Koller and Kase (1986) showed that 38% community dwelling individuals with PD reported a fall, with 13% falling more than once during a week. Falls may result in hospitalizations, and in 3%, in wheelchair confinement. Other studies have reported a 63% to 65% risk of falling amongst community-dwelling individuals with PD (Ashburn et al. 2001; Schrag et al. 2002).

There are various causes which explain why individuals with PD fall. Postural instability, freezing and festination, levodopa-induced dyskinesias, symptomatic orthostatic hypotension, sudden loss of postural reflexes, co-existing neurological or other medical and environmental conditions are all examples of why these individuals might fall (Michalowska et al. 2002). Wielinski et al. (2001) have shown that although fractures occur in a relatively small number of individuals with PD who fall, 35.5% of the subjects studied sustained an injury as a result of the fall. Health care professional services were required in 27% of those falls, amongst which 13.4% required surgery. Bloem et al. (1999) conducted a review of prospective surveys and found that 50.8% of individuals with PD fell at least once a year.

Falls may thus lead to several problems, including the risks of fractures, admission to nursing homes, immobility and increased mortality. A fear of

walking can also be present, which in turn might affect the functionality of the individual and ultimately affects his/her independence. This will in turn affect the individual's quality of life (Schrag et al. 2002). In individuals with PD, falling is a common risk and occurs most frequently during walking or other locomotor activities that involve a shift in the centre of mass, as in the Sit-To-Stand (STS) transfer. This might result from direct effects of the disease. Berardelli et al. (2001) have shown how the clinical features of PD (rigidity, bradykinesia, postural instability, freezing of gait, proprioceptive deficits) can predispose the individual to falls. Other indirect effects can also play a role in falls, for example, a fixed flexion posture, biomechanical changes in hip/pelvis alignment and impaired dual task performance. Munton et al. (1981) have shown that one-third to one-half of individuals with PD have difficulty rising up from a chair. These individuals usually experience a combination of difficulties, these being mainly attributed to balance problems, muscle weakness, and a decrease in the ability to shift the centre of mass forwards. In some cases, they were also seen to fall back into the chair during the movement.

#### ***2.4 The Sit-To-Stand (STS) transfer***

The STS is an activity most people perform numerous times daily. The capacity of an individual to stand up from a chair has been regarded as an important indicator of an elderly person's functional independence and if impaired, increases the risk factor for falls (Inkster & Eng, 2004). Problems with successful

execution can ultimately lead to institutionalisation. Munton et al. (1981) studied 379 elderly persons with arthritis and found that 42% reported having difficulty with rising from a chair in the home; 18% of these either experienced great difficulty or could not rise unaided.

In clinical research, the STS has been used for a variety of purposes. Csuka and McCarty (1985) used this task as a measure of lower extremity strength, which provided information on the force-generating capacity of the muscles. More recently, this task has also been used to analyze balance capabilities in elderly people, both in healthy individuals and also in persons with various medical conditions.

Lord et al. (2002) studied 669 elderly individuals, aged 75-93 years, and found that the STS performance depends on a number of factors. These factors include peripheral tactile sensitivity, speed, balance, proprioception and psychological status (reported pain, anxiety and vitality) in addition to strength. Quadriceps strength showed the highest correlation with STS speed indicating that it was the most important variable in explaining the variance in STS times. The findings of Lord et al. (2002) are consistent with those of Schenkman & colleagues (1990) who demonstrated that strength played a more important role than balance in predicting the time to stand in functionally-impaired older people.

#### 2.4.1 The STS as an outcome measure of intervention

Frailty in the older adult has been defined as a loss of physiological reserve that leads to a decline in physical performance and functional independence. Chandler et al. (1998) argued that a decrease in strength might be one of the main aspects of frailty and thus, strength gain might be associated with improved function, decrease in the number of falls and a decrease in the need for social support services. These authors have found that lower extremity strength gain is significantly associated with an increased ability to rise from a chair, together with improvement in ability at tasks such as gait, transfers, stooping and stair climbing. Unfortunately, these authors did not measure the time to complete the STS.

Dean and Shepherd (1997) have also shown that balance training exercises for reaching tasks in stroke subjects also improved the ability to perform the sit to stand task. The stroke subjects were able to increase hip flexion prior to the extension phase of the STS. Drabsch et al. (1998) also found an improvement in the performance of the STS after task-specific training in subjects who had a total hip replacement. The subjects showed an increase in force on the operated leg during the extension phase of the STS. Headley et al. (2002) studied 10 medically stable haemodialysis subjects and found that resistance training exercises were found to improve strength and functional measures in these subjects. In fact, the time to complete 10 repetitions of the STS decreased after

12 weeks of resistance training. Monger et al. (2002) used a home programme incorporated with an in-patient training programme and found that the STS improved in subjects with chronic stroke.

#### 2.4.2 Overview of the STS – Biomechanical and temporal factors

The technique used to rise from sitting typically involves a stereotyped sequence in which joints are either stationary or moving in a particular way (Nuzik et al. 1986). Large moments are usually produced in both the hip and knee during the STS, and thus any problems with muscle weakness (Corcos et al. 1996), or postural instability (Inkster & Eng, 2004) will lead to the use of alternative strategies.

The idea of utilizing momentum in any transfer technique is a valuable option to any person who exhibits muscle weakness or other problems in standing up (Nuzik et al. 1986). The injection of a burst of energy transfer is usually the first step, which must be later recovered in order to finish the task. Butler et al. (1991) provided a good analogy of the idea of momentum, by giving an example of trying to close a door which is difficult to close. If the door is closed from an open position, slamming would definitely make it close, due to the energy imparted to the area. However, trying to push the door might not achieve the goal.

Kelley et al. (1976) provided an early description of the STS transfer, this being done in two main phases. The first phase is the forward flexion which is followed by extension. Millington et al. (1992) divided the first phase into two. They described phase one as the weight shift phase where a forward shift in the centre of gravity occurred, as a result of trunk flexion. Phase two, the transition phase, starts immediately on lift-off of the buttocks from the chair and at the start of knee extension and ends immediately when trunk flexion ends and trunk extension begins. This will take the individual to phase three, which is equivalent to the extension phase in the study by Kelley et al. (1976). Schenkman et al. (1990) agreed with Millington et al. (1992) and described the first initial phase as a flexion in the pelvis and trunk which helps to generate upper body momentum. This is followed by a second transitional phase, whereby the buttocks are lifted off the seat of the chair. This would also include a forward momentum of the trunk as the centre of mass moves horizontally forward, reaching the individual's centre of gravity. This stage would require adequate strength of the quadriceps muscles, which would decrease the pelvic tilt and raise the centre of mass to a less stable position over the extended lower limbs. The third phase, the extension phase, involves maximum dorsiflexion at the ankle joint, and ends when complete trunk and hip extension is reached, once again showing the importance of adequate muscle strength in the lower limbs and trunk. Schenkman et al. (1990) added a fourth and final phase that included the stabilization period, where the individual was in full erect standing, and the usual amount of anterior and posterior sway of quiet standing is present.

Numerous studies have reported on the duration of one STS transfer, with times in seconds varying between 1.15 (Schenkman et al. 1990), 1.2 (Riley et al. 1991), 1.3 (Jeng et al. 1990), 1.89 (Inkster et al. 2003), 2 seconds (Kelley et al. 1976), 2.03 (Millington et al. 1992) and 2.04 seconds (Tully et al. (2005). Transfers using unrestrained protocols (no description of foot or arm position at start of transfer, seat height) have reported values between 1.8 and 3.3 seconds (Nuzik et al. 1986; Kralj et al.1990). The interpretation of these studies is difficult because different studies use different criteria to define the beginning and end of the movement. In people with PD, Ramsey et al. (2004), used kinematics and has reported a rising time of 4.18 seconds whilst Inkster et al. (2003) reported a rising time of 1.89 seconds (using kinematic analysis). However, these authors did not explain when the timing was started or stopped. It is therefore not clear whether people with PD take longer to complete the task or whether this apparent difference is merely due to different methods of timing used. Some studies have also incorporated the stabilization phase in their analysis, which may account for the longer time durations reported. Mak and Hui-Chan (2005) have also shown that individuals with PD tend to take longer than healthy individuals when they calculated the time to complete the three phases of the STS at a self selected speed. However, when asked to perform this transfer at a faster speed, the subjects with PD were able to increase the speed with the same percentage changes as those of controls.

The STS transfer has been thoroughly analyzed in healthy individuals of different ages. Researchers have used kinetic, kinematic and electromyography (EMG) analysis to describe the different phases of the STS transfer. Some authors have incorporated one analysis with another (or both) to give a better understanding to the reader. Kinematic analysis allows the investigator to study the spatial and temporal characteristics of the STS whilst kinetic analysis gives the investigator more information on the actual joint forces occurring during the task at hand, this depending on how the actual analysis was performed.

### 2.4.3 The STS in healthy individuals

#### 2.4.3.1 Kinetic Studies

The use of force plates permits an analysis of what is happening to the ground reaction force as the subject stands up. Lindemann et al. (2003) have studied ground reaction forces to analyze the different phases of the STS transfer. They divided the STS in three phases. Phase one of the STS started with a decrease in the vertical force by more than 2.5% of body weight. At the start of the STS, hip flexion occurred which causes a slight decrease in the GRF under the feet, and lasted until the peak vertical force was reached (Phase one). The latter was considered to be coincident with seat off and demarcated the end of Phase one. Naumann et al (1982, as cited in Millington et al. 1992) has shown that maximum compressive and shear forces under the feet usually occurred immediately after seat contact ended, and interestingly found no difference between the adults and

children studied in ground reaction forces (GRF). After this, GRF reached a peak, a result of the knee and hip torques which pushed the body into standing. Phase two started when Phase one ended, and ended when the vertical force reached body weight. Schenkman et al. (1990), who defined the phases using kinematic analysis (see later) has shown that maximum hip and knee torques were also present during Phase two and this occurred at a time when the subjects were first full weight-bearing and whilst the hip and knee were near maximum flexion. The quadriceps worked maximally to redirect the centre of gravity forward and generate the forward shift of the upper body. Phase three, the extension phase, started when Phase two ended, and ended when the vertical force oscillated around body weight ( $\pm 2.5\%$  body weight).

#### 2.4.3.2 Kinematic and EMG studies

Millington et al. (1992) gave a kinematic representation of the STS in healthy individuals. Phase one typically took 27% (0%-27%) of the STS transfer and encompassed trunk flexion. Wheeler et al. (1985) used electrogoniometry to study 10 young women and 10 older women rising from a chair. The latter study reported a significant difference in trunk forward lean between the elderly and young individuals ( $75.0^{\circ} \pm 4.9^{\circ}$  vs.  $78.1^{\circ} \pm 5.6^{\circ}$  respectively). Muscle activity was similar in both groups. The erector spinae acted eccentrically in both groups to control this motion. At the end of this phase, quadriceps activity began to prepare for standing. Hamstrings and quadriceps activity were active throughout the

whole transfer and Richards (1985, as cited in Winter et al. 1990) has found peak activity in hamstrings and quadriceps muscles just after seat off.

In Phase 2 lasting 9% (27%-36%) of the transfer, the sharpest rise in vertical force (as measured by a force plate) was found (Millington et al. 1992). Ellis et al. (1984) found that peak muscle activity also occurred in the erector spinae, hamstrings, quadriceps and gluteus maximus during this phase. Interestingly, they also found that forces at the knee joint can be up to seven times the body weight just after lift-off from the chair.

The third phase, which lasted approximately 64% of the transfer, began whilst knee extension continued until full standing was reached (Millington et al. 1992). The peak vertical force, which was slightly greater than body weight, occurred closely after the time of seat clearance. As trunk and both knees extend, muscle activity continues to diminish until full erect standing occurs; at this point, the person then enters the stabilization phase (Schenkman et al. 1990).

The differences in phase duration in different studies can be attributed to variations in experimental designs. Some authors have instructed the subjects to fold their arms across their chests (Mak et al. 2003; Riley et al. 1991; Schenkman et al. 1990; Tully et al, 2005), whilst others instructed their subjects to place their arms resting on their laps (Millington et al. 1992). Differences in knee angles at the start of the transfer have also been noted, some authors describe a knee

angle of 90° (Millington et al, 1992; Mak et al. 2003; Inkster & Eng, 2004), others an 85° angle (Mak et al. 2003), others a 72° angle (Riley et al. 1991). Nikfekar et al. (2002) provided no restrictions of knee or foot angles prior to the start.

Schenkman et al. (1990) studied young healthy subjects to describe the three phases of the STS, with particular emphasis to kinematics. These authors showed that in Phase 1, the trunk moved forward which was coupled with anterior pelvic rotation. The trunk averaged 16° flexion relative to the pelvis. Maximum trunk flexion angular velocity, hip flexion velocity and head extension angular velocity were also reached during this phase and occurred almost simultaneously.

The second phase started on lift-off of the buttocks from the seat and ended on maximum forward flexion of the trunk and hips. Maximum ankle dorsiflexion was also present at the end of this phase. The sequence of events was maximum hip flexion, maximum trunk flexion, maximum head extension and finally maximum ankle dorsiflexion.

In the early part of Phase 2, flexion velocity of the hip and trunk was already decreasing, and reached 0°/sec during the second half of the phase, as extension started. The flexion to extension transition then continued as the body COG shifted from moving in principally an anterior direction to moving in a combined upward and anterior direction as the subject entered Phase 3.

Finally, the transition from a dynamic position to a quasi-static stable position is important to note during this third phase. At the start of Phase 2, the vertical projection of the COM was posterior to the COF (Centre Of Force - dynamic stability). However as Phase 2 reached completion, the vertical projection of the COM moved close to the COF (quasi-stable position).

Schenkman et al. (1990) continued to describe Phase 3 which started with the attainment of maximum ankle dorsiflexion and ended when hip extension velocity reached 0°/sec and the body starts to stabilize. In this phase, maximum hip, trunk and knee extension and maximum head flexion velocity were reached. The authors described a Phase 4 as the Stabilization phase, occurring after Phase 3, but did not provide an analysis of it.

Tully et al. (2005) studied a group of 47 students, with an average age of 22 years. In this study, the STS start was determined as the initiation of horizontal displacement of a marker placed on the 1<sup>st</sup> thoracic spinous process. The STS was considered to be complete at the point of maximal vertical displacement of a marker placed on the 1<sup>st</sup> thoracic spinous process. They showed that lift-off occurred typically at 41.2% of the STS cycle (lift-off was defined at the point of the vertical displacement of a marker placed on 2/3 thigh distance). They showed that as the trunk flexed forward (mean maximum trunk flexion of 45.7°, the thoracic spine extended (as lumbar spine and hip joint flexed). The lumbar spine reached its mean maximum flexion at 32% of the cycle, whilst the thoracic spine

continued to extend until lift-off occurred. Mean maximum hip flexion occurred at 39% of the cycle. Interestingly, for every 3.1° of hip flexion, there was an average of 1° lumbar flexion. During Phase 3, the hips once again extended more rapidly than the lumbar spine.

Khemlani et al. (1999) investigated the activation pattern on biceps femoris, vastus lateralis, rectus femoris, tibialis anterior, lateral gastrocnemius and medial soleus under two initial foot conditions (knee and hip at 90/90°, heel 0.10m posterior to anterior aspect of tibia). The sequence of onsets of muscle activity was the same under both conditions. Tibialis anterior was activated first followed by rectus femoris, biceps femoris and vastus lateralis. All these muscles were activated just before lift-off of the buttocks. Lateral gastrocnemius and medial soleus were both activated after lift-off.

## **2.5 Determinants of the STS**

A number of parameters are important to consider during the STS task. These include seat height and presence of back support, position of the head, trunk, arms, hip, knee and ankle at the start, feet distance apart and buttock position on the seat.

### 2.5.1 Chair related determinants

**Seat height:** The height of the chair plays a major influence on the performance of the STS. As one lowers the seat height, the demands of the task increases. A lower seat height resulted in an increase in the angular velocity of the hip (Hughes et al. 1996, Rodosky et al. 1989). Rodosky et al. (1989) also showed that a lower seat resulted in an increase in trunk, knee and ankle angle displacements. The maximum moment needed at the hip and knee also increased when a lower seat height was used. A change in biomechanical demands (e.g. change in centre of mass over a larger distance) or an altered strategy (longer stabilization phase) was also present. Weiner et al. (1993) have shown that the minimum height for a successful STS for elderly people (community dwelling and nursing home residents aged 64-105 years of age) with chair rise difficulties appeared to be 120% of lower leg length.

Only a limited number of studies have analyzed the STS transfer in individuals with PD. Nikfekar et al (2002) used a seat height of 450mm (for all subjects regardless of their height), with no restriction of the position of the feet, meaning the knee angles could have been different in different subjects. The subjects were instructed to stand up without the use of their arms. Mak et al. (2003) used an armless, adjustable chair in their study. The height of the seat was adjusted in accordance with the subjects' knee angle, which was always at 90 degrees prior to the start of the STS. From this initial position, the subjects were instructed to

stand up without further flexing the knee or taking a step forwards. Inkster et al. (2003) also used an armless, adjustable chair. The seat height was adjusted to allow a 90-degree angle at the knee joint. The thigh was parallel with the ground in these studies. Inkster and Eng (2004) used the same protocol as Inkster et al. (2003). Ramsey et al. (2004) used a chair height of 438.1 mm, and also explained that the chair was slightly padded, which was rarely described in other studies. However, they gave no description of knee or foot angles at the start. Bishop et al. (2005) allowed a 90° knee flexion angle with no description of seat height.

**Chair type and Back support:** Only three studies have used specially designed chairs during STS. Wheeler et al. (1985) used a standard chair and a special chair designed for comfort and showed that standing up from a chair designed for comfort resulted in more activity in the vastus lateralis. Furthermore, the elderly individuals showed greater knee flexion and greater forward trunk lean than the younger group when a comfortable chair was used.

Dubost et al. (2005) used a back support on the seat to make sure that the trunk was aligned vertically prior to the start of the STS. Most studies did not use a back support on the chair (Kerr et al. 1994, Millington et al. 1992, Riley et al. 1991, Schenkman et al. 1990, Tully et al. 2005). All studies done on individuals with PD did not use a back support.

### **Arm support and position:**

Different studies have used different constraints on arm support and position. Subjects were either instructed to stand up with their hands in their laps, folded (Jeng et al. 1990, Mak et al. 2003, 2005, Nikfekar et al. 2002, Schenkman et al. 1990), flat against rib cage (Bishop et al. 2005), relaxed by their sides (Butler et al. 1991, Inkster et al. 2003) or placed on their knees (Nuzik et al. 1986).

Using arm rests resulted in lower moments at the knee and hip (Burdett et al. 1985), with moments at the hip decreasing by 50% with the use of armrests, compared to standing from the same seat without arm rests. These authors found no change in joint angles in healthy individuals across arm rest conditions. No studies have used an armrest in individuals with PD. The majority of the studies that included individuals with PD required their subjects to fold their arms across their chest. This will definitely affect the motor performance of the task, but this position was adopted to avoid obstruction of the camera's view of the reflective markers as Tully et al. (2005) have pointed out. Also, this would prevent the use of the upper extremities to assist in the execution of the task. Nuzik et al. (1986), in their study of healthy individuals, allowed the placement of the arms in accordance with the comfort of the subject, but these authors' analysis was based on visual observation rather than instrumented measurements.

## 2.5.2 Strategy related determinants

**Trunk position and movement:** Shepherd & Gentile (1994) used an initial trunk position that incorporated more trunk flexion (erect versus 30° versus 60°) at the beginning of the STS and showed no changes in peak support moments. However, the duration of maximum support moment increased as the angle increased. The duration of the extension phase also increased. Schenkman et al. (1990) also explained the importance of adequate trunk flexion prior to lift-off as this would generate the required moment necessary to complete Phase 3 of the STS. Doorenbosch et al. (1994) studied how healthy adults perform a STS transfer. They asked the subjects to maximally flex their trunk during Phase 1. Kinematic changes around the hip changed but total range of motion at the knee and ankle did not. However, a 27% lower (net) knee joint moment was achieved during this task (sitting to standing with a start position that involved a full flexion of the trunk) as compared with natural rising.

**Feet, knee and buttock position:** All studies that involved a STS transfer placed the feet parallel to each other. Tully et al. (2005), Nuzik et al. (1986), Millington et al. (1992), Kralj et al. (1990), Baer and Ashburn (1995) and Yu et al. (2000) did not measure the distance of one foot from the other. Mak et al. (2003) stated that the feet were placed at shoulder width apart. Schenkman et al. (1990) used a distance of 10.6cm (4 inches) distance between the two feet. Riley et al. (1991), Wheeler et al. (1985) and Kerr et al. (1994) used a distance of 10 cm.

This information is important as it gives an idea of the position of the hip (abduction/adduction), together with the size of the base of support.

Shepherd and Gentile (1994) studied the effect of foot position prior to the start of the STS movement. Three positions of the feet were studied, one being posterior placement of both feet to the knees, versus preferred position of the feet and also versus anterior placement of both feet to the knees. They showed that a posterior foot position resulted in a faster STS transfer than when an anterior or preferred foot position was used. Hip flexion and hip flexion speed were also lowered in the posterior foot position condition. An anterior foot position increased the duration of the pre-extension phase. Kawagoe et al. (2000) showed that a posterior foot placement also affected the extension moment at the hip. The mean hip extension moment in the posterior foot condition in healthy adults was 32.7Nm in contrast to 148.8Nm in the posterior foot position condition. Interestingly, Munton et al. (1981) found no difference in EMG activity in six large lower extremity muscles with feet placed directly under knees compared to feet placed in a posterior position.

Buttock position relative to the front edge of the seat is also important to consider. Only two studies (Schenkman et al. (1990), Riley et al. (1991) explained clearly, stating that the subjects' buttocks were on the seat, but the thighs were unsupported. Inkster et al. (2004) went a step further and stated that thigh support was achieved by calculating a 20cm distance between the anterior

edge of the chair and most anterior part of the patella. Although this is a novel idea, it does not standardize for the subjects' height.

The position of the knees is also important. Fleckenstein (1988) positioned the knee in more extension than preferred (75° of knee flexion and 105° of knee flexion from full extension) prior to the start of the STS transfer. The greater knee flexion angle appeared to increase hip joint angular displacements, with an increase of hip extension moment of 77%. The knee extension position in this study is similar to the condition of placing the feet anterior to the knees. Once again, this shows the importance of the position of the feet prior to the start of the STS, as it would change both the hip, knee and ankle angles, together with the biomechanics of the task.

**Speed and Light conditions:** Rogers (1988) have shown that as the STS movement speed increases, the hip flexion, knee extension and ankle dorsiflexion joint moments also increased. Roebroek et al. (1994) used a metronome to impose a selected speed for the STS. Rogers (1988) also reported that a faster STS movement affected the peak vertical momentum of the centre of mass. The peak horizontal momentum remained relatively the same. Also, as the STS movement speed increases, Phase 2 tends to be of shorter duration (Vander Linden et al.1994). Gross et al. (1988) have shown that as the speed increases, less hip flexion occurs as lift-off occurs.

Mourey et al (2000) manipulated vision during the STS movement. Subjects were asked to sit to stand in light and dark conditions at 2 different speeds. No effect on movement time was found in young (20-25 years of age) and elderly (71-82 years of age) when vision was varied (light versus dark). The speed of the centre of mass was lower in the blindfolded condition for the elderly subjects as compared to the younger population.

## **2.6 Summary of Literature Review, Rationale and Hypothesis**

The transfer from sitting to standing is a vital prerequisite for many activities of daily living, including upright walking. In contrast to the analysis of gait, relatively few studies have been performed on standing up from a chair in individuals with PD. Sitting to standing is also one of the most mechanically demanding tasks that one performs daily (Riley et al. 1991). It requires a transition from a relatively large, stable base of support in sitting, to a considerably smaller base of support in standing. The manner in which the STS transfer is defined depends to some extent on the aims of the study. The determinants of the STS are also important to consider. Biomechanical analysis will provide clinical insight into different strategies that individuals with PD might use to successfully accomplish a STS transfer. Although the STS has been studied considerably in healthy individuals using techniques such as use of force plates, video analysis, use of optoelectronic systems, goniometry, and accelerometry, the methods that researchers used have varied and has not always been explained well.

Furthermore, this important everyday task has not been investigated sufficiently in individuals with PD, who often have difficulty rising up from a chair. The present study aimed to develop a better understanding of the biomechanical analysis of the STS transfer in individuals with PD, and ultimately help clinicians in designing treatment. The purpose of this investigation is to analyze the STS motion using kinematic and kinetic data in individuals with PD and age-matched healthy controls. It was designed to provide a logical explanation of the task and aims to explore the differences observed between controls and individuals with PD. We aimed to test two main hypotheses. The first hypothesis was that individuals with PD will take longer to complete each phase of the STS than control subjects. The second hypothesis was that there will be a difference in the ground reaction forces (GRF) between individuals with PD and controls (greatest instantaneous GRF rise, difference in peak GRF and body weight). This study also aimed to study whether individuals with PD have developed an alternative strategy compared to control subjects for sitting to standing, this being examined by the analysis of joint angular movements.

## **Chapter 3: Methods**

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### **3.1 Research Design**

The research design for this study was a cross-sectional cohort study, in which the analysis of STS transfers in individuals with PD was compared with the analysis of STS transfers in age and gender-matched control subjects.

### **3.2. Sample Selection**

#### **3.2.1. Sample Size**

A precise sample size calculation was not undertaken. Instead, the sample size was projected based on existing literature and the experience from previous studies in the laboratory of recruiting subjects with PD in the Kingston area. The few reports comparing STS in people with PD to control subjects have used relatively small sample sizes: seven subjects with PD and 10 control subjects (Inkster & Eng, 2004); 13 subjects with PD and 11 control subjects (Ramsey et al, 2004). The most recent PD-related study in the laboratory (Jiang & Norman, 2006) recruited 14 subjects with PD, and previous studies recruited between 11 and 18 subjects with PD. Using the same recruitment methods, it was estimated that 12 to 16 subjects with PD could be recruited for this study, as a well as a

comparable number of subjects in the control group, and that these numbers would be adequate to address the research question.

### 3.2.2. Subject Recruitment

The subjects were recruited by a sample of convenience. The sources of subject recruitment were the Movement Disorders clinic at Kingston General Hospital, and through advertising for subjects in the Kingston chapter of the Parkinson Society of Canada. Subjects for the control group were obtained through personal acquaintances, and were invited to participate based on matching age and gender of subjects with PD. For subjects recruited from the clinic, the neurologist, who knew the exclusion and inclusion criteria, was asked to refer subjects who fit the criteria. For subjects recruited by advertisement, the advertisement stated the eligibility. Their eligibility was confirmed by discussing the information in the “purpose and aims of the study” section in the consent form. (Appendix I)

### 3.2.3. Inclusion and Exclusion Criteria

Inclusion Criteria for all subjects:

- Ability to ambulate 25m without the use of assistance.
- Ability to stand from a chair independently, without the use of their arms.

- No change in prescription medication in the past two weeks.

Exclusion Criteria for all subjects:

- The presence of musculoskeletal or cardiorespiratory problems that would affect sit-to-stand, or any neurological problems (other than PD in the PD subjects).

### **3.3 Initial intake information**

Total testing time took approximately 1.5 hours. During this time, the initial process involved explaining the project, obtaining informed consent, and performing the intake interview. The age, height, weight, medication and years since onset of the disease was recorded. The staging of the disease was also recorded by the use of the Hoehn and Yahr Scale (Hoehn & Yahr, 1967, Appendix III). Testing was done in a single laboratory visit to the Motor Performance Laboratory of the School of Rehabilitation Therapy, Queen's University.

### 3.3.1 Consent Form and Personal Information

Prior to testing, subjects were asked to read an information letter for the study and sign a consent form (Appendix I) in accordance with the Queen's University Health Sciences & Affiliated Teaching Hospitals Research Ethics Board.

After reading and signing the information letter and consent form, an intake interview (Appendix II) was used to obtain general and medical information, such as medication intake, duration of disease, health status, characteristics of tremor (length of the symptoms, body part affected). Subjects with PD who were taking anti-parkinson medications were studied 1-2 hours post-medication intake, which is typically the peak time of the treatment effect.

### 3.3.2 Measure of PD severity

The Hoehn and Yahr scale (Hoehn & Yahr, 1967) was used as a measure of PD severity. The Hoehn and Yahr scale (Appendix III) is a commonly used scale to assess the symptoms the individual with PD disease currently presents with. Possible scales values range from 0, indicating no evidence of disease, to 5, indicating maximum disability. Having symptoms on one side of the body only is classified as stage 1 of the disease, having symptoms on both sides with no balance impairments is classified as stage 2, whilst stage 3 signifies that the individual has balance impairments but is still able to be physically independent.

Stage 4 indicates severe disability affecting function but still able to walk or stand unassisted. Stage 5 is the final stage of the disease and it is reached when the individual with PD is wheelchair or bed bound. The Hoehn and Yahr Scale was only applicable to the PD subjects as it is a disease-specific scale.

### **3.4 Procedure for recording the STS**

In this study, a firm backless, armless seat was used, similar to ones used in other studies of STS (Riley et al. 1991, Schenkman et al. 1990, Tully et al. 2005, Kerr et al. 1994, and Millington et al. 1992). The height of this seat was determined by a measurement made when the subject was sitting on a standard chair. The subject's feet were placed so that his/her lower legs were vertical. The distance from the top of the knees to the floor was measured. The height of the testing seat was then set at 80% of the distance measured above. The thigh length was measured from the lateral aspect of the knee joint to the greater trochanter. The subject was then seated such that the distance from the greater trochanter to the front edge of the seat was 30% of the thigh length. This ensured that the buttocks were supported on the seat but not much of the thighs. The feet were placed on two separate force plates. The subject was able to place his/her feet as desired, as long as there was one foot on each force plate. This position of the feet on the force plates allowed the subject to choose his/her knee angle prior to the start of the STS. The position of the feet was recorded by the

researcher prior to the start of every STS trial (refer to Appendix II). On-off switches were built into the flat wooden platform on which the subjects were seated. These switches provided information about when the buttocks left the seat contact, and therefore contributed to distinguishing the phases in the STS transfer. Each subject was asked to place his/her hands on his/her lap at the start of the transfer. Each subject was instructed that as he/she stands up, he/she should make a small movement of both arms in order to minimize the chances of having any of the markers “missing” for the Optotrak®. This movement was to flex the elbows to around 90° and medially rotate the shoulder so as to rest the hands on the abdomen. The subjects were instructed not to make any effort with their arms which might aid the transfer.

An Optotrak® System was used to track the position of markers as well as to record information from force plates and seat switches. Infrared Emitting Diodes (IREDS), 3.5 mm in diameter, were placed on the right side of the body using non-irritant adhesive discs (Figure 1). The specific locations include the lateral aspect of the head of the 5<sup>th</sup> metatarsal<sup>1</sup>, lateral malleolus, lateral knee joint line, greater trochanter, lateral aspect of anterior superior iliac spine (ASIS), tragus of the ear and the Frankfort plane. Plastic projections with an attached marker were placed on the superior aspect of the sacrum and spinous processes of the 2nd lumbar vertebra (L2), the 12<sup>th</sup>, 2nd thoracic vertebrae (T12 and T2) and the 7<sup>th</sup> cervical (C7) vertebra. These projections were used to prevent any missing data

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<sup>1</sup> The marker was placed on the subject’s shoe, over the location of the lateral aspect of the head of the 5th metatarsal bone.

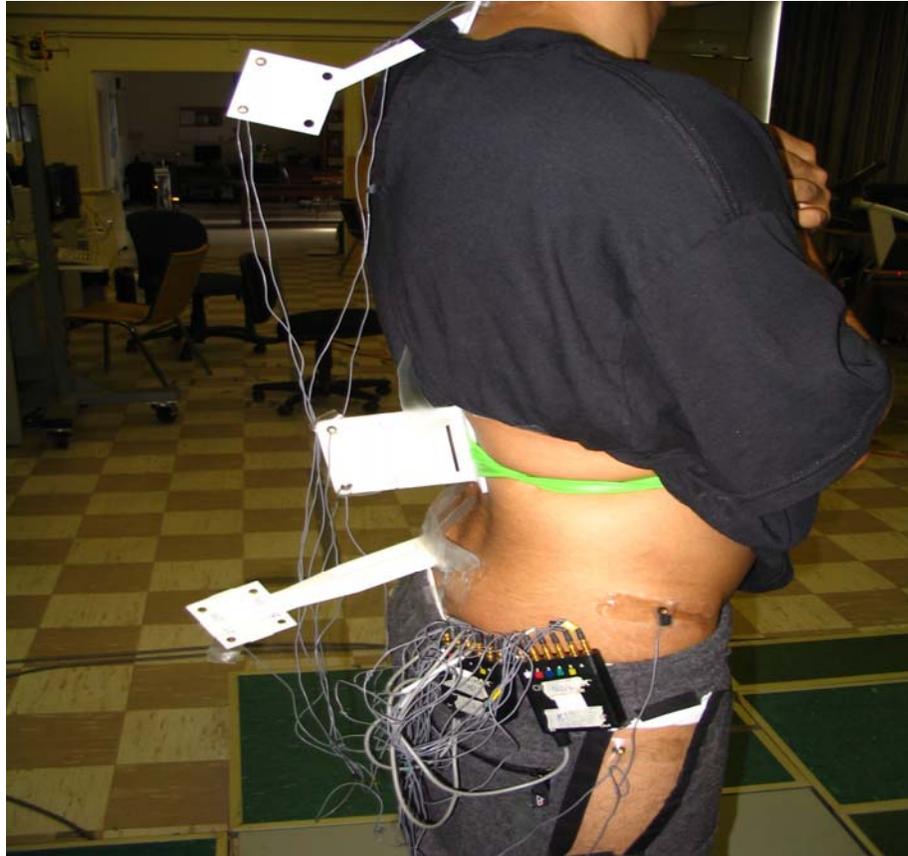
that might be covered by the subject's clothes and to change the orientation making sure they could be maximally captured by the camera (see Figure 1).

To locate the spinous processes of C7 and T2, the following method was used.

The first thoracic spinous process (T1) was first located by asking the subject to flex his/her head and neck while the examiner kept a finger on the spinous process thought to be that of cervical spinous process 6 or 7. The spinous process of C6 was felt to move forward while that of C7 remained stationary.

Having located the spinous process of C7, the spinous processes of T1 and T2 were found by palpating the spinous processes at the next caudal level.

To locate the spinous process of L2 and T12, the following method was used. A mark was first placed over the lumbar spinous process at the level corresponding to the highest point of the iliac crest, deemed to be at the level of L4. This was confirmed by palpation. The examiner then moved cephalad to locate the spinous process of L2. L2 was also in line with the 12<sup>th</sup> rib as located by palpation. T12 was located by palpation of the spinous processes as one moved in a cephalad direction. The Frankfort plane, the center of which approximates the head's centre of gravity, was found by locating the mid point between the tragus and the lowest point of the orbit (Nuzik et al, 1986). It is defined as the line connecting the superior border of the external auditory meatus with the infraorbital rim.



**Figure 1:** Experimental set-up. Subject standing with attached IREDs on the different joints on the body (Showing the white projections and attached markers to the specific locations as described in the text).

After the IREDs were placed and the subject was sitting comfortably on the testing seat, each subject performed three to five practice trials of sitting to standing. A number of criteria were checked prior to the collection of data. The subject was sitting comfortably and was ready to start the sitting to standing transfer. The posture at the start and end of the STS was checked visually, making sure the subjects were sitting erect both at the start and end of the trial. The wires connecting the IREDs to the strobers of the OPTOTRAK ® were free

to move adequately and not in the way to hinder the performance of the STS. Also, the signal qualities both from the IREDS and the force platforms could be viewed from the computer being used for data collection.

Recordings were first obtained with the subject in a total erect standing position. The subjects were asked to stand for 1 minute and data was recorded during this time. Subjects were instructed to self initiate the STS after the verbal instruction – “Please stand up”, and data was recorded after the subject reached a total erect standing position. The examiner checked the computer monitor display for any missing data from the OPTOTRAK® prior to the start and during standing. This data was compared with a similar final standing trial of one minute (see below) to verify any postural changes that may have been attributable to fatigue or wearing off of anti-parkinson medication.

The subject was then asked to perform five STS transfers, and data was recorded for 10 seconds in each five trials. After each trial was completed, the subject was asked to sit down for 1 minute before the next trial. The verbal instruction “Please stand up” was used and the subject was allowed to stand up at their preferred speed. The verbal instruction was provided 1-2 seconds after the data recording started.

The subject was then given a 5 minute break. Following this, five more STS transfers were done, and data was recorded for 10 seconds in each of five trials.

After each trial was completed, the subject was asked to sit down for 1 minute before the next trial. The breaks between the trials were intended to minimize the chances that that no fatigue was present which would affect the data.

The subject was then asked to stand for 1 minute and data was recorded during this time. Once again, subjects were instructed to self initiate the STS after the verbal instruction – “Please stand up”, and data was recorded for 1 minute after the subject reached a total erect standing position

### **3.5 Instrumentation**

#### **3.5.1 Kinematics**

An optoelectronic three-camera motion analysis system (OPTOTRAK® 3020) which has been verified to have high trial-to-trial reliability ( $r \geq 0.88$ ) (Chang and Krebs, 1999) was used to record the kinematic parameters. This system records the 3D (x,y,z) positions of the IREDs. The OPTOTRAK is a precalibrated and noncontact system capable of recording high-velocity motion in 3D. The position sensor containing the three cameras records precise movement with 0.3mm accuracy at a distance of 4m and 0.45mm accuracy at a distance of 6m, according to the manufacturer’s specifications (Northern Digital Inc). For the present study, the camera was placed about 4 metres from the chair which the

subject used to perform the STS transfer. The marker position data were collected at a sampling rate of 200Hz.

### 3.5.2 Kinetics

Two separate AMTI force platforms (Advanced Mechanical Technology Inc, Massachusetts, USA) were used in this study. The two force plates gave information on the ground reaction force under each foot. This enabled analysis of vertical forces, and was used to measure the Ground Reaction Forces (GRF), and the rate of rise in force, and body weight. All signals were collected at 200Hz.

## 3.6 Data processing

Displacement in millimetres of the IREDs and force plate data was collected and transformed into an ASCII text file using the Northern Digital Inc. software file conversion. In order to calculate outcome variables of interest, data were then transferred onto a Personal Computer for offline processing in Matlab software (version 7.0).

### 3.6.1 Missing Data

The Optotrak<sup>®</sup> only records data from markers that are visible to the position sensor. Therefore, during the STS, some markers might have gone missing during the trial. Data replacement algorithms were, however, created to replace

these missing data points based on spatial relationship of IREDs (Larocerie-Salgado, 2006). It is important to note that the IREDs from all markers rarely had missing data.

### 3.6.2 Kinematics

#### Calculation of Joint Angles

Sagittal ankle, knee, hip, pelvic tilt, lumbar, thoracic and neck angles were calculated in this study. Sagittal ankle angle was calculated from the position of the markers located on the lateral aspect of the 5<sup>th</sup> metatarsal, lateral malleolus and lateral aspect of the knee joint. The sagittal knee joint angle was calculated from the position of the markers located on the lateral malleolus, lateral aspect of the knee joint line and the greater trochanter. The sagittal hip joint angle was calculated from the position of the markers located on the lateral aspect of the knee joint line, the greater trochanter and the lateral aspect of the ASIS. The pelvic tilt angle was calculated as a result of the marker placed on the lateral aspect of the ASIS and the superior aspect of the sacrum, and defined as the angle with respect to horizontal. The sagittal lumbar angle was calculated as a straight line joining L2-T12, and the angle was defined as that which the straight line makes with respect to the vertical plane. The sagittal thoracic angle was calculated as a straight line joining T2-C7, and the angle was defined as that which the straight line makes with respect to vertical plane. The sagittal neck angle was calculated from the position of the markers placed on the 7<sup>th</sup> cervical

spinous process, tragus of the right ear and the Frankfort plane. Although some of these angle definitions do not correspond to anatomical angles in terms of where the zero position is (most notably the ankle and hip), movement through the range corresponds to movement of the respective joints or segments.

The following angular positions and angular excursions were studied.

1) Ankle – The analysis of the ankle angle was done from the start of the STS to the minimum angle obtained during the STS. This shows how the subject moved from Phase 1 to Phase 2, reaching maximum dorsiflexion in the process. The subject then stands up reaching Phase 3 and phase 4, and the start of the STS (ankle angle) to the end of the STS (ankle angle) was also calculated.

2) Knee angle – The start of the angle during sitting was of interest as it gave information about the actual position of the knee prior to the start.

3) Hip angle - The analysis of the hip angle was done from the start of the STS to the minimum angle obtained during the STS. This shows how the subject's hip moved during the STS (Phase 1 to phase 2), reaching maximum hip flexion in the process.

4) Pelvic Tilt angle – The pelvic tilt angle at the start of the STS versus the end of the STS was studied, to give information on the pelvis position at these stages.

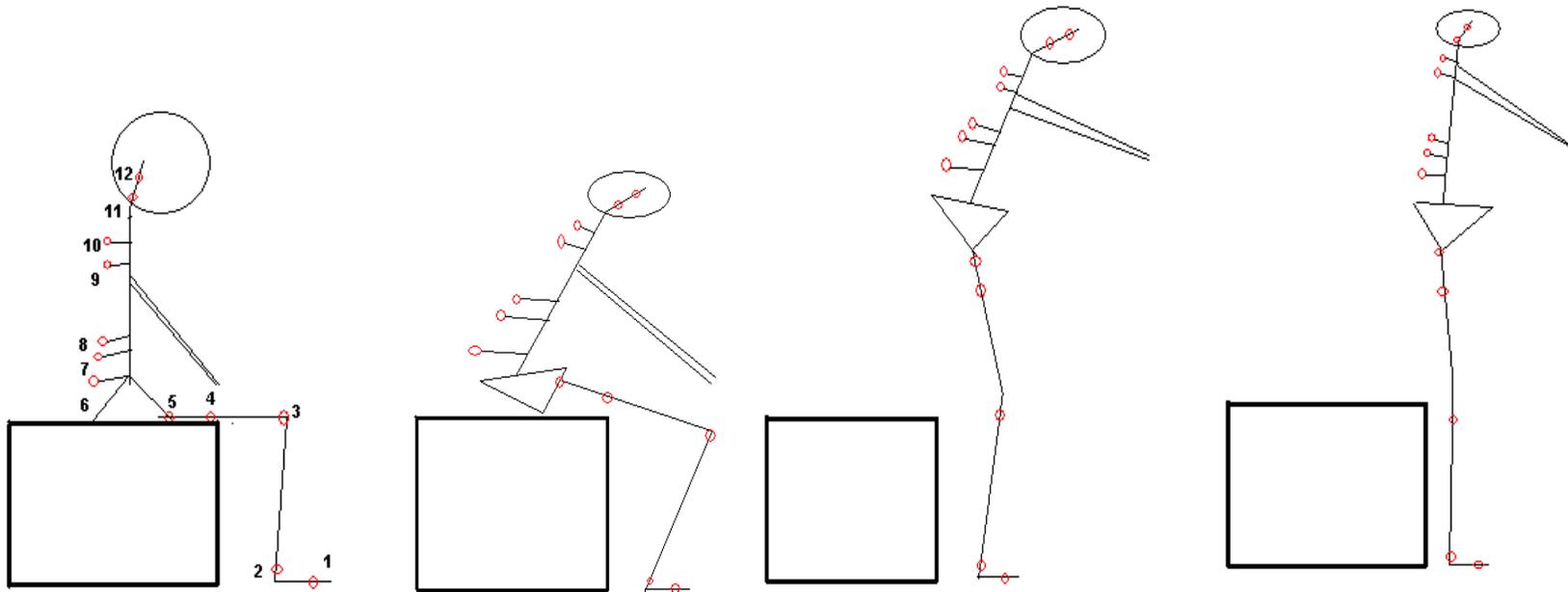
The angle at the start of the STS to the minimum angle obtained during the STS was also studied.

5) Thoracic angle – The thoracic angle at the start of the STS versus the end of the STS was studied, to give information on the thoracic posture at these stages. The angle at the start of the STS to the minimum angle obtained during the STS was also studied.

6) Lumbar angle - The lumbar angle at the start of the STS versus the end of the STS was studied, to give information on the lumbar posture at these stages. The angle at the start of the STS to the minimum angle obtained during the STS was also studied.

7) Neck angle - The neck angle at the start of the STS versus the end of the STS was studied, to give information on the neck posture at these stages. A comparison between the neck angle at the start of the STS as compared to the minimum angle during the STS was also analyzed. A comparison between the neck angle at the end of the STS as compared to the minimum angle during the STS was also analyzed.

### 3.6.3 Identification of events of the STS using Kinematics



**Figure 2:** Showing the different phases of the STS. (black circles represent IREDs position)

Numbers identify location of the IREDS

1 – Lateral aspect of 5<sup>th</sup> metatarsal

3 – Lateral aspect of knee joint

5 – ASIS

7 – L2 spinous process

9 – T1 spinous process

11 – Tragus of ear

2 – Lateral malleolus

4 – Greater trochanter

6 – Superior aspect of sacrum

8 – T12 spinous process (on same projection as 7)

10 – C7 spinous process (on same projection as 9)

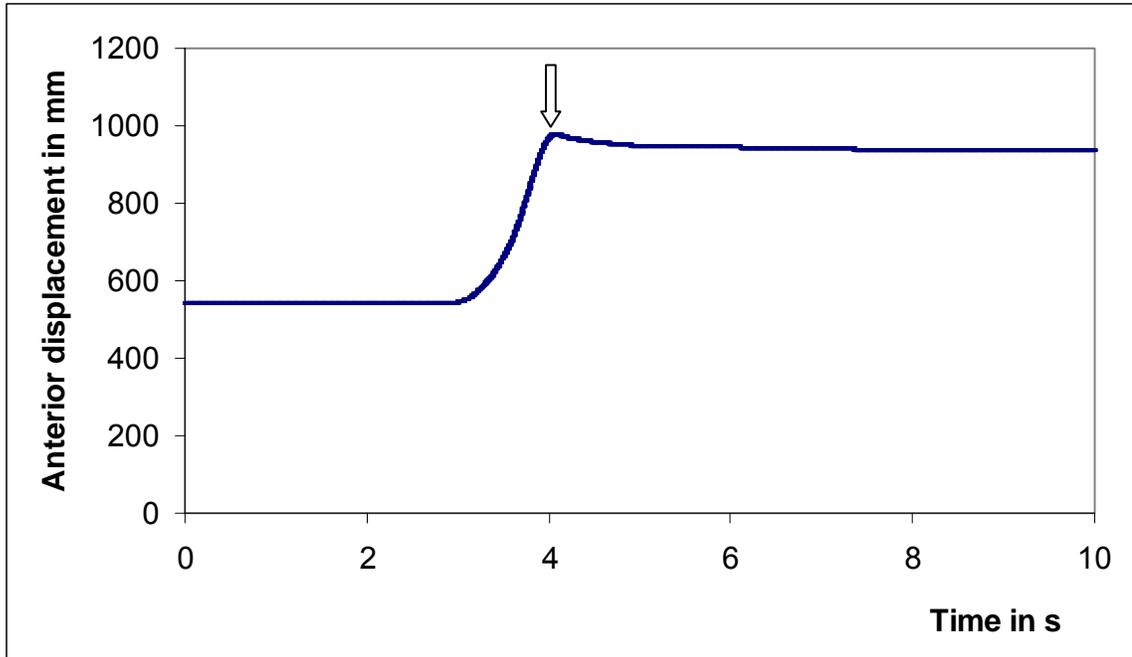
12 – Frankfort Plane\*

\* Frankfort plane - line connecting the superior border of the external auditory meatus with the infraorbital rim.

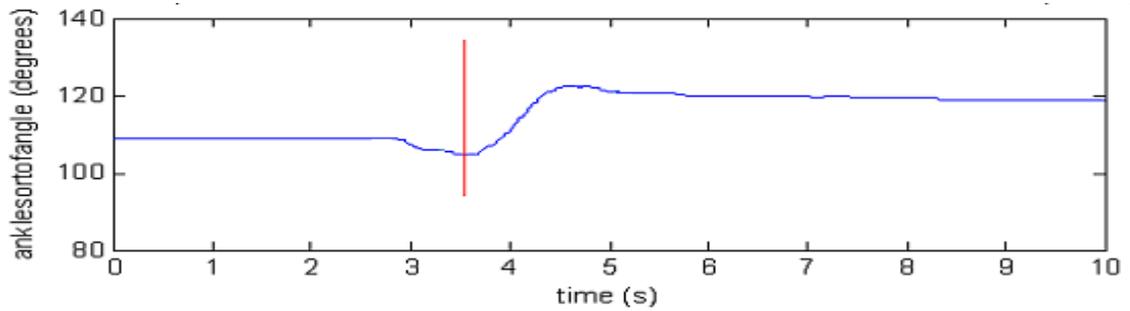
A number of events were identified that marked the start and end of the different phases of the STS. The first phase, also known as the Weight Shift Phase, was identified by the commencement of horizontal displacement of the T2 marker. This phase ended when all the seat switches were turned off, indicating completion of lift-off of the buttocks from the seat. The second phase, also known as the Transition phase, started when Phase one finished and ended when maximum dorsiflexion at the angle was achieved. Phase three, also known as the Extension Phase, started when Phase two finished, and ended when the T2 marker was maximally vertically displaced. Phase four, also known as the Stabilization Phase, started when Phase 3 finished, and ended when the GRF was oscillating within a corridor of 1.5% of body weight. There was no kinematic event for the end of Phase 4. Instead, a kinetic event was used, specifically when the ground reaction forces showed reduced oscillations (see section 3.8.1).

### **3.7 Identification of events using Kinematics**

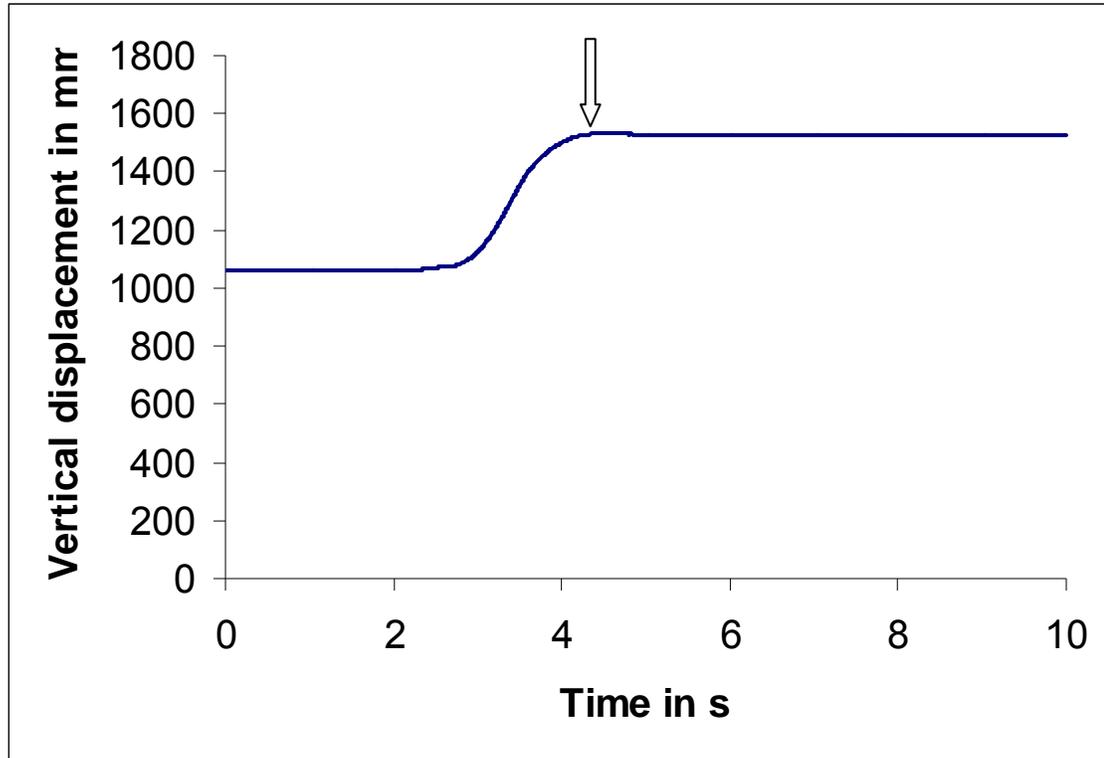
One subject from the PD group was selected to illustrate how the events were identified. This will explain how the kinematic events were identified in order to determine the phases of the STS.



**Figure 3:** Anterior T2 marker displacement in the 2<sup>nd</sup> trial during the STS in PD04. The arrow indicates maximum anterior displacement.



**Figure 4:** Ankle angle in the 2<sup>nd</sup> trial during the STS in PD04. The red line signifies the time when the minimum angle was obtained during the STS.



**Figure 5:** Vertical T2 marker displacement of the 2<sup>nd</sup> trial during the STS in PD04. The arrow indicates maximum vertical displacement.

### 3.8 Kinetics

#### 3.8.1 Analysis of the Phases of the STS using Kinetics

Vertical ground reaction forces were obtained from the two separate force plates under both feet. Force plate data were later low-pass filtered with a fourth-order Butterworth low pass zero-lag filter, with a cut-off frequency of 10Hz. The vertical ground reaction forces were then added together to calculate the forces of the body weight. From the STS trials, the vertical ground reaction force and the rate of rise in force were analyzed from the information obtained from the force plates.

**Table 1:** The 4 main phases of the STS were analyzed using Kinetics

<b><u>PHASES</u></b>	<b><u>START</u></b>	<b><u>END</u></b>
<b><u>Weight Shift</u></b>	A 3.5% decrease in GRF under feet weight	Maximum rate of changing GRF* (All seat switches indicate completion of lift-off of the buttocks from the seat)
<b><u>Transition</u></b>	Maximum rate of changing GRF* (All seat switches indicate completion of lift-off of the buttocks from the seat)	Maximum GRF*
<b><u>Extension</u></b>	Maximum GRF*	GRF* returns to near Body Weight after brief drop
<b><u>Stabilization</u></b>	GRF* returns to near Body Weight after brief drop	GRF oscillates inside a corridor of 1.5% ± body weight GRF.

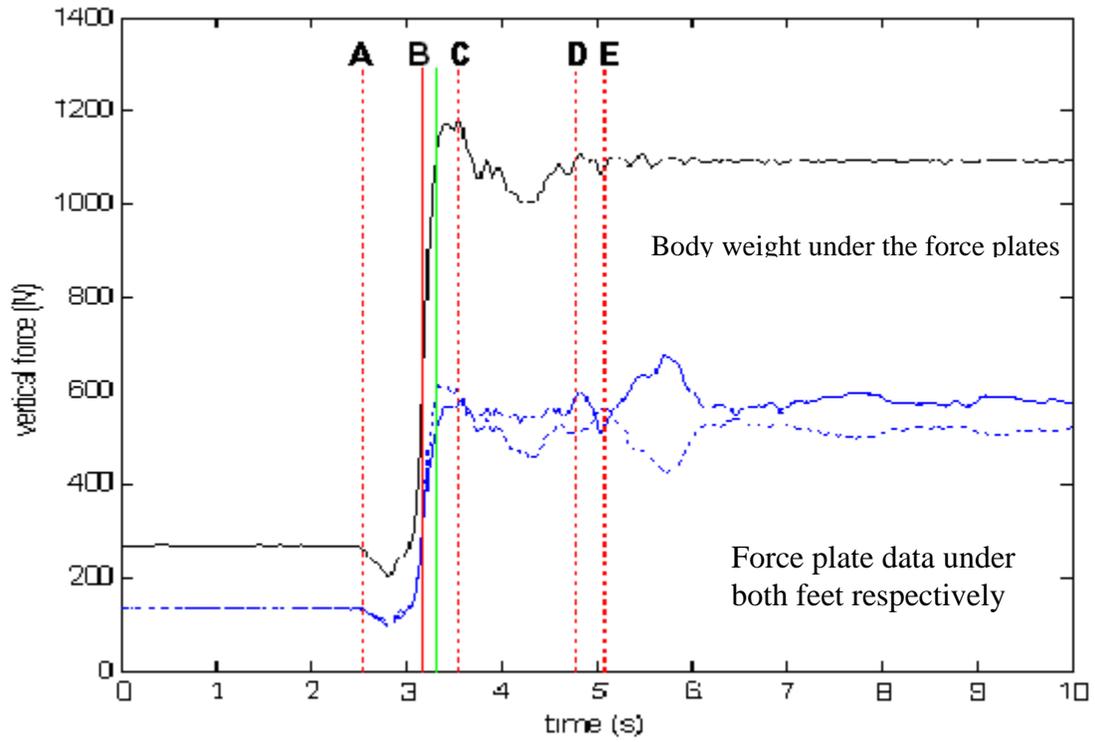
\*GRF = ground reaction force

### 3.8.2 Identification of events using Kinetics

One subject from the PD group was selected to illustrate how the events were identified (see Figure 6). This will explain how the kinetic events were identified in order to determine the phases of the STS.

The constant force during the first few seconds represents the weight of the feet on the force plates during sitting. As the subject stands up, force initially decreases. This occurred as a result of the action of the hip and trunk flexors that

initiate hip and trunk flexion. Vertical force then increases as weight is placed on the force plates on standing up. The overshoot, as seen in the graphs, corresponds to the acceleration of the body mass during rising. This value was calculated by subtracting the maximal vertical force from the body weight. The plateau in force represents the stability associated on standing up and is equivalent to the weight of the individual on the force plates.



**Figure 6:** Ground reaction forces in the 2<sup>nd</sup> trial during the STS in PD04.

This figure shows the force data under the feet as the subject stood up. The red lines signify the events demarcating the 4 different Phases of the STS, the solid red line signifies the instant when the rate or rise in GRF was maximal, whilst the solid green line signifies the instant when the seat switches are switched off (buttocks lift-off). The solid blue trace shows the forces under the right foot, whilst the blue dotted trace shows the forces under the left foot. The black trace shows the sum of the forces from both feet. The phase durations are as follows:

- Phase 1 – A to B
- Phase 2 – B to C
- Phase 3 – C to D
- Phase 4 – D to E

Events signifying the Start of Phase 1 – 3.5% decrease in GRF

Event signifying end of Phase 1 and start of Phase 2 – Max rate of rise in force

Event signifying end of Phase 2 and start of Phase 3- MAX GRF

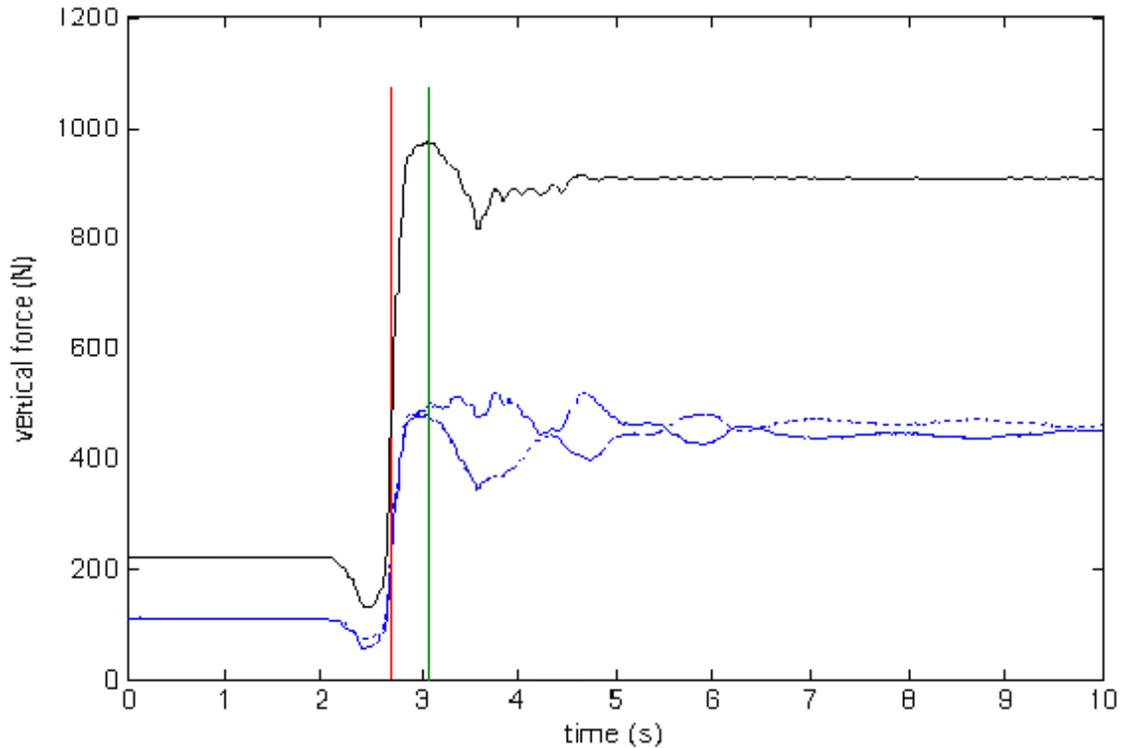
Event signifying end of Phase 3 and start of Phase 4- GRF returning to near body weight after brief drop

Event signifying end of Phase 4 - GRF oscillating within a corridor of 1.5% (Note that this event was also used to signify the termination of the Phase using Kinematic analysis)

*Note that the difference between the 4 red lines signifies the time that this subject took in each of the Phase of the STS.*

### 3.8.3 Force data analysis

The maximal rate of rise in force and the difference between the maximum GRF and the GRF corresponding to body weight – i.e., the overshoot – were analyzed and compared between the PD and the control group.



**Figure 7:** Ground reaction forces of the 5th trial during the STS in PD02.

The solid red line signifies the instant of the maximal rate of rise in force, whilst the second solid green line signifies the instant of the maximum GRF. The blue and black traces are as described in Figure 6.

### 3.9 Statistical Analysis

Mann-Whitney tests were conducted to compare demographic data between groups. Mann-Whitney tests were also used to compare the dependent variables (joint angles, GRF measures, duration of phases from the STS task measurements between groups. An alpha level of .05 was used to identify significance.

## Chapter 4: RESULTS

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### 4.1. Subjects

Fourteen subjects with idiopathic PD and fourteen subjects without PD were recruited for this study. All of them were living in the community. Ten individuals with PD were recruited from the Kingston Chapter of the Parkinson Society of Canada, whilst the 4 other PD subjects were recruited from a Movement Disorders clinic in Kingston, Canada. The control subjects were recruited by word of mouth through Queen's University and a Physiotherapy clinic in Kingston, Canada.

In each group, there were 8 men and 6 women. On average, subjects in the control group were 69 years old ( $\pm$  (Standard Deviation, SD) 8), and subjects in the PD group were 69 years old ( $\pm 7$ ). The mean height of the individuals in the control group was 1.70m ( $\pm 0.06$ ) and 1.69 m ( $\pm 0.06$ ) in the PD group. The mean weight of the individuals in the control group was 74.07 kg ( $\pm 11.79$ ) and 77.50 kg ( $\pm 19.08$ ) in the PD group. The duration of the disease in the PD group was 6.9 years ( $\pm 4$ ). The Hoehn and Yahr scale in the PD group had a mean of 2 (minimum 1, maximum 3).

The characteristics of the subjects from both the PD group and control groups, and descriptive statistics for the groups for age, height and weight, are listed in

Table 1 and 2. Codes were used instead of names, according to the order of participation. There were no significant group differences in any of the variables of age, height or weight ( $p > 0.05$ ).

**TABLE 2:** Characteristics of control subjects.

	<b>Gender</b>	<b>Age (in years)</b>	<b>Height (in m)</b>	<b>Weight* (in kgs)</b>	<b>Medication</b>
Control 1	M	61	1.83	84.54	NIL
Control 2	M	68	1.67	78.19	NIL
Control 3	F	74	1.62	71.59	NIL
Control 4	M	84	1.63	69.35	levothyroxine pramipexole† simvastatin
Control 5	M	76	1.70	78.07	levothyroxine
Control 6	F	76	1.77	101.35	levothyroxine
Control 7	M	58	1.71	72.42	levothyroxine atorvastatin
Control 8	F	66	1.64	54.46	NIL
Control 9	F	69	1.70	64.58	etidronate + calcium
Control 10	F	78	1.69	59.04	ranitidine
Control 11	M	59	1.77	78.97	etidronate + calcium Vitamins
Control 12	M	72	1.72	70.32	NIL
Control 13	F	72	1.66	65.41	NIL
Control 14	M	53	1.68	88.72	NIL
<b>Mean</b>	<b>8M/6F</b>	<b>69</b>	<b>1.70</b>	<b>74.07</b>	
<b>SD</b>		<b>8.8</b>	<b>0.06</b>	<b>12.24</b>	

Abbreviations: M=Male, F=Female, SD = Standard Deviation

\* Weight was obtained from the vertical forces reached during quiet standing, thus allowing a high degree of precision.

† Although pramipexole is an anti-parkinson drug, it is also used for Restless Leg Syndrome, which was the reason for its use by Control subject #4.

**TABLE 3:** Characteristics of subjects with Parkinson's Disease

Name	Gender	AGE (yrs)	Height (m)	WEIGHT (kg) <sup>a</sup>	Duration of disease (yrs)	Anti- Parkinson medication		Hoehn And Yahr Scale	Other medication
						Levodopa <sup>b</sup>	Requip <sup>c</sup>		
PD 1	M	76	1.78	80.10	1	NIL	NIL	2	lorazepam, tamsulosin
PD 2	M	81	1.79	93.13	10	100 mg	18 mg	3	NIL
PD 3	F	73	1.74	80.39	4	500 mg	0.5 mg	1	NIL
PD 4	M	63	1.74	111.5	7	NIL	NIL	1	NIL
PD 5	M	53	1.73	70.70	12	400 mg		3	ASA
PD 6	M	68	1.69	74.03	4	500 mg	9 mg	2	ASA, diclofenac, rosuvastatin, irbesartan
PD 7	M	70	1.70	81.80	2		9 mg	3	NIL
PD 8	M	69	1.70	81.80	10	300 mg	3 mg	1	domperidone, lorazepam
PD 9 <sup>d</sup>	F	74	1.63	56.00	10	200 mg	8 mg	3	NIL
PD 10	F	61	1.63	73.21	5	100 mg	21 mg	3	NIL
PD 11	F	73	1.61	54.89	3	350mg	NIL	2	ASA, domperidone
PD 12	M	68	1.68	117.2	10	100 mg		3	NIL
PD 13	F	72	1.66	56.55	4	100 mg		1	estrogen, docusate
PD 14	F	62	1.59	53.57	1	100 mg		1	acetaminophen, alendronate
<b>MEAN</b>		<b>68.8</b>	<b>1.69</b>	<b>77.5</b>	<b>6.9</b>			<b>2</b>	
<b>SD</b>		<b>7.2</b>	<b>0.06</b>	<b>19.8</b>	<b>3.8</b>				

Abbreviations: M=Male, F=Female, SD = Standard Deviation, PD = Parkinson's Disease, ASA = acetylsalicylic acid

<sup>a</sup> Weight was obtained from the vertical forces reached during quiet standing, thus allowing a high degree of precision.

<sup>b</sup> Quantities of levodopa are listed in total daily doses of levodopa in any form. All forms of levodopa taken by the subjects included a carbidopa component in the medication. <sup>c</sup> Requip® is the trade name for ropinirole hydrochloride, a dopaminergic agonist. No subjects took any other dopaminergic agonists. <sup>d</sup> PD 9 was exhibiting dyskinesia.

All 28 subjects were able to complete all trials as described in section 3.4. Using the algorithms described in section 3.6, kinematic and kinetic measures were obtained for all trials.

## **4.2 Kinematic Analysis**

### **4.2.1 Timing of the Phases using Kinematic events**

Although the timing of kinematic events, as defined in section 3.7, could be obtained from every trial, the sequence of these events did not always follow the sequence that was anticipated based on the literature review. Examples of unexpected order of events can be found in Table 4 showing the timing of events for PD subject #4 across all 10 trials. In Trial 1, the subject's T2 marker reached its maximum vertical value more than 3 seconds after his GRF had stabilized. The same unexpected order occurred in Trials 3 and 10. Also in Trial 1, the subject's ankle reached maximum dorsiflexion before the seat switches indicated that the subject's buttocks had left the seat. The same unexpected order occurred in Trials 2, 9 and 10. In Trial 5, by contrast, the subject's ankle reached maximum dorsiflexion after his T2 marker reached its maximum vertical value. In Trials 4 and 5, the seat switches indicated the subject's buttocks had left the seat before his T2 marker showed anterior displacement. The sequence of events from Trial 5 is shown graphically in Figure 8. Thus, only three of the 10 STS trials from this subject showed the expected sequencing of kinematic events that would

have made phase duration calculable. For one of these trials (trial #6) the sequence of events is shown in Figure 8.

**Table 4:** Kinematic events from Sit-to-Stand trials in Parkinson’s disease subject #4

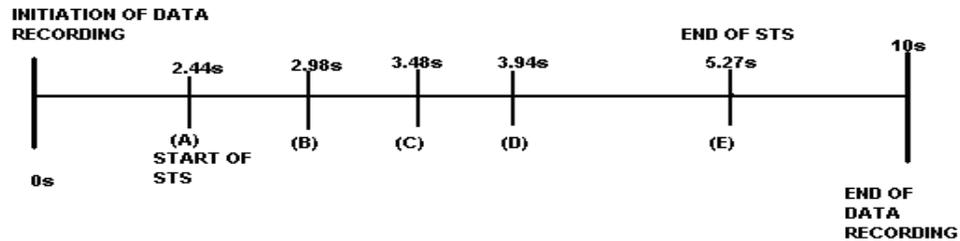
<b>TRIALS</b>	<b>T2 starts to move anteriorly</b>	<b>Seat switches off</b>	<b>Maximum ankle dorsiflexion</b>	<b>T2 max vertical</b>	<b>GRF* stabilizes</b>
1	2.33	3.65	2.98	7.68	3.97
2	2.42	3.30	3.19	4.70	4.69
3	2.48	3.06	3.34	5.62	4.40
4	3.39	3.03	4.39	4.29	5.32
5	4.09	3.00	4.81	4.11	5.86
6	2.44	2.98	3.48	3.94	5.27
7	2.72	3.02	3.55	4.23	5.08
8	1.22	3.17	3.19	4.30	4.54
9	1.59	4.22	3.24	5.29	5.13
10	2.34	4.61	3.14	5.70	4.97

**\*GRF = Ground reaction force**

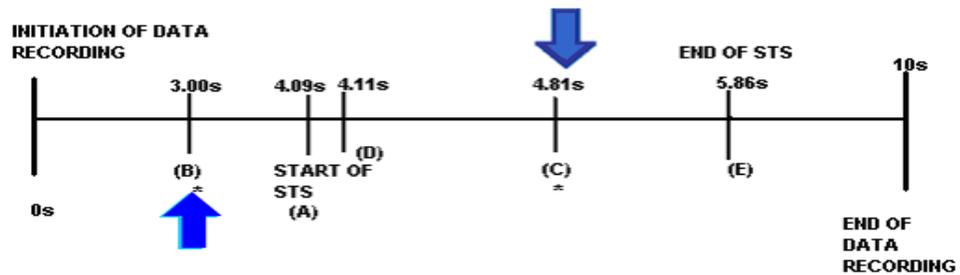
All values are in seconds, calculated from the start of the trial.

**Figure 8: Events identifying the STS using Kinematics**

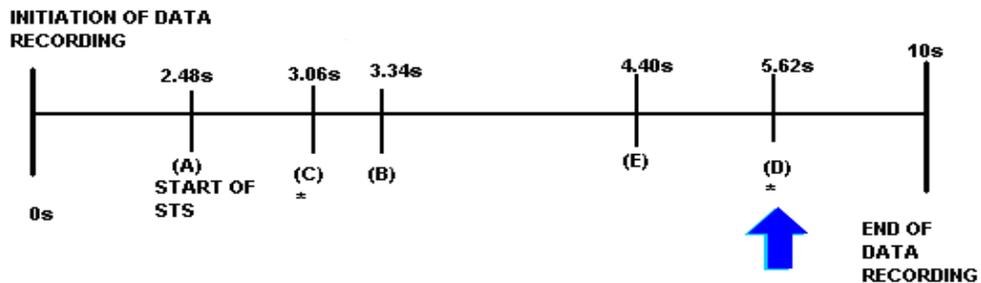
- A) Start of Movement of T2 marker anteriorly
- B) Seat Switches off
- C) Maximum ankle dorsiflexion reached
- D) Maximum vertical displacement of the T2 marker
- E) Ground Reaction Force Stabilization



**Figure 8(i): Timing of phases using kinematic events in Trial number 6 in PD subject #4.**



**Figure 8(ii): Timing of phases using kinematic events in Trial number 5 in PD subject #4**



**Figure 8(iii): Timing of phases using kinematic events in Trial number 3 in PD subject #4**

Similar sequencing anomalies occurred in at least one trial from all PD subjects and also occurred in trials from some control subjects. This problem was initially noted using previous versions of the algorithms. The algorithms were then slightly modified to try to reduce the anomalies identified. The explanation of the algorithms in section 3.7 reflects the final version of these algorithms, and the values in the table (Table 4) were calculated from the final version. These unexpected sequences of events occurred within subjects in both groups. From the 28 subjects tested (14 individuals in each group), and after studying the 10 trials in every group (280 trials), there were 176 trials which had unexpected sequencing in the kinematic events that signify the phases of the STS.

At the same time, it was noted that the algorithms to identify kinetic events (forthcoming section 4.4) were much more satisfactory and phase durations could therefore be calculated. We therefore did not make additional attempts to modify the algorithms for identifying kinematic events for the purpose of studying phase durations.

### **4.3 Joint angles**

The excursions and range of movements of sagittal ankle, knee, hip, pelvic tilt, lumbar, thoracic, neck and head movements during the STS are shown in Table 5.

The *Start angle position* was defined as the average angle of the respective joint when the subject was sitting down, and was calculated based on the first one second of data. The angular excursion from the start of the STS to the minimum angle obtained during the STS was also calculated. The minimum angle was obtained at the end of Phase one, when the subject was maximally flexed forward, and prior to seat lift-off. The angular excursion from the *start* of the STS to the angle obtained at the *end* of the STS was also calculated. The *end angle* was defined as the angle of the respective joint when the subject was standing fully erect, and was calculated at the end of the STS.

1) Ankle – There was no significant difference between the control and the PD groups in mean angular position at the start of the STS (U=110.5; p=0.57). There was no significant difference between the control and the PD groups in the mean angle obtained from the start of the STS to the minimum angle obtained during the STS (U=122; p=0.29). There was no significant difference between the control and the PD groups in the mean angular position at the end of the STS (U=110.5; p=0.57)

2) Knee angle –There was no significant difference between the control and the PD groups in mean angular excursion at the start of the STS (U=138; p=0.07). The mean knee angular position obtained at the end of the STS was full extension as the client was fully erect at the end of the STS.

3) Hip angle – There was no significant difference between the control and the PD groups in mean angular position at the start of the STS (U=118; p=0.35). There was no significant difference between the control and the PD groups in the mean angle obtained from the start of the STS to the minimum angle obtained during the STS (U=108; p=0.67). The mean hip angular position obtained at the end of the STS was full extension as the subject was standing fully erect at the end of the STS.

4) Pelvic Tilt angle – There was no significant difference between the control and the PD groups in the mean angular position at the start of the STS (U=123; p=0.25). There was no significant difference between the control and the PD groups in the mean angles obtained from the Start of the STS to the minimum angular excursion obtained during the STS (U=122.5; p=0.13). There was no significant difference between the control and the PD groups in mean angular position at the end of the STS (U=107; p=0.68). There was no significant difference between the control and the PD groups in the mean angular excursion obtained from the start of the STS to the angle obtained at the end of the STS (U=123; p=0.26).

5) Lumbar angle – There was no significant difference between the control and the PD groups in mean angular position at the start of the STS (U=179; p=0.14). There was a significant difference between the control and the PD groups in the mean angular excursion obtained from the Start of the STS to the

minimum angle obtained during the STS (U=146; p=0.027). There was no significant difference between the control and the PD groups in mean angular position at the end of the STS (U=122; p=0.27). There was no significant difference between the control and the PD groups in the mean angular excursion obtained from the start of the STS to the angle obtained at the end of the STS (U=132; p=0.13).

6) Thoracic Angle – There was no significant difference between the control and the PD groups in mean angular position at the start of the STS (U=138; p=0.069). There was no significant difference between the control and the PD groups in the mean angular excursion obtained from the start of the STS to the minimum angle obtained during the STS (U=117; p=0.40). There was a significant difference between the control and the PD groups in mean angular position at the end of the STS (U=163; p=0.002). There was no significant difference between the control and the PD groups in the mean angular excursion obtained from the start of the STS to the angle obtained at the end of the STS (U=131; p=0.14).

7) Neck angle – There was no significant difference between the control and the PD groups in mean angular position at the start of the STS (U=138; p=0.069). There was no significant difference between the control and the PD groups in the mean angular excursion obtained from the Start of the STS to the minimum angle obtained during the STS (U=107; p=0.7). There was no significant difference

between the control and the PD groups in mean angular position at the end of the STS (U=135.5; p=0.08). There was no significant difference between the control and the PD groups in the mean angular excursion obtained from the start of the STS to the angle obtained at the end of the STS (U=129; p=0.16).

**Table 5:** Joint angles during the Sit-To-Stand in the control and Parkinson's disease group

Angles	Controls		PD	
Ankle position (at start)	101.2°	(5.4°)	103.5°	(7.5°)
Ankle excursion (start – minimum)	20.9°	(3.8°)	15.2°	(20.4°)
Knee position (at start)	104.6°	(5.9°)	98.5°	(24.5°)
Hip position (at start)	120.2°	(13.7°)	129.8°	(17.5°)
Hip excursion (start – minimum)	17.5°	(10.2°)	20.1°	(9.8°)
Pelvic tilt position (at start)	-11.4°	(7.9°)	-14.8°	(4.6°)
Pelvic tilt excursion (start – minimum)	- 5.0°	(5.3°)	1.2°	(1.8°)
Pelvic tilt position (at end)	-5.4°	(9.3°)	-3.4°	(9.1°)
Pelvic tilt excursion (start – end)	6.0°	(7.3°)	11.5°	(7.7°)
Lumbar angle position (at start)	96.5°	(7.6°)	97.5°	(7.6°)
Lumbar angle position (at end)	106.4°	(12.4°)	100.5°	(12.4°)
Lumbar angle excursion (start – end)*	9.9°	(10.4°)	3.0°	(10.4°)
Lumbar angle excursion (start – minimum)	29.4°	(13.0°)	35.4°	(13.0°)
Thoracic angle position (at start)	51.2°	(2.3°)	45.5°	(8.4°)
Thoracic angle position (at end)*	61.0°	(8.3°)	50.9°	(7.9°)
Thoracic angle excursion (start – end)	16.0°	(7.0°)	4.4°	(6.7°)
Thoracic angle excursion (start – minimum)	17.0°	(8.9°)	17.2°	(12.0°)
Neck angle position (at start)	12.2°	(3.2°)	6.8	(11.3°)
Neck angle position (at end)	14.1°	(10.2°)	6.9°	(13.0°)
Neck angle excursion (start – end)	-1.2°	(5.8°)	-2°	(6.2°)
Neck angle excursion (start – minimum)	8.5°	(9.2°)	9.3°	(8.0°)

\* indicates significant difference between the 2 groups

All values represent mean (standard deviation) from all subjects in each group.

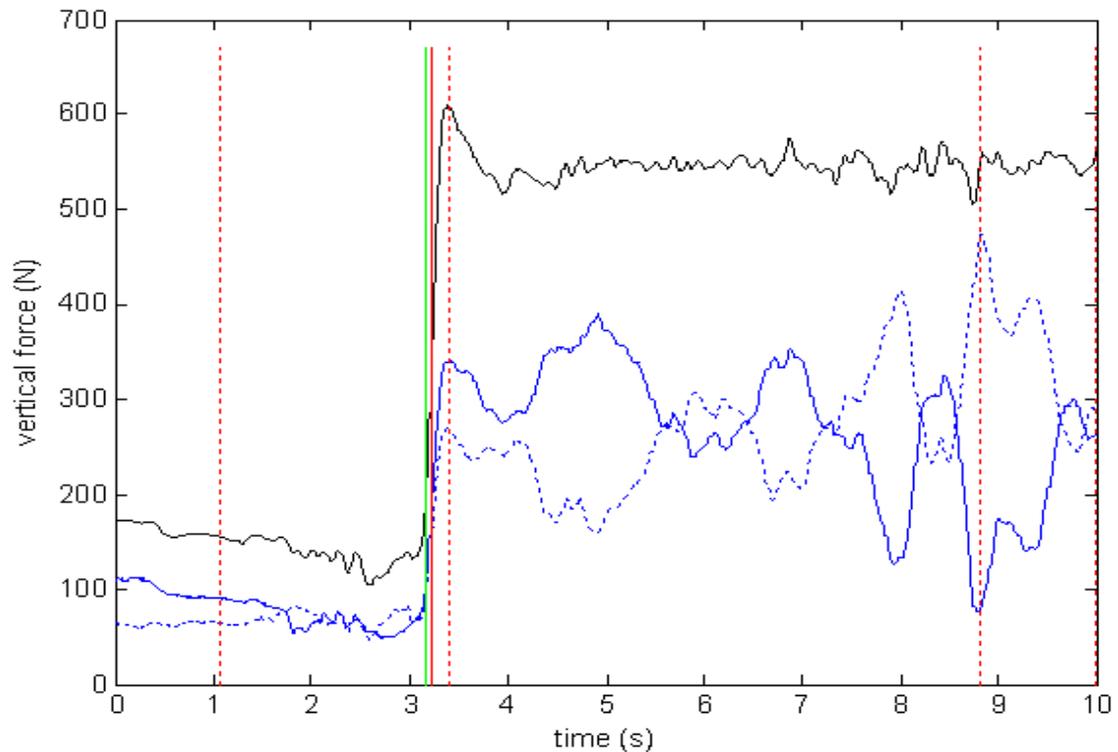
## **4.4 Kinetic Analysis**

### **4.4.1 General findings**

The algorithm worked successfully in 13 of the 14 PD subjects (one PD subject had dyskinesia – see Section 4.4.2), and for all the 14 controls. The events which identified the phases of the STS occurred in the expected sequence in the STS, and thus allowed an accurate analysis of the time duration of every phase of the STS. The phase durations were calculated as described in Section 3.8.2 (Methods).

### **4.4.2 Subject exhibiting Dyskinesia**

As seen in figure 9, the events identifying Phases 1 and 3 were not identified properly by the algorithms due to the fluctuations under the feet presumably due to the dyskinesia. Furthermore, the subject never stabilized at the end of the STS as observed in the figure. The data from this subject was not included in the group averages.



**Figure 9:** Ground reaction force in the 1<sup>st</sup> trial during the STS in PD09. The fluctuation in forces as a result of the dyskinesia can be seen. Please See Methods Section 3.8.2 and Figure 6 for explanation of colored lines).

#### 4.5 Timing of the phases using Kinetics

The mean time of the total STS transfer was 2.61s ( $\pm 0.5$ ) in the PD group and 1.89s ( $\pm 0.33$ ) for the control group. There was a significant difference between the two groups ( $U= 155, p=0.001$ ). The greater length of time in individuals with PD was reflected in all phases of the STS. In PD individuals, Phase one lasted a mean of 0.77s ( $\pm 0.37$ ) or 28.6% of the total movement, whilst in the control group, Phase one lasted a mean of 0.55s ( $\pm 0.13$ ) or 30.6% of the total movement. There was a significant difference between the two groups ( $U= 144, p=0.009$ ). In the PD group, Phase two lasted a mean of 0.26s ( $\pm 0.09$ ) or 10% of

the total movement whilst in the control group, Phase two lasted a mean of 0.21s ( $\pm 0.05$ ) or 11.3% of the total movement. There was a significant difference between the two groups ( $U= 142$ ,  $p=0.044$ ). In the PD group, Phase three lasted a mean of 1.14s ( $\pm 0.86$ ) or 47.8% of the total movement. In the control group, Phase three lasted a mean of 0.86s ( $\pm 0.26$ ) or 50% of the total movement. There was a significant difference between the two groups ( $U=194$ ,  $p<0.00001$ ). In the PD group, Phase four lasted a mean of 0.44s ( $\pm 0.3$ ) or 13.6% of the total movement. In the control group, Phase four lasted a mean of 0.27s ( $\pm 0.15$ ) or 8.1% of the total movement. There was a significant difference between the two groups ( $U= 173$ ,  $p<0.00001$ ).

**Table 6:** Duration of each phase during the Sit-To-Stand determined by kinetic events

<b>Mean (SD)</b>	<b>Phase 1 Duration (s)</b>	<b>Phase 2 Duration (s)</b>	<b>Phase 3 Duration (s)</b>	<b>Phase 4 Duration (s)</b>	<b>Total Duration (s)</b>
<b>PD N=13</b>	0.77 ( $\pm 0.37$ )	0.26 ( $\pm 0.09$ )	1.14 ( $\pm 0.86$ )	0.44 ( $\pm 0.30$ )	2.61 ( $\pm 0.50$ )
<b>Control N=14</b>	0.55 ( $\pm 0.13$ )	0.21 ( $\pm 0.05$ )	0.86 ( $\pm 0.26$ )	0.27 ( $\pm 0.15$ )	1.89 ( $\pm 0.33$ )
<b>p-value</b>	$p=0.009^*$	$p=0.044^*$	$p<0.00001^*$	$p<0.00001^*$	$p=0.001^*$

Values are means  $\pm$ SD for duration of phases with the total Sit-to-Stand time in seconds. (\*) represent significant different values between individuals with PD and control groups at  $p < 0.05$ .

#### 4.6 Force data

The peak rate of rise in force is the event that demarcates the end of Phase one and the beginning of Phase two and is measured in N/s. The mean peak rate of rise in force in the control group was 5528.5N/s compared to a mean peak rate of 3496.5N/s in the PD group. These values were significantly different (U= 173, p=0.00027).

The mean overshoot of force (See Methods Section 3.8.2) in the PD group was also significantly different (U = 172, p=0.00034). The mean overshoot of force in the control group was 123.4N compared to the 81.3N in the PD group.

**Table 7:** Measures based on ground reaction forces during the STS

<b>Subjects</b>	<b>Rate of rise in force (N/s)</b>	<b>Overshoot (N)</b>
<b>Control</b>	5528.5 ( $\pm$ 1254.7)	123.4 ( $\pm$ 23.9)
<b>PD</b>	3496.5 ( $\pm$ 1148.8)	81.3 ( $\pm$ 27.0)
<b>p-value</b>	p=0.00027*	p=0.00034*

Values are means  $\pm$ SD for forces. (\*) represent significant different values between individuals with PD and control groups at p < 0.05.

## Chapter 5: Discussion

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### 5.1 Summary of findings of the study

In this study, biomechanical features of the STS transfer in individuals with PD were compared to those of age-matched controls. In general, individuals with PD in the present study showed a number of significant differences as compared to the healthy controls in the pattern and speed of the STS. The first hypothesis was that individuals with PD would take longer to complete the STS. This hypothesis was supported because all individuals with PD took longer than age-matched controls in the 4 phases of the STS. The second hypothesis was that there would be a difference in the ground reaction forces (GRF) between individuals with PD and controls (greatest instantaneous GRF rise, difference between peak GRF and body weight). This hypothesis was also supported as individuals with PD exhibited lower mean forces and lower mean rate of rise in force than control subjects. A few differences in kinematic patterns were also observed between the two groups. These differences imply that individuals with PD use different strategies than age-matched controls during the STS. To our knowledge, this is the first study that has studied the events signifying the phases of the STS in people with PD. No previous studies have analyzed the Stabilization or Phase 4 of the STS in individuals with PD.

## **5.2 Total STS time finding in comparison to other studies**

The mean time taken to complete the STS transfer for subjects with PD in the present study was 2.61s as compared to a mean of 1.89s in the control group. This represents a mean of 51.3% greater time in individuals with PD. To our knowledge, only four other studies have reported a total time for a STS in individuals with PD. Mak and Hui-Chan (2005) have reported a mean time of 2.86s for completion of the STS at natural speed by their subjects with PD, which was approximately 50% longer than the mean STS time of their control subjects. These findings, both in absolute values and in proportional group differences, are very similar to those of our study.

In contrast, our findings and those of Mak & Hui-Chan (2005) for total STS time are not similar to the findings of the other three studies. Inkster et al (2003) have reported a mean time of 1.86s in 10 subjects with PD (ON-medication) and a mean time of 1.97 in the same individuals with PD during their OFF-medication state. Control subjects' mean STS time was 1.89 s. The lower STS time observed by Inkster et al. (2003) can be attributed to a number of reasons. The individuals with PD had a mean duration of disease of 4.4 years which was lower than the subjects with PD in our study (mean of 6.9 years). Also, the mean ages of their PD and control groups were about 5 years younger than the mean ages of our groups. However, the most likely reason for the difference lies in the difference in measuring the STS. These authors defined the start of the STS as the initial

change in horizontal force beyond a baseline level under the buttock. The end of the STS was defined as the point in time when the vertical movement of the ear marker reached a plateau. These authors did not divide the STS in phases. Although their start point of STS likely occurs close to our start of phase 1, their end point of STS is likely within phase 3 of our framework.

The third study is by Ramsey et al. (2004) in which they reported a mean time of 4.18s for the STS in individuals with PD and a mean of 3.79s in control subjects. There was no statistically significant difference. Although they describe the seat in detail, including height in millimetres, and they describe their kinematic and kinetic measuring equipment in detail, they do not describe what events they used to denote the start and end of the STS.

The fourth study is by Bishop et al (2005) who studied only individuals with PD and no control subjects. They reported a mean STS time of just 0.807 s, much lower than any of the other studies. Similar to what was discussed above in relation to the findings by Inkster et al (2003), the individuals with PD were slightly younger and with lower disease duration than the subjects in the current study, but the principal reason for the difference lies in how STS was measured. Bishop et al (2005) considered the STS to be complete when the vertical force reached a maximum rather than when it stabilized.

### 5.2.1 Possible explanation of PD underlying the findings

The individuals with PD in the present study took longer than age-matched controls to finish the STS, in keeping with one of our initial hypotheses. This suggests that bradykinesia might be the reason why these individuals are slower during the different phases of the STS transfer. This finding is unsurprising because bradykinesia is a fundamental part of the clinical presentation of PD. The term bradykinesia dates back to the time James Parkinson first described the cardinal features of the disease. Bradykinesia is often used interchangeably with akinesia and hypokinesia but definition of the terms are required because many agree that they are slightly different. Bradykinesia usually describes the slowness of a performed movement whereas akinesia refers to a poverty of spontaneous movement (e.g. in facial expression) or associated movement (e.g. arm swing during walking). Freezing and problems with initiating a task are other examples of akinesia (Berardelli et al. 2001). Hypokinesia refers more to the size of movement in a particular task (e.g. diminished handwriting amplitude known as micrographia). These characteristics affect the daily activities of the individual with PD.

### **5.3 Phases 1 and 2: Weight-shift, flexion, push-off and transition into extension**

#### 5.3.1 Key findings in this study in relation to other studies

Phase 1 lasted a mean time of 0.77s in the PD group, about 40% slower than the mean time of 0.55s in the control group and this difference was statistically significant. This phase started when there was a 3.5% decrease in ground reaction forces under the feet and ended when the maximum rate of rise in force was present. Bishop et al. (2005) also used kinetic analysis (specifically the analysis of ground reaction forces), to study Phase 1 in 41 individuals with PD. They divided the individuals with PD into 2 groups. Individuals with mean total STS times equal to or less than half a standard deviation below the mean of all 41 subjects were placed in one group (Group A), whilst those individuals with a mean time equal to or greater than half a standard deviation above the mean of all 41 subjects were placed in a separate group (Group B). Subjects in group A had a mean age of 66.1 years, a mean duration of disease of 4.8 years and a mean Hoehn and Yahr Scale rating of 2. Subjects in group B had a longer mean duration of disease (7.4 years), a higher mean Hoehn and Yahr Scale rating (2.5) and a higher mean age (66.5 years), although the authors do not specify if the aforementioned group differences are statistically significant. In contrast to our study, Bishop et al. (2005) defined Phase 1 using horizontal ground reaction forces. Movement onset was defined as the first detectable shift in force plate

activity whilst the termination of Phase 1 was defined by the peak anterior/posterior ground reaction force. Bishop and colleagues found that individuals with PD (Group A) took 0.34s to complete this phase. Individuals in group B took a mean of 0.66s to complete Phase 1. There have been no other studies that have analyzed the Phase 1 of the STS in PD individuals.

In the present study, phase 2 lasted a mean time of 0.26s in the PD group, about 24% slower than the mean time of 0.21s in the control group. As in the findings for phase 1, this difference was statistically significant. Phase 2 started when the maximum rate of rise in force occurred and ended when the maximum ground reaction force was reached. Bishop et al. (2005) also used kinetic measures to analyze Phase 2 of the STS. They described the start of Phase 2 as being when the peak anterior/posterior ground reaction force was reached and the end as being when maximum vertical ground reaction force was reached. These authors found that the less disabled individuals with PD took 0.30s to complete this phase (their Group A) whilst in, individuals with more severe PD (their Group B) took a mean of 0.39s to complete the phase 2 of the STS. There have been no other studies that have analyzed the Phase 2 of the STS in PD individuals.

### 5.3.2 Features of PD underlying the findings

Berardelli et al. (2001) have shown that slowness of movement in individuals with PD might occur as a result of problems in recruiting an appropriate level of muscle force fast enough. In phase 2, the hip and knee extensors are activated

to push the buttocks off the seat and start the upward movement of the centre of mass. Individuals with PD have been shown to have difficulty in activating muscles rapidly. In our study, individuals with PD exhibited a lower rate of rise in ground reaction force than the control group, which was statistically significant. In broad terms, this finding is consistent with that of Mak et al. (1997) who found that the rate of torque build-up across lower limb joints was significantly lower in the PD group when compared to age-matched controls. Hip flexion, hip extension, knee extension and ankle dorsiflexion rate of torque build-up were all lower in individuals with PD when compared to age-matched controls. Mak and Hui-Chan (2005) published additional observations, again reporting that the peak hip flexion torque was lower in individuals with PD and also that time to peak in the hip and knee extension torques was significantly longer in individuals with PD than age-matched controls. Inkster et al. (2003) also found that hip extensor and knee extensor torques were lower in individuals with PD as compared to age-matched controls. This has important implications as it suggests that individuals with PD have problems in the Transition phase (Phase 2) of the STS. As the disease progresses, maximum voluntary contraction takes longer to be achieved in people with PD as compared with muscle contraction in healthy individuals (Corcos et al. 1996). Using EMG studies, Hallett and Khoshbin (1980) pointed out that the first agonist bursts of a particular action are usually very small in individuals with PD. These authors went on to explain how individuals with PD tend to add further EMG bursts to the pattern, in order to successfully complete the required task. Benecke et al. (1986) found that individuals with PD exhibited a

longer pause between one task and another. This is in line with a study by Bennett et al. (1995) who found that prolonged pauses were present in everyday movements in individuals with PD. Although these studies are not directly related to the STS, it is important to note that the above examples are tasks that an individual performs daily and all show reduced amount and/or rate of build-up of force.

Individuals with PD might rely more on the use of their hip and knee extensors and use less force (and motion) from their lower back to push into the second phase of the STS. This is in line with the aforementioned study by Mak et al. (2003) showing that individuals with PD tend to exhibit a lower net peak hip flexion torque than age-matched controls. Reduced hip flexor torque will ultimately increase the magnitude of the extensor moment that must be generated from the quadriceps if the STS task is to be successfully achieved, and this makes the task more difficult. Nikfekar et al. (2002) have also shown that individuals with PD have difficulty in recruiting quadriceps muscular activity as compared to age-matched controls. They are less able to overcome the flexion moment generated by the body weight during Phase 1 of the STS. Thus, they tend to flex their trunk and hips forward so that the centre of mass will approach the base of support, reducing the sagittal moment arm.

Jordan et al. (1992) showed that rate of rise in force was longer in individuals with PD, using computerized determinants of latency of response and rate of force

generation and release. The peak rate of rise in force was significantly different between the individuals with PD and the healthy controls. This is consistent with our study, as we found that individuals with PD had a lower mean rate of rise in force as compared to age-matched controls. Other authors have studied the relationship between strength and how it relates to problems of daily living. Gehlsen and Whaley (1990) have established a relationship between leg strength and falls in older adults. A lower rate of rise in force may relate to a decrease in leg muscle strength. Fleming et al. (1991) were in agreement, and reported that fallers had a significantly lower rate of rise in force. In fact, Cheng et al. (1998) found that individuals who had had a stroke and had experienced a fall had a significantly lower rate of rise in force than individuals who had had a stroke but had never experienced a fall. This has important implications in individuals with PD. Falls are common in this population, and strength is an objective measure that needs to be studied in depth in these individuals. Hughes et al. (1996) showed that strength is one of the most important limiting factors that affect the ability to rise from a chair. Knee extension strength is the most important and knee extension moment increases as seat height decreases (Rodosky et al. 1989). From a clinical standpoint, strength can be modifiable. Buchner and DeLateur (1991) have shown a 5-20% increase in strength when healthy elderly adults underwent a strength-training programme. One must also keep in mind that although strength plays a major role, balance, coordination and postural stability are also important.

The issue of force production in PD has also been studied extensively, primarily in upper limb muscles. Nevertheless, the effect of PD acts similarly on different muscle groups in the body. A number of objective measures have been used to compare healthy control subjects with individuals with PD. Homann et al. (2003) have used tapping tasks whilst Corcos et al. (1996) have used isometric measures to study the motor symptoms in PD. Both found a reduction in forces produced in individuals with PD. A number of reasons might explain why individuals with PD exhibit a reduction in force. Brown et al. (1997) and Brown (2000) have shown that tremor might impose a limitation on the ability to completely fuse a muscle contraction. Stelmach and Worringham (1988) suggested that the basal ganglia play an important role in the co-regulation of time and force. Sheridan et al. (1987) explained that the amplitude of movement and the magnitude of muscle forces might not be necessarily underscaled in individuals with PD, but more variable, this occurring as a result of the inability of produce force in a consistent manner over time. The slowness of movement, and the reliance on visual observation, are ways in which individuals with PD would adapt to overcome these problems in muscle forces. Thus, force magnitude and movement amplitude have to be studied together. Stelmach and Worringham (1988) showed that both isometric and isotonic movements are affected by bradykinesia. Pope et al. (2006) showed that force accuracy is also compromised in the individuals with PD. The noisy output of the basal ganglia to the motor cortical structures might cause the greater variability of movement seen in individuals with PD (Marsden and Obeso, 1994). Nogaki et al. (2001) studied 10

individuals with PD and tested isokinetic muscle strength of the quadriceps and hamstrings musculature. They found that muscle weakness was dependent on movement velocity. However, this is not in agreement with Koller and Kase (1986) who found no difference in muscle strength between healthy controls and individuals with PD. However, the latter authors tested isometric strength, and thus, this type of testing might not be sensitive enough to detect reduced power. The effect of isokinetic strength testing is interesting, because, bradykinesia might affect the timing and the generation of forces. Reduced power might be a result of the reduced speed, whilst reduced speed might be a result of the bradykinesia, this showing an inter-relationship among these concepts.

With regard to kinematic features, in our study during Phase 1, there was a statistically significant difference in the lumbar angle excursion (mean of 29.4° in individuals with PD versus a mean of 35.4° in the control group). This means that during Phase 1, the individuals with PD were exhibiting less movement in the lumbar spine (less lordosis or flattening of the lumbar spine) as compared to the control subjects. This might be explained by the stiffness in individuals with PD which is linked with rigidity that is one of the cardinal features of this disease. All this would ultimately lead to the characteristic feature of hypokinesia. The effect of rigidity on a task such as the STS transfer plays an important role because the stiffness present in muscles would affect the ability to perform the task in an efficient manner. Berardelli et al. (1983) have described rigidity as an increase in resistance to muscle stretch irrespective of the direction or rate of stretch.

Research on rigidity in PD has mainly focused on single joint, uni-directional upper limb movements (Abbruzzese et al. 1985) and found an increase in muscle stiffness in these individuals. Although rigidity is thus well documented in single joint movements, the application of these ideas to a whole body task like the STS is complex. Phase 1 of the STS usually requires greater coordination than the other phases and thus muscle stiffness in the trunk can cause greater difficulties in moving to phase 2 of the STS. Richard et al (1999) also showed a decrease in trunk rotation in individuals with PD during locomotion and attributed this to the axial rigidity in individuals with PD which was in line with a study by Mutch et al. (1986) who reported that 83.6% of individuals with PD experience symptoms of rigidity. The speed of the STS is also important as Mak et al. (2007) showed that with an increase in the movement speed, trunk muscle tone was also found to increase.

Numerous studies have analyzed the joint angles in healthy individuals during the STS but studies on individuals with PD are lacking. One notable exception is that Nikfekar et al. (2002) studied trunk movement in individuals with PD as they rose from a seated position. They explain how the trunk is the main contributor to the centre of mass and plays a very important role in the maintenance of equilibrium during the STS transfer. These authors found a statistically significant difference in the range of trunk flexion between the individuals with PD and healthy controls ( $26.8^\circ \pm 2.8^\circ$  versus  $16.3 \pm 3.1^\circ$ ). These authors defined the trunk angle as a single segment, with markers on the 7<sup>th</sup> cervical vertebra and sacrum. This might

suggest that individuals with PD exhibit a greater range of motion as a compensatory strategy for the slowed movement during the STS. This is interesting as it implies that individuals with PD flex their trunk more anteriorly over the base of support, as a compensatory strategy for the slowness in Phase 1 of the STS. This is line with our study. Nikfekar et al. (2002) also found that the mean flexion trunk velocity was higher in the individuals with PD than in control subjects. During the initial phase of the STS (sagittal plane) the increased speed and angular motion enabled the individuals with PD to generate a greater forward momentum of the upper body to make the STS transfer easier.

Another interesting thing to note is the reversal pattern that occurs as the individual transfer from the fully flexed position, or the end of phase 2, to the start of the extension phase or phase 3. Individuals with PD tend to have problems with reversal movements according to other literature. Pfann et al. (2004) have shown that a longer pause is present during reversal movement in some individuals with PD. This shows that a movement containing a reversal may not be performed as a single continuous task. Two discrete movements might thus be present in the STS. This is important, as the advantage of the elastic properties of the muscles to conserve energy to one consistent movement would therefore be decreased. As a result, the transition from phase 2 into phase 3, might be more difficult and affect the timing and efficiency of the task. This is important, as the individuals with PD have problems during the transition phase,

and performing the task as two discrete movements will further limit the efficiency of the STS.

#### **5.4 Phase 3 and 4: Completing extension and stabilization**

##### **5.4.1 Key findings in this study in relation to other studies**

Phase 3 lasted a mean time of 1.14s in the PD group, 33% slower than the mean time of 0.86s in the control group, which was a statistically significant difference. This phase started when the maximum ground reaction force was reached and ended when the ground reaction force first reached body weight after a brief drop. We are not aware of any study that has analyzed Phase 3 in individuals with PD. The extension phase of the STS brings the individual from an unstable base of support (at the end of Phase 2) to a very stable position, which would initiate the Phase 4 or the Stabilization phase.

Phase 4 lasted a mean time of 0.44s in the PD group, 63% slower than the mean time of 0.27s in the control group, and again a statistically significant difference. This phase started when the maximum ground reaction force first reached body weight after a brief drop and ended when the ground reaction force oscillated within a corridor of 1.5% of body weight. We are not aware of any study that has analyzed Phase 4 in individuals with PD. The increased timing in Phase 4 in the individuals with PD, the Stabilization period, is interesting.

#### 5.4.2 Features of PD underlying the findings

The third phase is also known as the Extension phase, as in this phase, the body posture changes from a maximum flexion position, to extension, until the body is fully standing, and Phase 4 starts. The importance of extensor muscle strength in individuals in PD thus needs to be studied. As discussed in section 5.3.2, the importance of extensor versus flexor muscle force is important to consider. A number of other studies have also analyzed the issue of extensor versus flexor muscle force and how this can relate to individuals with PD. Corcos et al. (1996) studied individuals with PD and found that muscle weakness was evident more in extensor muscles than the flexor muscles, and worsened as the disease progresses. Pfann et al. (2004) used point to point and reversal movements in ten healthy individuals and ten individuals with PD. They found that in the individuals with PD, both the amplitude of flexor and extensor EMG were significantly smaller than that found in the healthy individuals. These authors continue to explain that systematic modulation of activation patterns, especially with changes in speed, might be suggestive of an underlying motor deficit in PD. This is in line with studies by Corcos et al. (1996) and Schmidt (1988).

Bloem et al. (1999) also showed that a greater flexor tone might be present in individuals with PD as compared to healthy-matched controls. This might, in fact, create a problem in individuals with PD. The transfer from phase 2 to phase 3 is a

change from a flexion position to an extension position. As a result of the increased tone, these individuals might find it harder to straighten up.

#### 5.4.2.1 Neurophysiological differences controlling extensor and flexor muscle groups.

Neurophysiological evidence supports structural differences between the neural pathways activating flexor and extensor muscle groups in healthy individuals. Differences between neural pathways associated with extensor and flexor muscle groups have been noted in the descending projections to the motor neuron pool. Yu et al. (2000) used both Functional Magnetic Resonance Imaging (fMRI) and electroencephalography-derived movement related cortical potentials and showed that during planning and execution of thumb extension movements, there was an increase in the brain volume being activated, as compared to that during flexion movements. No other studies were done on lower limb movements.

As phase 3 of the STS ends, the body comes to a total standing position. This stabilization phase was never studied in other studies that dealt with the STS in individuals with PD. This phase is of utmost important, as any balance problems will definitely affect the time and efficiency to complete this phase. The assessment of balance in standing is important. Although stabilization in STS has not been studied in people with PD, postural sway in quiet standing has been extensively studied in people with PD. This research has found a wide array of

results. Horak et al. (1992) reported a decrease in postural sway in PD subjects as compared to age matched controls. On the other hand, Kitamura et al. (1993) reported an increase in the amplitude of sway in individuals with PD. Viitasalo et al. (2002) claimed that antero-posterior sway characteristics in PD patients are not significantly different than age-matched controls. Blasczyk et al. (2007) found significant differences between PD patients and healthy elderly in sway area and sway range, these being larger in the PD group. Recently, Crenna et al. (2006) and Guehl et al. (2006) studied postural effects in standing using deep brain stimulation in people with PD. A significant improvement of the vertical alignment of the trunk and shank, decrease of the hip joint moment, reduction of abnormal tonic and/or rhythmic activity in the thigh and leg muscles and a backward shift of the centre of pressure were all found when the stimulator was on. The flexed posture in the elderly and in individuals with PD tends to shift the centre of pressure forward, making the stabilization phase hard to accomplish. Mitchell et al. (1995) have documented an increase in the medio-lateral stability in individuals with PD, which was not present in healthy elderly individuals, and this might reflect an attempt to compensate the increased antero-posterior instability found in the PD population. Furthermore, an increase in the centre of pressure movement during standing was found to increase as the duration of the disease increased. Beckley et al. (1993) showed that there is an attenuation and/or inflexibility of correcting long-latency automatic postural responses in individuals with PD, which also influenced postural stability. Having said this, the

pathophysiological mechanism of postural instability in people with PD is still unknown (Elble, 2000)

Finally, in this study, a significant difference was observed in the thoracic angle at the end of the STS (in standing) between the individuals with PD and age-matched controls. Individuals with PD exhibited a greater thoracic kyphotic angle. A characteristic feature of PD is the flexed posture often observed in these individuals. This generally affects the arms, legs and trunk. PD has a differential effect on the neural activation of flexor and extensor muscle groups, at least in the larger muscle groups, as described above. Our finding is consistent with the stooped posture that one often sees in people with PD. As a result of the flexion posture, the centre of gravity of these individuals in standing might lie relatively anteriorly in relation to their base of support. As a result, this might lead to problems with balance, and might be another reason why some of the individuals with PD tend to fall upon standing up.

## **5.5 Limitations of the Study**

Individuals with PD we recruited had a Hoehn and Yahr scale score between 1 and 3, inclusive. Thus, our findings cannot be generalized to people with more advanced disease. For the results to be extended to the whole population of PD, other studies involving individuals with PD who exhibit a greater severity of the disease or who were during their OFF-medication would need to be studied.

We used ten trials in the present study to examine the STS transfer. The task involved is tiring and a few subjects with PD reported that they were getting slightly fatigued by the end of the last trial. Most subjects with PD were tested 1-2 hours post-medication. Each subject's laboratory visit took around 1.5 hours. We made sure that the testing process was kept as short as possible to reduce the extent to which it coincided with the OFF-medication phase. Moreover, the ten trials took a maximum of 20 minutes to complete. There was, thus, little time for change in the subjects' effect of medication level.

The sample size used in this population was only fourteen subjects in each group. Other studies that have been done on individuals with PD studied 10-20 subjects, so fourteen individuals was considered to be sufficient to study this task. Furthermore, it would be difficult to recruit more subjects than were tested in the present study in this geographic area unless more time was available for recruitment.

The primary limitation of the study was the constraint of the arm position during the STS. The subjects were asked to place their arms directly in front of them during the STS and were asked not to use them in any way. This method affects the natural arm movement during standing up. This method was chosen to reduce variability between subjects and also to prevent having the pelvis and hip markers disappear from the ability of the Optotrak® to track. We must acknowledge that a position of the arms anterior to the center of mass will affect

the biomechanics of this transfer. Furthermore, people seldom rise in this manner spontaneously. The whole standardization with respect to the seat height can also be considered a limitation.

Future studies should also examine coronal and transverse plane angles as Nikfekar et al. (2002) have found differences in individuals with PD and age-matched controls when these angles were studied. Furthermore, we placed markers on the right side of the body and thus assumed bilateral symmetry during the STS transfer. This presents a limitation for strategy analysis in the present study but did not interfere with phase analysis or kinetic data.

## Chapter 6: Conclusion

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Fourteen individuals with PD and fourteen age-matched healthy individuals participated in the present study. The subjects performed a STS transfer and a number of variables were studied. The time to complete each phase of the STS, forces exerted and strategies used to complete the transfer were compared between the two groups. The individuals with PD were slower, exerted less force and used different strategies than age-matched controls. Bradykinesia, tremor, rigidity, postural instability, muscle weakness are all characteristics evident in individuals with PD and appear to give rise to altered performance of a STS transfer. This study also extends the observations noted by other investigators and gives new insight on the different phases of the STS.

The understanding of rising up from a chair can aid the clinician in developing a detailed and graded description of every phase of the STS. This is a novel idea as the therapist can train the individual with PD according to the problems he/she is exhibiting. For example, one might ask: Is the patient having problems with lift-off as a result of weakness in his/her knee and hip extensors? Is the patient flexing forward enough at the end of Phase 1? Is he standing fully erect at the end of the transfer? Is Phase 3 taking too long and affecting the total time to achieve a successful STS transfer? Is the patient taking too long to stabilize at the end of the transfer? Once the clinician is able to answer these type of questions, alternative strategies can then be used to help these individuals

perform a successful STS transfer. Some impairments can be corrected, others can be changed using different strategies. By keeping the above in mind, the quality of life of the individual with PD is likely to improve. They will become more functionally independent, eventually reducing the risks of falls and any problems associated with this.

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## **Suppliers**

Northern Digital Inc. 103 Randall Drive, Waterloo, Ontario, Canada.

## Appendix I

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### Letter of Information & Consent Form

A Biomechanical analysis of the Sit-To-Stand (STS) transfer in individuals with Parkinson's Disease (PD).

#### **Investigators:**

Dr. Kathleen Norman  
Associate Professor  
School of Rehabilitation Therapy  
613-533-6104 (office)  
613-533-6000, ext 78005 (lab)

Mr. Carl Cachia, PT  
MSc. Rehab Science Candidate  
School of Rehabilitation Therapy  
Queen's University  
613-533-6000, ext 78005 (lab)

Dear \_\_\_\_\_

You are being invited to participate in a research study which will investigate the Sit-to-Transfer in PD individuals and how this differs from healthy individuals. The procedure will be described to you prior to the start of the study and no pressure to participate will occur. All benefits and risks will be explained to you too.

#### **Purpose and Aims of the Study:**

In individuals with Parkinson's Disease, falling is a common risk and occurs most frequently during walking or other locomotor activities that involve a shift in the Centre of Mass (around middle of the person's weight), an example being the daily Sit-To-Stand transfer. This study will aim to develop a better understanding of how this task is performed in individuals with Parkinson's Disease and how it differs from normal people.

#### **Objectives:**

This study will aim to compare the STS transfer in normal elderly subjects and people with PD, using kinematic (Time to stand, joint angles) and kinetic analysis (Joint reaction forces).

#### **You are invited to participate if the following statements are true:**

- A mini-mental Status Examination score of less than 26/30 (Folstein & McHugh, 1978).
- You are able to walk 25m without the use of assistance
- You are able to stand from a chair alone, without the use of arms.

#### **You are not invited to participate if you have:**

- Any neurological problems in addition to Parkinson's disease
- Any major problems with your joints (e.g Severe arthritis) or heart or lung problems

### **Procedures during Testing**

Testing will involve a 1.5 hour visit to the of Rehabilitation Therapy Motor Performance laboratory. This visit will be scheduled at your convenience. If you come by car, we will be able to provide a reserved parking spot for the duration of your laboratory time. Over the course of the visit, you will be asked to participate in the following procedures (not necessarily in this order).

Interview and questionnaires: You will be asked for a brief medical history, including a list of any medications you take. If you have PD, you will be asked about how long since you had the disease and any problems you might be having during sitting to standing.

If you accept the invitation to participate, a physiotherapist will first ask you some questions to check for the history of your condition. A Mini-Mental Status Examination test will then be performed, followed by some questions to check your level of mobility, using the Hoehn & Yahr Scale.

You will be provided with a shorts and a t-shirt to wear.

Following this, a number of markers will be placed on a number of joints on your body. The Sit-To-Stand transfer will be recorded using a motion analysis system and pressure sensors under the seat and feet. You will be asked to perform the Sit-To-Stand transfer three times. The motion analysis system (OptoTrak) will track the location of markers placed at various locations on your body. Pressure sensors will enable the investigator to determine the timing of shifting weight from the seat to the feet.

### **Risks of Participation**

There are no major risks in this study. The most significant risk is that the testing procedure will be slightly tiring. Rest breaks will be given as often as you need. The risk of falling is no greater than you would face in your everyday life, and will be minimized by the supervision of investigators.

### **Benefits of Participation:**

You will not be directly benefiting from this study. However, by taking part in this study, the subject will help in providing data to this study, which will give the clinician further insight into the performance of this task in PD subjects. This will help physiotherapists in their treatment protocols and ultimately help these clients in this common activity of daily living.

**Confidentiality:** All information obtained during this research project will be strictly confidential and your anonymity will be protected at all times. A participation identification number will be assigned to the data of each participant and this information will be kept in a secure location. Only the investigators will have access to the information collected. When the results are reported, your identity will not be revealed because we will only be revealing the general characteristics of the group (e.g., average age, number of men and women, duration of disease for the participants with PD, etc.).

### **Voluntary Nature of the Study:**

Your participation in this study is completely voluntary. You may withdraw from this study at any time without penalty or coercion. Your data will be removed if you wish it withdrawn.

### **Compensation:**

You will not receive any payment for your participation. You will be reimbursed for parking expenses if you have any.

**Liability:**

By signing the consent form, you do NOT waive your legal rights nor release the investigator(s) from their legal and professional responsibilities.

**Subject Statement and Signature:**

As a volunteer participant, I have read and understand the consent form for this study. The purposes, procedures and technical language have been explained to me. I have been given sufficient time to consider the above information and withdraw if I choose to do so. I have had the opportunity to ask questions which have been answered to my satisfaction. I understand that I can withdraw at any time. I am voluntarily signing this consent form below. I will receive a copy of this consent form for future reference.

If I am dissatisfied with any aspect of the study, or have questions, concerns or adverse events, I have been encouraged to contact the principal investigators, Dr. Kathleen E. Norman on (613)533-6104 (office) or (613) 533-6000, ext 78005 (laboratory), Mr. Carl Cachia (613) 533-6000, ext 78005 (laboratory) or the Acting Director of the School of Rehabilitation Therapy, Dr. Elsie Culham (613) 533- 6727 or with the Chair of the Queen's University Health Sciences Research Ethics Board, Dr. Albert F. Clark on (613) 533-6081.

By signing this consent form, I am indicating that I agree to participate in this study.

\_\_\_\_\_  
Signature of Subject

\_\_\_\_\_  
Date

By signing this consent form, I confirm that I have carefully explained the nature of the above research study to the subject. I certify that, to the best of my knowledge, the subject understands clearly the nature of the study and the demands, benefits, and risks involved to participants in this study.

\_\_\_\_\_  
Signature of Witness

\_\_\_\_\_  
Date

## Appendix II

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### Information form

Subject code: \_\_\_\_\_

Date of testing: \_\_\_\_\_

Subject Name: \_\_\_\_\_

Date of Birth: \_\_\_\_\_

Gender:    M   F (Circle where appropriate)

Weight: \_\_\_\_\_

Height: \_\_\_\_\_

Duration of disease: \_\_\_\_\_

Medication: \_\_\_\_\_

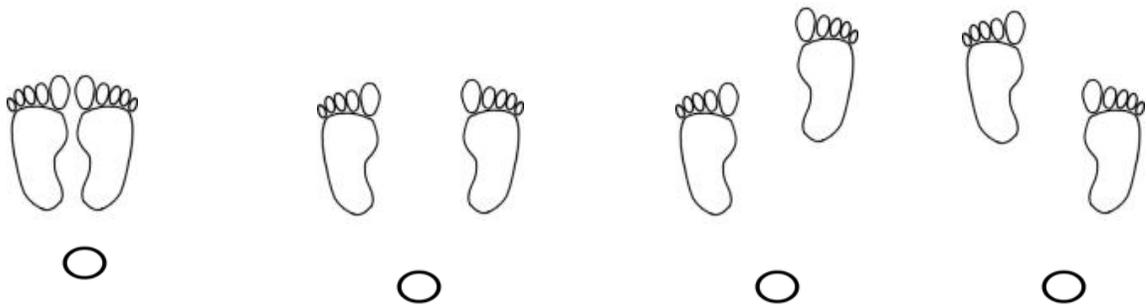
Duration: \_\_\_\_\_; Dosage: \_\_\_\_\_

Hoehn & Yahr Scale: 1      2      3      4      4  
(Circle where appropriate)

Distance (Top of knee to floor) = \_\_\_\_\_  
80% of this distance = \_\_\_\_\_

Distance (Greater trochanter to edge of chair) = \_\_\_\_\_  
30% of this distance = \_\_\_\_\_

Foot position at start of the STS (Mark where applicable)



Comments:

## Appendix III

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### Hoehn & Yahr Scale

#### Hoehn and Yahr Staging of Parkinson's Disease

1. Stage One
  1. Signs and symptoms on one side only
  2. Symptoms mild
  3. Symptoms inconvenient but not disabling
  4. Usually presents with tremor of one limb
  5. Friends have noticed changes in posture, locomotion and facial expression
2. Stage Two
  1. Symptoms are bilateral
  2. Minimal disability
  3. Posture and gait affected
3. Stage Three
  1. Significant slowing of body movements
  2. Early impairment of equilibrium on walking or standing
  3. Generalized dysfunction that is moderately severe
4. Stage Four
  1. Severe symptoms
  2. Can still walk to a limited extent
  3. Rigidity and bradykinesia
  4. No longer able to live alone
  5. Tremor may be less than earlier stages
5. Stage Five
  1. Cachectic stage
  2. Invalidism complete
  3. Cannot stand or walk
  4. Requires constant nursing care

Adapted from Hoehn & Yahr, (1967)